WP 1-086(PPRO 4/45/12) - Application of Remote Survey Data for Geotechnical Asset Condition & Performance

Phase 1 Report

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1. Introduction

1.1. Purpose of Document

This report presents the findings from Phase 1 of work within task 1-086 ‘Application of Remote Survey Data for Geotechnical Asset Condition & Performance’.

In particular, this phase seeks to:

- Review previous research work
- Review current procurement and use of remote sensing techniques within Highways England
- Undertake a review of other/emerging remote sensing techniques that could be used for monitoring performance and condition of geotechnical assets
- Review ongoing and related initiatives to identify opportunities and synergies and maximise benefits for this project
- Identify most promising techniques and their potential applications and give recommendations for further research in the next phase of work

More widely, this task is delivering a set of potential benefits and, ultimately, helping to directly and indirectly contribute to the realisation of a number of the key strategic outcomes set out in Highways England Delivery Plan 2015-2020 (Highways England, 2015).

1.2. Background

Highways England has a history of research in the area of remote sensing. Advances and development from previous programmes of work have led, amongst many other achievements, to the use of remote survey techniques to capture inventory and condition data requiring less ‘on network’ activity. Condition data are currently routinely captured but only for selected surface visible assets e.g. signs, markings, pavement.

Previous work on remote sensing at Highways England goes back to 2000. Around this time there was a significant change in capability of remote sensing technologies due to the commercial availability of GPS and inertial measurement units for positional accuracy on aircraft and the arrival of sub-metre resolution satellite imagery. Highways England (then Highways Agency) was an early adopter of these new systems following a research and development project carried out between 2000 and 2005. This research project, called ‘Remote Rapid Assessment’, included trials of various remote techniques over sections of the network. Following this the ‘LiDAR Framework’ was set up and operated from 2003 to 2011.

Highways England are currently in the process of procuring remote sensing surveys through the Specialist Professional and Technical Services (SPaTS) framework. These include van-mounted mobile mapping surveys and rotary wing surveys and will provide imagery and LiDAR datasets of the network. The mobile mapping will be captured at yearly intervals for asset inventory and other non-geotechnical purposes.

However, remote sensing technologies, data platforms and processing options have all advanced significantly in recent years, creating an opportunity for these tools to become more mainstream in asset management. In this context, there is a need for Highways England to refresh previous work carried out on this subject and to focus the research on the use of remote sensing data to monitor condition and performance of geotechnical assets.
1.3. Scope

This task has been split into two phases. As outlined in Figure 1.1, Phase 1 is the 'discovery phase' where the focus is on technologies, i.e. investigating technological advances of known/currently used and emerging techniques. Phase 2 will be 'application-led' where there will be specific investigation of potential practical applications related to geotechnical assets.

This report presents the findings of Phase 1 which has included the following activities:

- Summary of previous research (Activity 1.1)
- Research techniques currently procured by Highways England (Activity 1.2)
- Research techniques not currently procured by Highways England (Activity 1.3)
- Wider stakeholder workshop (Activity 1.4).

These are shown in Figure 1.1 below, alongside where they are discussed within this report.

In addition to the above, a review of ongoing initiatives and related tasks has been undertaken (Section 6), supported by stakeholder engagement activities (Section 5).

Conclusions and recommendations for Phase 2 and for further work beyond this task are included in Section 7.
1.4. Potential benefits

The envisaged benefits of this task are to contribute to:

- A safe and serviceable network by potentially reducing the need for physical inspections hence directly contributing to improving safety for those who work on and use the network
- Better knowledge of the asset condition and performance which would allow to make more informed and efficient asset management decisions and lead to a more serviceable network
- Supporting economic growth by maintaining an efficient and effective network. Remote sensing techniques could be a potentially cost effective, rapid and innovative way to capture asset data achieving efficiencies
- A more free flowing network, by optimising asset management workflows and ‘on network’ interventions thus potentially reducing network disruption
- An improved environment, by adopting a more proactive and sustainable asset management approach with the whole life cycle of the asset in mind
- Future-proof the network by allowing fast and automated detection of potential issues and contribute to improving the resilience of geotechnical assets
- Delivery of innovation through pilots and trials as set out in Highways England’s Innovation Strategy (Highways England, 2016)
2. Review of previous research (2000-2011)

A review of previous research work (Activity 1.1) undertaken between 2000 and 2011 is included in this section. Recommendations on how these techniques could be employed for geotechnical asset management applications are also included in this section.

2.1. Background

Remote sensing technologies went through a step change in capability around the turn of the century, which meant that many of the techniques previously available or that were becoming available were able to provide data that was more suited to engineering scale applications. This included the commercial arrival of Global Positioning Systems (GPS) and Inertial Measurement Units (IMU) which allowed highly accurate determinations of airborne sensor position in 3D space and consequently the ground area being imaged or scanned. At the same time the Ikonos satellite was launched (in 1999) and sub-metre resolution satellite imagery was available to purchase for the first time. Airborne LiDAR systems began to arrive in the UK, with the Environment Agency being one of the first government organisations to realise the benefits – they had purchased a scanner and were carrying out fixed wing LiDAR surveys for flood plain mapping across the country.

Highways England were very interested in the potential of these new systems and technologies and their potential for helping to improve the way in which the geotechnical asset was managed across the network. A research project to investigate this potential was commissioned in 2000 and awarded to Arup through competitive tender. The ‘Remote Rapid Assessment’ research project (3/303) ran until 2005 and included several phases of work, the scope of which developed over the project duration as applications for the techniques were identified, trialled and some adopted by Highways England. There were three stages – a Phase 1 desk study and pilot trials planning, Phase 2a research trials and Phase 2b further research, development and implementation trials.

In addition to the main research project a number of smaller supplementary projects were also commissioned to investigate or further develop particular aspects around the adoption of selected remote techniques by Highways England. These were carried out from around 2003 to 2008 and were awarded under the Safety Standards and Research Technical Consultancy (666) and Research & Development (387) frameworks. These were undertaken by Arup partnering with various specialist remote sensing contractors as well as other consultants including Mott MacDonald, Atkins, Parkman and Mouchel.

One of the outcomes from the main and supplementary research projects was confirmation that airborne LiDAR data combined with high resolution photographic imagery could be used to generate topographic survey mapping at 1:500 scale, both significantly faster and at lower cost than traditional ground survey methods. The LiDAR Framework was set up by Highways England in 2004 to enable procurement of these types of survey for motorway widening and improvement schemes. At the time Major Projects were managing several such schemes and providing the required 1:500 scale mapping needed for Early Contractor Involvement (ECI) was identified as a significant challenge. Remote surveys carried out under the LiDAR Framework were able to provide this mapping to the programmed timescale and were the main driver for the initial set-up of the framework, which ran until 2011.

A summary of the work carried out under the main and supplementary research projects as well as the LiDAR Framework are described below.
2.2. Remote Rapid Assessment project (2000-2005)

The previous main research work on the use of remote sensing for geotechnical asset management – project 3/303 ‘Remote Rapid Assessment’ - ran for five years from 2000 to 2005. It comprised three stages – a Phase 1 desk study and pilot trials planning, Phase 2a research trials and Phase 2b further research, development and implementation trials.

A technical steering group was co-opted to help guide and validate the research and comprised 13 members drawn from infrastructure owners - Highways England (geotechnical and pavement), Network Rail, British Waterways, London Underground; other consultants - TRL, Mott MacDonald, Capita; and remote sensing specialists - BGS, Infoterra. Five steering group meetings were held during the course of the research.

The original drivers for the research were identifying methods for rapid, accurate, repeatable and safe condition assessments of the (then) 7,000 km of embankments and cuttings. The aim was to reduce the need for on-foot inspections, which at that time were incomplete for the network and of variable quality. This was restricting Highways England in the planning of a network wide proactive maintenance strategy. Various previous studies had reported that proactive maintenance is three to five times cheaper than reactive maintenance.

It is worth noting that at the start of the research the HD 41 standard, which currently covers maintenance of the geotechnical asset, was not in use. Inspections were in accordance with the requirements of Section 1.9 Vol.2 of the Trunk Road Maintenance Manual (TRMM) and Advice Note 48/93. Early drafts of what was to become HD 41/03 were however available and it was agreed by the Steering Group that this would form the basis for identifying remote techniques that offered potential benefits. The introduction of HD 41/03 required a substantial increase in the quantity and quality of earthwork inspection data collected and it was thought at the time that it might not be possible to rely on foot inspections alone for this.

2.2.1. Phase 1

This initial phase comprised a desk study review of available remote sensing techniques through consultation with a wide range of specialist contractors and consultants to identify potential applications to earthworks management. Questionnaires were issued to potential users and other stakeholders within and outside Highways England as part of a ‘requirements capture’ study.

During the second steering group meeting selected remote sensing contractors presented their techniques and sample datasets. During the third meeting potential sites for the trial stage were discussed, with a range of geotechnical features and issues. Techniques and trial sites were selected by the steering group to move forward into the trial stage which was scoped, specified and awarded by the research team.

It was decided to split the trials into two stages with Phase 2a being a pilot scale trial of eleven techniques (out of an initial 18 identified), at a single site – the M25 between J27 and J30. This was due to the site’s known history of instability and the prevalence of failures on overconsolidated clay earthworks. The Phase 1 report (Arup, Feb. 2002) provides a full account of the Phase 1 study including the background, drivers, inspection regimes, techniques, applications, trial site and technique selection, assessment criteria and trial recommendations.
2.2.2. Phase 2a trials

The Phase 2a research trials were carried out along an 18 km section of the M25 motorway from J27 to J30 between October and December 2001. The following techniques were trialled:

- 1 m resolution Ikonos satellite imagery (processed by NPA Group)
- 1:10,000 scale 'off-the-shelf' colour vertical aerial photography (UK Perspectives from Infoterra)
- 1:2,000 scale infra-red vertical aerial photography (Blom Aerofilms)
- Stereo oblique aerial photography - rotary wing (Donaldson Associates)
- Airborne digital videography (VideoRoute)
- Fixed wing airborne LiDAR (Infoterra Optech 2033)
- Rotary wing airborne LiDAR (2 systems: Blom TopEye and Fugro FLIMAP]
- Airborne thermal line scanning (Blom Aerofilms)
- Vehicle digital videography (VideoRoute)

To provide ground truthing for comparison with the remote surveys the following were also undertaken:

- On-foot walkover surveys along the whole trial site length recording earthwork features in line with HD 41/03
- A base-line ground survey along the full 18 km length with vector strings marking top and bottom of slopes, carriageway extent, highway boundaries, structure edges and crash barriers
- A detailed survey along a 1 km section in accordance with HD 12/96

The data and imagery from all these techniques was reviewed against a number of criteria including the ability of the techniques to provide the necessary information for completion of the HD 41/03 Principal Inspection Form as well as the suitability of the data for storage and delivery across the HA GDMS. A number of other issues were also taken into account including the rate of collection, the quality and consistency of data, safety and potential reduction of delays, access to restricted areas, weather dependency, provision and use of electronic data and improvements to data interpretation.

The result of the assessment of the remote techniques indicated that all had potential to provide relevant data to some degree but that only two could be recommended for immediate use for earthworks inspections and condition appraisals to HD41/03. These were airborne laser scanning (LiDAR) and high resolution vertical aerial photography and were of most use when captured and used together. Oblique aerial photography also scored very highly in the assessment and at the time was used by Network Rail in Scotland, but there were limitations on geo-referencing and access via GIS interface databases.

An important conclusion reached during the trial was that helicopters flying at 100 m above the carriageway form no hazard to road users and no special measures such as warning signage or rolling road closures are necessary during surveys. This was agreed with Essex Police who were in attendance during the trials and observed the traffic flows during the surveys.

A programme of presentations, published technical papers, leaflets and manning stands at conferences (e.g. the Highways England Trunk Road Management Conferences) was undertaken to raise awareness of the research findings. It became apparent from feedback that there were a number of potential secondary applications for the datasets - including those datasets which were not considered ‘first choice’ for HD 41/03 earthworks inspections.
Following this a number of Managing Agents and other Highways England teams expressed interest in commissioning remote surveys, to investigate the potential benefits to their business, and these were put forward for inclusion in the Phase 2b trials.

Work proposed during Phase 2b to enable implementation of the techniques by Highways England included the following:

- Further research trials to test selected techniques in a range of other conditions not trialled during Phase 2a
- Investigate storage and delivery of remote sensing datasets across the Highways England databases, including HA GDMS
- Develop specifications, standards and/or advice notes for use of the techniques across Highways England
- Carry out implementation trials in a number of areas for Managing Agents and Area Teams

The Phase 2a report (Arup, May 2003) provides a full account of the trials, the subsequent findings and conclusions.

### 2.2.3. Phase 2b trials

The Phase 2b trials included a wide range of activities looking at different aspects of remote sensing surveys during 2003 and 2004. This work helped Highways England move on from the early research findings to the launch of the LiDAR Framework in 2004 and beyond (the Phase 2b work continued after this). The findings are too numerous and detailed to present in this summary and reference should be made to the Phase 2b report (Arup, Dec 2005) for a full account of this. Many of the findings are still relevant to the current SPaTS project. A summary of the main activities undertaken and conclusions are briefly described below.

Further research trials:

- **M25 J23-30 and M11 J4-7.** Further and more detailed investigation of the capabilities of fixed and rotary wing LiDAR and high resolution vertical aerial photography across a wider range of earthwork slope and slip geometries. The trials included further walkover surveys for ground truthing and studies on vegetation penetration and automated change detection.

- **A26 Lewes and M6 Lune Gorge.** These sites have large rock slopes adjacent to the carriageway and require rock slope inspections. The number of rock slopes across the network is relatively small and inspection methodologies are not included in HD 41. Rotary wing LiDAR surveys were carried out at both sites and fixed wing oblique aerial photography at the M6 site. It was concluded that although airborne LiDAR is very suitable for capturing rock slope geometry and major features it is not the right technique for obtaining the required level of detailed discontinuity data. Static terrestrial LiDAR systems were considered a more appropriate method and various published papers at the time and since have demonstrated success with this for coastal cliff monitoring. The aerial photography from the fixed wing aircraft was similarly insufficiently detailed and rotary wing platforms were considered to be more appropriate.

- **M1 Strelley and M6 Corley.** Both these sites suffer from on-going ground settlements related to previous mining activity. Preliminary studies on the feasibility of using the Permanent Scatterer (PS) 4 Interferometric Synthetic Aperture Radar (InSAR) technique to monitor these deformations were carried out. The studies showed that the motorway corridor and the mainly rural surrounding areas did not contain sufficient PS points to warrant full scale PSInSAR processing being undertaken. These motorway sections are fairly typical in relation to the amount of roadside furniture and other structures which
form PS points and it was concluded that PSinSAR is not viable in this type of environment. Movements greater than 15 mm between monthly scenes could not be detected then.

Development trials:

- **A1(M) Bramham**: Rotary wing LiDAR with high resolution imagery captured along a 13 km section with topographic mapping prepared by the remote sensing contractor. Ground proving surveys were then carried out by Pell Frischmann and Parkman and it was established that the accuracy of vector strings derived from the remote data were +/- 45 mm RMSE vertical and +/- 75 mm RMSE horizontal. This is compatible with 1:500 scale topographic mapping.

- **A31 Ringwood**: Rotary wing LiDAR and photography were captured and used to generate a ground model for use in a noise assessment study and to compare with the results provided by OS MasterMap. This was an initial study only and further work was carried out later but it indicated that the more representative ground model provided by LiDAR improved the sensitivity of the noise assessment analysis.

Implementation trials:

- **A23 (23 km) and A31 (50 km)**. Rotary wing LiDAR and photography surveys commissioned by the Area Managing Agent teams for their own purposes – including identifying any potential benefits beyond geotechnical applications. These surveys also helped the research team identify the optimum process and methodology for carrying out remote surveys within the Highways England context and the observations made were used during the set-up of the LiDAR Framework. Feedback from Managing Agents (MAs) and the police is provided in the Phase 2b report.

Other work:

- Review of off-the-shelf datasets for automated population of earthwork geometry fields in HA GDMS. A separate advice note (Arup, June 2004) and report were issued (Arup, Mott MacDonald, Keynetix & Infoterra, Feb 2004).

- Produced a specification to enable procurement of remote sensing data by Highways England through the LiDAR Framework. This was the first detailed UK specification of its type

**2.3. Further and associated research**

In addition to the main research and development work carried out under the Remote Rapid Assessment project there were a series of other projects carried out between 2003 and 2008 as linked, follow-on or spin-off activities to support the use of remote sensing data within Highways England. These were either carried out under the Technical Consultancy (666) or Research and Development (387) Frameworks.

**Integration of Remotely sensed datasets into the HA GDMS**

A selection of datasets from the Phase 2a trials were issued to Mott MacDonald and Keynetix to see how they could be stored and accessed through HA GDMS. This included aerial and satellite photography, thermal imagery, LiDAR contour data and topographic mapping. A description of this work is given in their report (Mott MacDonald, Feb 2003) and covers issues relating to image compression, contour file generation, matching adjoining image and contour tiles as well as file sizes and download speeds. The study showed that it was possible to access all the datasets
with the exception of oblique aerial photography which could only be accessed as linked documents.

**LiDAR Framework – Storage Architecture Scoping Study**

It was identified during the Phase 2b work that storage of the remote sensing data captured across the network needed to be maintained in a central storage facility so that data is accessible to all and could be re-used. This study and the project report (Infoterra & Arup, Jan 2004) identifies the process towards development of this facility and issues around its operation.

**Pictometry Trial, Phase 1**

Oblique aerial photography was highly rated for geotechnical assessments during the Phase 2a trials but issues were identified around geo-referencing and access to the imagery through GIS interfaces. Pictometry was a new oblique aerial photography system launched in the UK at this time by Blom and resolved many of these issues. A five camera set-up provides imagery at two flying heights and is viewed through proprietary software which allows nine different perspective views. The imagery is geo-referenced and allows measurements to be taken within the software. The oblique imagery is very useful for visualising the highway corridor and surroundings at a resolution of up to 12 cm. The project report (Arup, June 2006) describes an initial review of the system and imagery following trial surveys along the M6 (Lune Gorge) and the M1 (Nottingham).

A later study was carried out by Blom and Mott MacDonald / Keynetix to investigate ways of integrating Pictometry within HA GDMS.

**Evaluation of Earthworks Profile Change Detection using LiDAR data**

This study built on initial work carried out during Phase 2b and identified the processes required to carry out slope change detection with surfaces created from LiDAR point clouds. The results showed that the resolution of vertical change detection (i.e. height) possible with the Phase 2a and 2b datasets were 10 - 15 cm with fixed wing LiDAR (1 to 5 points / m²) and 5 - 10 cm with rotary wing LiDAR (6 to 10 points / m²). The findings are described in the project report (Infoterra & Arup, July 2006).

**Use of HA Aerial Imagery for RTA Investigation Surveys – Proof of Concept Development Trial**

Collision investigation surveys are carried out by police survey teams at the scene of Road Traffic Accidents (RTA). The collision survey details the final position of all the vehicles involved together with transitory objects such as debris, skid marks and oil patches. In addition the permanent highway features are also surveyed, typically over distances of several hundred metres. The survey data is later used in court and must therefore be of an adequate, consistent and known accuracy so that the validity of the survey cannot be brought in question. These surveys can take a significant time to complete and contribute to delays in re-opening the highway after the accident scene has been cleared.

Blom and Arup carried out development work with Surrey and West Midlands Police to see if remote sensing data captured for the network can be used to help speed up this process by reducing the need to survey permanent highway features and to concentrate on the transitory objects. A system compatible with existing police total station equipment was successfully developed which allowed aerial imagery to be used as a base layer for marking on transitory objects. The work is described in the project report (Arup, March 2007).

**CATinSAR Trial, M1 Strelley**

The Phase 2b trials showed that highway corridors do not contain sufficient Permanent Scatterer (PS) features for a reliable assessment of settlement by the PSinSAR technique. CATinSAR is a variant of this technique and uses Compact
Active Transponder (CAT) units placed on the ground to receive, amplify and return back the radar signal to the passing satellite(s). This equipment had only recently been developed by Nigel Press Associates and was trialled at the M1 Strelley site.

15 CAT units were placed along the embankment and radar scenes collected over a five month period. These were processed and compared with ground survey data but it was found that the CAT units were malfunctioning and no viable data was obtained. The technique was therefore considered to be one possibly for the future. The work is described in the project report (Arup, July 2007).

Further LiDAR Studies: Foliage Penetration and Surface Absorption

The aim of this study was to review the performance of various LiDAR systems (fixed and rotary wing) with respect to vegetation penetration and surface absorbency. Data collected under the LiDAR Framework was used.

The vegetation study concluded that only rotary wing systems should be used for detailed earthworks surveys inside the highway boundaries, particularly where dense vegetation is present, and that multiple return systems are considerably better than single return systems. Most LiDAR systems are now multiple return.

The surface absorbency study showed high levels of variation between different sensors and even differences between different flight-lines with the same system and at different time of the day.

The findings are presented in the project report (Arup, Sept 2008).

2.4. The LiDAR Framework (2004 – 2011)

Following several successful outcomes from the Remote Assessment project the LiDAR Framework was set by Highways England to enable collection of a range of remotely sensed datasets for various applications, beyond the original geotechnical asset management applications envisaged. The initial driver for the framework was the requirement by Major Projects to quickly collect 1:500 scale topographic surveys for a number of motorway widening schemes starting up at that time (e.g. M1, M25, A1M) and the research trials had shown this was possible by remote survey and considerably cheaper and quicker than by ground survey. The M25 DBFO contract was also due to tendered and a detailed survey was required for this as well as the ‘stubs and tails’ of the intersecting motorways.

The survey specification for data collection by various remote sensing techniques was developed by Arup for Highways England with assistance from specialist contractors and academics in the field of geospatial surveys. As well as airborne LiDAR and photography surveys the specification also included ground based surveys including terrestrial LiDAR and the Clearcone system.

The LiDAR Framework ran from 2004 to 2011 with three contractor teams: GeoSurvey Solutions (Blom & Infoterra), BKS & Fugro and Terralimaging. Project management of the framework was undertaken by Mouchel Parkman and Arup were the Technical Advisor.

Over £7 million of survey work was commissioned over this time period. A list showing all the Task Orders carried out is presented in Appendix E.

2.5. Recommendations

The research work carried out between 2000 and 2008 was highly innovative but was commissioned at a time when remote sensing data resolutions and accuracies...
had just gone through a step-change in development which made many techniques much more suited to engineering scale applications.

15 years on many of these techniques, such as LiDAR, high resolution digital imagery and InSAR, have now reached a level of maturity and their use is widespread.

Other techniques such as thermal scanning, aerial video, infra-red photography and variants of InSAR trialled during the research were found to be ‘not quite there’ but some are now potential candidates for further investigation as discussed in Section 4.

The Phase 2a and 2b reports contain detailed information about the assessment of the remote techniques against HD 41 criteria. This approach is important to show whether there is any benefit from using remote techniques to reduce the need for on-foot inspections to assess condition of geotechnical assets. An assessment of research findings from Phase 1 against HD 41/15 requirements will be undertaken in the next Phase.

The major applications of the remote sensing data sets collected during the LiDAR Framework were not geotechnical and it was not readily adopted by the Area geotechnical teams. There are likely to be other additional reasons why this was the case, including allocation of funding for geotechnical inspections within the maintenance contracts, but unless there is a stronger push towards the use of remote techniques by Highways England, then the status quo is likely to remain and remote surveys for geotechnical applications will be mainly for earthwork geometry, assessment of steep natural slopes and other restricted access areas.

Consultation with end-users (i.e. managing agents) should be undertaken in the next phase to understand how remote sensing data are currently used for and how their use can be increased for routine assessments, maintenance and renewals.
3. Review of techniques currently procured by Highways England

This section outlines the findings of Activity 1.2, which - as defined in the programme of work for this task - involved researching remote sensing techniques that are currently procured by Highways England. For the purposes of this study ‘current’ means techniques used and data collected from the start of the Special Project Services (SPS) Framework in 2012. This was when there was a change in emphasis on application of the collected data from the Light Detection and Ranging (LiDAR) Framework. This is similar to the surveys carried out under the current SPaTS Framework. Both SPS and SPaTS frameworks are briefly discussed in Section 3.1 below.

The main remote sensing techniques currently procured by Highways England include:

1) LiDAR – vehicle and rotary wing platforms
2) Vertical Aerial Imagery
3) Video Imagery – vehicle platform

Research findings have been condensed into a two page research summary sheets for these three techniques. The summary sheets have been developed with the aim to provide concise reference material in a consistent and usable format and to enable quick high level comparison between different techniques.

An overview of the researched techniques is included in Section 3.2 and more explanation on the format of the summary sheets is provided in Section 3.3 below. Research summary sheets are included in Appendix B.

Other techniques and datasets have also been or are about to be procured and these are also listed in this section, see Section 3.4.

Recommendations on how these techniques could potentially be employed for geotechnical asset management applications are provided.

3.1. SPS and SPaTS Frameworks

Following termination of the LiDAR Framework in 2011 there was a hiatus during which Highways England were deciding on the future requirements and direction of the framework. There was no longer a need for topographic surveys for motorway widening schemes on the scale required by Major Projects and other groups during the operation of the LiDAR Framework.

In 2012 the SPS Framework was set up and ran until 2015. This was followed by the SPaTS Framework, awarded in 2016 and currently on-going. The new Project Sponsor for these was the Asset Information Group (AIG) and the emphasis changed to the collection of highways asset information for more cost effective award of Area MAC contracts.

A task order under the SPaTS Framework was issued recently for rotary wing data capture (‘National Rotary Wing Surveying Project (North)’) by AIG. This will involve the capture of LiDAR point cloud data, high resolution RGB imagery and hyperspectral imagery. Outputs include the point cloud data and imagery from which orthophotos, 3D digital terrain and surface models and slope contours are to be generated. The point cloud density is to be a minimum of 25 points/m2 and to an
absolute accuracy of +/- 30 mm (2σ). The imagery is to be of 5cm pixel size. This contract covers Areas 7, 9, 10, 12, 13 and 14 and seven DBFO schemes comprising the A1, A19, A1M, A50, A69, M6 and the M1/A1.

3.2. Overview of researched techniques

3.2.1. LiDAR
Following on from the success of the LiDAR framework contact, outlined above in section 2.4, LiDAR procurement has continued across the entire Highways England network. From 2012 this has mainly been vehicle based LiDAR.

In addition to the vehicle based LiDAR already procured under these frameworks a new network-wide rotary wing LiDAR data capture programme was awarded in Q4 of 2016. This new high resolution rotary wing LiDAR coverage will finally include an ‘as-built’ capture of many areas which changed during the major projects construction programmes a decade ago. The rotary wing dataset also includes the entire width of the network, from boundary fence to boundary fence. This will fill in gaps caused by limitations of the vehicle based LiDAR dataset, particularly in the areas here there are earthworks embankments and where the boundary fence is some distance from the carriageway.

Whilst LiDAR datasets are particularly useful for management of geotechnical assets, current procurement is driven by other applications for the LiDAR dataset. It is truly a ‘multi-use’ dataset which has numerous applications many of which come from the further processing of LiDAR data from its raw form into other valuable geospatial intelligence datasets for Highways England.

3.2.2. Vertical aerial imagery
Under the original LIDAR Framework detailed above in section 2.4 vertical aerial imagery was procured in two forms. Off-the-shelf imagery at 12.5cm and 25cm resolution was purchased under a national licence agreement and this ensured that a general level of imagery covered the entire network from 2004 onwards. This imagery was in line with that which is common-place today in Google or Bing Maps and was loaded to the HAGDMS system in ‘tiles’ of 1km (25cm) or 0.5km (12.5cm).

The dataset was refreshed by the contractors on a periodic basis (approx. every 2 years) and so this dataset enabled not only an aerial view of geotechnical and other highways assets, but an assessment of change from the periodic update of the imagery. The down-side to this imagery was resolution, whilst the coverage was of the entire network any asset smaller than 50cm or so, could not be ‘seen’ in the imagery and its condition certainly could not be assessed.

To help overcome this, a second type of vertical aerial imagery was procured at a higher resolution. Where major projects specified rotary wing LiDAR to be captured a camera was specified to be installed on the same platform to ensure collocated high resolution imagery was collected during the LiDAR survey. This was captured at 2cm to 5cm resolution according to the Task Order, and was also processed into an orthophoto tile for loading to HAGDMS. This imagery enabled users to understand highways assets at a size of approximately 10cm.

However, whilst the imagery had this capability, it also had two major disadvantages. Firstly the imagery was only procured for the areas where Major Projects had a scheme and so coverage was not widespread across the network. Secondly the image was of very little value beyond the date of the construction. The scheme nearly always destroyed the original features and once the new construction was completed no as-built survey was carried out to capture high resolution imagery over the new assets. One exception was the imagery for the M42 as noted in section 2 above.
Procurement of off-the-shelf vertical aerial imagery has continued under the SPS and SPaTS frameworks as is maintained as a layer within HAGDMS. High resolution imagery has not been procured for some time but will now be procured at 5cm resolution as part of the National Rotary Wing Surveying Project (North) as mentioned above.

3.2.3. Video imagery

Video imagery from a moving vehicle, captured at approximately 50 mph, has been procured in two forms since approximately the year 2000. One type has been stereo imagery in high resolution with a frame rate of approximately 5Hz.

This was initially procured as a dataset by a Managing Agent (MA) as part of their requirement to fulfil asset inventory condition assessment as specified by the Routine Maintenance Management System (RMMS) document. This dataset was not procured by the agency as part of the LiDAR Framework contract, however during the latter stages of this framework in 2010 and 2011, the contractors (notably Geosurvey Solutions) trialled a mobile LiDAR system at certain junctions and for minor schemes.

It was soon recognised that this mobile LiDAR system could quite simply be combined with current video data platforms being used by the MAs. With the new SPS framework and the change of emphasis to AIG, several task orders were awarded to capture full network video (and LiDAR). The main difference at this time was that the procurement direct by Highways England for the whole network and not on an ad-hoc basis by the MAs.

These datasets were also made available from archive using an Asset Visualisation and Information Software (AVIS) software system (see below) whilst the previous datasets procured by the MAs were often held locally in a data ‘silo’.

A second type of vehicle based video has also been procured as part of the Traffic speed Condition Survey (TraCS) contract. The first contract was let in 2000 and the most recent, TraCS4 is due to start in 2017. However, a major difference is that this video is of a lower quality and frame-rate and has not been captured in stereo. The positioning of the vehicle platform is also to a lower level of accuracy. TraCS uses a cm grade trajectory rather than the mm grade trajectory required for the SPS and now SPaTS combined imagery and LiDAR vehicles.

The TraCS video is only used as a quality control dataset for the main TraCS instrument data and cannot be used for management of geotechnical assets.

However the other dataset procured by AIG under the SPaTS Framework (available on AVIS) is suitable for management of geotechnical assets. It provides a ‘drivers-eye’ view of the assets and basic measurements can be extracted from the imagery to understand geometry and the extent of vegetation.

3.3. Research summary sheets

A two-page research summary sheet was produced for each of the techniques currently being procured by Highways England.

The summary sheets have been developed with the aim to provide concise reference material in a consistent and usable format and to enable quick high level comparison between different techniques. Consistent title headings have been used for the summary sheets and they cover:

- the history of the use of each technique within Highways England,
- the main drivers for procurement,
• consultants and experts that have been involved in technical advice and procurement,
• current methods for survey and coverage,
• data format and usage and;
• considerations on potential application of the technique for monitoring condition and performance of geotechnical assets.

In addition, a table has been added on the second page of the summary sheets summarising positive attributes as well as what could be improved in the context of application for geotechnical assets.

3.4. Other techniques and datasets currently being procured.

In addition to the main three techniques a number of other initiatives have been or are being undertaken, some on a smaller scale. These include the following:
• A40 Leys Bend site (Area 9) - Unmanned Aerial Vehicle (UAV) trial survey with a LiDAR sensor. This is being carried out by Fly Phru who are also able to mount (individually) a camera, thermal scanner or Near InfraRed (NIR) scanner on to the UAV. The trials are being undertaken to help with management of the large unstable natural slope at this location
• Areas 4 and 7 and the M40 DBFO - Rotary wing hyperspectral imaging surveys have been carried out in 2015/16 for drainage asset information
• Terrestrial LiDAR survey of the M6 Lune Gorge rock cutting at 400 points/m²
• M5 J7 and J8 - UAV surveys with a LiDAR sensor to detect tension cracks
• A500 (local authority) – UAV LiDAR for 1:500 scale topographic survey
• UAV survey trials with a Go-Pro camera for structural inspections of bridges. An unpublished technical paper describing this work has been made available to the research team and has useful information about constraints relevant to UAV surveys

3.5. Highway England’s Asset Visualisation and Information System (AVIS)

AVIS is an online national-level repository for Highways England’s visual data and databased information about their assets. The AVIS system contains asset imagery, mapping and LiDAR remote sensing datasets. It is the first ever essentially complete and centralised digital inventory of assets for Highways England that can be interrogated.

A half day AVIS training course introduced two project team members to the AVIS online viewer. This training was comprehensive and afterwards a login was provided to allow further self-training and data enquiry. AVIS can be accessed via an online log-in allowing a registered inquirer to view high definition images, LiDAR point clouds, asset inventory and network maps (of the latest Ordinance Survey data).

AVIS contains data collected since 2013 using the Highways England ‘mobile mapping’ system, which consisted of 2 LiDAR scanners and 4 cameras mounted on a vehicle. The initial mobile mapper datasets, which cover 75% of the strategic network, form the benchmark of asset data for England. The plan is to collect and update the data annually.
To date the data has been used to identify surface visible assets. The network assets are characterised into one of 63 asset types, and are defined and catalogued into the Asset Inventory, according to the Asset Data Management Manual (ADMM).

Visual identification of assets is limited by line of sight. Asset coverage quality is affected by the nature of the deployed remote sensing techniques and is ranked in terms of quality to allow the user an understanding of the data limitations.

For example, very good coverage quality is recorded of assets on the carriageway, such as signs and road markings. Conversely, poor quality or non-collection of asset coverage quality is recorded of culverts under bridges, fences at the bottom of hills and steep or deep gullies.

It has been noted that on occasion images can suffer from ‘speed blur’, especially if the lighting conditions are not good, and it can mean that the materials provide a poor contrast and low brightness.

**3.5.1. LiDAR data stored in AVIS**

The survey vehicles collect LiDAR data. Resulting ‘point cloud’ data provides a 3D model of everything the vehicle has passed. An example of a LiDAR 3D model of a section of the strategic network is shown in Figure 3.2 below. The LiDAR point clouds are currently accurate to 30 mm. In addition, LiDAR control markers are currently being added to the strategic network to increase spatial accuracy of the point cloud. Future annual collections of LiDAR will be spatially accurate to 10 mm.
Figure 3.2: LiDAR 3D point cloud model (coloured by reflection intensity) of a section of the strategic network. Image extracted from AVIS.

It is possible to view the LiDAR point cloud alongside the imagery and, in particular, various measurements of different assets can be made including width, height/slope, and reflectivity (LiDAR point intensity). All of these measurements are useful in monitoring assets over time, for example sign reflectivity, lane width, road roughness, embankment slope and height, etc.

3.5.2. Use of AVIS for geotechnical applications

Although AVIS is currently predominantly utilised as a network asset inventory tool, there is potential to use it for geotechnical asset management applications.

For example, slope geometry could be extracted from LiDAR data either manually or in an automated fashion from contour datasets using tools within GIS. Geometry could then be used for slope stability and risk analysis for earthwork assets. Currently, only cuttings are available within AVIS; embankments could be included in the system, however in order to include these, a fence-to-fence survey would need to be performed and incorporated into AVIS.

The AVIS online viewer could potentially host and integrate additional data collected from surveys using new and different remote sensing techniques, such as soil moisture data, or multispectral imagery, with existing data. It is the combination of the remote sensing datasets that will allow asset change detection over time to be monitored effectively.

Use of AVIS for geotechnical applications will be reviewed further in Phase 2.

3.6. Remote sensing data in HA GDMS

HA GDMS is a web-based system with a mapping interface onto which asset information is projected. This enables the user to see the spatial representation of the assets against a mapping background and other spatial datasets, such as the geological map and hazard information.

HA GDMS also holds mapping layers derived from remote sensing techniques. The main data sources are aerial photographs and airborne, fixed wing LiDAR. The representation of this information is in the form of orthophotographs at resolutions of between 10 and 20cm, interpreted contours at a vertical interval of 25 to 500cm and a shaded relief map based on LiDAR data. The data set also includes a 10m resolution Digital Terrain Model (DTM), created from stereo imagery captured via a framework contract.
A review and refresh of the remote sensing layers held on HA GDMS was carried out in 2016. The dates shown in the table below represent the most up-to-date data that is available; the table also shows that not all layers have national coverage. The lack of up-to-date data diminishes the usability of the data for condition monitoring.

Anecdotal evidence indicates that the remote sensing layers most frequently used on HA GDMS are the aerial photography layers, especially the high resolution photos, as these are not readily available elsewhere. The data behind the LiDAR contours are not available for download, so the representation of the data, i.e. the contours is only used to confirm the presence of slopes etc. If users need the data they typically obtain it through the framework contract. Generally the LiDAR data is used to create terrain models for preliminary appraisal, analysis and design prior to commissioning a more detailed topographic survey.

Whilst the remote sensing layers on HA GDMS have been used primarily for inventory purposes, it is fair to say that they have not been used to assess asset condition. This is mainly due to partial coverage and the layer not being refreshed at timely, guaranteed intervals. Whichever new, or replacement remote sensing layers are added to HA GDMS these key criteria should be met to ensure they can be used for condition assessment across the network. A history of layers would also be of benefit, to be able to see changes over time.

<table>
<thead>
<tr>
<th>Dataset Name</th>
<th>Source of Dataset</th>
<th>Date of acquisition (if known)</th>
<th>Date of upload to system</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Res &lt; 10cm Aerial Photos</td>
<td>InfoTerra/Astrium</td>
<td>18/Jul/2011</td>
<td>19/Sep/2011</td>
<td>Site specific coverage</td>
</tr>
<tr>
<td>Medium Res 10-20cm Aerial Photos</td>
<td>InfoTerra/Astrium</td>
<td>06/Feb/2013</td>
<td>03/May/2013</td>
<td>Partial coverage</td>
</tr>
<tr>
<td>Low Res &gt; 20cm Aerial Photos</td>
<td>InfoTerra/Astrium</td>
<td>06/Feb/2013</td>
<td>03/May/2013</td>
<td>National coverage</td>
</tr>
<tr>
<td>LiDAR 25cm contours</td>
<td>InfoTerra/Astrium</td>
<td>15/Aug/2011</td>
<td>19/Sep/2011</td>
<td>Partial coverage</td>
</tr>
<tr>
<td>LiDAR 50cm contours</td>
<td>InfoTerra/Astrium</td>
<td>15/Aug/2011</td>
<td>19/Sep/2011</td>
<td>Partial coverage</td>
</tr>
<tr>
<td>LiDAR 100cm contours</td>
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<td>15/Aug/2011</td>
<td>19/Sep/2011</td>
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<tr>
<td>LiDAR 500cm contours</td>
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<td>19/Sep/2011</td>
<td>Partial coverage</td>
</tr>
<tr>
<td>LiDAR shaded relief</td>
<td>InfoTerra/Astrium</td>
<td></td>
<td>21/May/2007</td>
<td>Partial coverage</td>
</tr>
<tr>
<td>Digital Terrain Model (NAIS)</td>
<td>InfoTerra/Astrium</td>
<td></td>
<td>31/Dec/2008</td>
<td>National coverage</td>
</tr>
</tbody>
</table>

3.7. Recommendations

LiDAR datasets are particularly useful for management of geotechnical assets. Further processing of LiDAR data could deliver valuable geospatial intelligence datasets for Highways England. The rotary wing dataset now being procured also includes the entire width of the network, which would allow to capture data for earthworks and not only for cuttings.
A further example is that LiDAR can be seen as a fundamental three dimensional geospatial dataset which enables management of geotechnical assets. However, when combined with additional datasets such as thermal imaging areas of concern can be more rapidly located than simply with LiDAR alone. Once a second LiDAR data capture is added some time ‘t’ later the monitoring of the geotechnical asset becomes possible prior to investigations and the installation of geotechnical instruments.

High resolution imagery could provide the ability to detect change between surveys. This technique will now be procured at 5cm resolution as part of the National Rotary Wing Surveying Project and – if timescales permit - there may be an opportunity to assess use of data captured as part of this initiative for geotechnical applications.

The combined LiDAR and imagery dataset currently been procured by AIG under the SPaTS Framework could be exploited for management of geotechnical assets. Basic measurements can be extracted from the imagery to understand geometry and the extent of vegetation.
This section outlines research findings for remote sensing techniques that are not currently procured by Highways England (Activity 1.3 as identified in the programme), but could be beneficial for remotely monitoring the condition of geotechnical assets over time.

A short-list of the remote sensing techniques with potential was established based on the expert knowledge of the project team and from a literature review. These techniques included:

4) Interferometric Synthetic Aperture Radar (InSAR)
5) Light Detection and Ranging (LiDAR)
6) Passive Microwave Radiometry (MIRA)
7) Multispectral Imaging
8) Hyperspectral Imaging
9) Thermal Scanning
10) Structure from Motion (SfM)

These seven techniques were agreed upon by the project team and project sponsor. An overview of these techniques is given in Section 4.1.

Research findings of the seven remote sensing techniques considered have been condensed into a series of two page research summary sheets. More explanation on the format of summary sheets is provided in Section 4.2 below. The research summary sheets are described in more detail below and are included in Appendix C.

### 4.1. Overview of researched techniques

All of the remote sensing techniques listed above provide data that is complementary to and can be used in combination with the existing survey datasets already collected by Highways England.

Whilst each of the individual techniques has potential to provide some information of value for monitoring geotechnical assets, it should be emphasised that analysis and interpretation is frequently best undertaken using a combination of techniques and by combining with other datasets. Examples of additional data include: field inspections; intrusive and non-intrusive (e.g. geophysics) investigations, and; physical instrumentation and monitoring (e.g. extensometers, soil moisture data loggers). Remote sensing techniques should be considered as complementary techniques rather than standalone techniques. Future developments to enhance data usage include data-fusion and geotechnical Building Information Modelling (BIM).

LiDAR has already been used by Highways England as a remote sensing technique to inventory geotechnical assets of the strategic network in an *ad hoc* fashion since 2000, and more comprehensively through the LiDAR framework from 2004 to 2011. Since 2013, LiDAR surveys of the strategic network have been collected more systematically using the ‘mobile mapper’ system. Though already procured, LiDAR has been researched as part of Activity 1.3 because the technique has potentially evolved quite significantly since it was last researched by Highways England. In particular, there have been recent and rapid developments in data-processing...
software and algorithms that allow detection of changes or differences in features over time.

Several of the techniques above, such as InSAR, LiDAR, and SfM, capture the shape of a landscape or feature as a digital 3D model with centimetre to millimetre scale resolution. Collected strategically over time, local and regional changes in geotechnical assets or highway structures can be monitored using this type of data. By contrast, other techniques, such as MIRA, thermal scanning, and multispectral and hyperspectral imaging provide chemical information about assets. For example, the MIRA technique is able to detect soil moisture content down to depths of several metres beneath the surface, whereas multispectral and hyperspectral imaging can indicate changes in vegetation, or surface soil mineral content.

Again, over time, these additional datasets can reveal important information relating to how and why geotechnical assets may be degrading. These chemical data can provide additional information that is complimentary to the ‘physical’ data provided by the existing LiDAR surveys.

4.2. Research summary sheets

A two-page research summary sheet was produced for each of the seven shortlisted techniques. The information is presented in a very concise format, which is not aimed to provide an introduction or background to the technique per se, but rather to indicate to the user the key characteristics of each technique, its uses and benefits in the context of geotechnical asset management. This two-page format and consistent title headings was chosen as it allows the user to rapidly gain an understanding of the key characteristics of each different technique and also to simply compare and contrast between the characteristics of each using the sheets.

The first page of each sheet provides information about the technique, the platforms upon which the sensor can be mounted. The second page has details of data usage and format, maturity of the technique, in addition to more specific examples of how the technique has been or could be used in application to geotechnical asset monitoring.

In particular, a ‘summary key’, which is located on the bottom right-hand side of the front page of each sheet, was developed with an aim to visually portray the key features of the technique in a user-friendly immediately comparable way.

For example, it highlights the platforms on which the sensor can be mounted; the type of sensor – whether it is active and can therefore collect data in all-weather day and night, or passive, in which case the technique requires daylight and good weather conditions; the type of measurement detected by the sensor, physical or chemical; and finally the data product, which can be an ortho-image or a point cloud and Digital Elevation Model (DEM).

Figure 4.1: Example of the ‘summary key’ - features shaded in blue highlight the key characteristics applicable to the technique in question
4.3. Recommendations

The applicability of each technique will vary according to the type and scale of the specific feature that is required to be assessed. All of the techniques have a range of sensors and platforms that the sensors can be utilised on and in general the closer distance the platform is to the feature being monitored (‘sensed’) the greater the resolution and accuracy. The choice of platform and sensor, both for trials and implementation, needs to be chosen according to specific user requirements, especially with regard to the type of feature wanting to be captured and the spatial scale of the feature and accuracy requirements.

The following presents some details of key considerations for potential future use of each technique and recommendations. It should be noted that these are initial recommendations. The full scope and potential use cases / applications of such techniques will be better defined following the Phase 2 work and trials.

InSAR
- Spaceborne InSAR is increasing in usage due to the larger number of radar satellites in orbit. Sentinel-1 satellite data, since 2014, with free and open data policy is having high temporal frequency of collection allowing for time-series datasets to be more readily available as a record of ground movements at lower cost. Higher spatial resolution COSMO-SkyMed commercial data is also beneficial. ISBAS processing method is allowing greater use of InSAR data for monitoring ground movement in rural areas. Potential areas of InSAR studies could include regions with suspected ground movement e.g. mining areas and groundwater abstraction areas.
- Consideration of installing corner reflectors on assets of interest (e.g. known high risk slopes) could be beneficial.
- Ground-based GB-SAR is a new technology that can potentially monitor ground deformation of pavement or slopes

**Recommendation** – **Collaboration with other initiatives (e.g. TIM and LiveLand, see Section 6.2). Consideration of InSAR trials at known HE sites with ground subsidence or slope instability issues, in conjunction with other monitoring techniques (e.g. instrumented slopes) and remote sensing trials.**

LiDAR
- Post-processing of data (existing archive data and new data collection) could provide useful data products, including: Digital Terrain Model (DTM), Digital Surface Model (DSM), change detection (e.g. DSM surface Time-2 minus DSM surface Time-1), shaded-relief and shaded-elevation datasets, and rock mass or 3D-discontinuity extraction from LiDAR datasets.
- Use of intensity reflectivity data – can be used as indicator of surface properties such as surface texture (roughness, pavement condition), reflectance (signage, paint, moisture content of bare soils etc.)
- Use of RGB coloured point cloud (feature identification and classification)

**Recommendation** – **Review of possible additional datasets and derived data from existing archive data and new surveys to enhance HAGDMS and AVIS. Consideration of LiDAR trials (airborne and terrestrial mobile) at test site(s) to compare with other remote sensing techniques (InSAR, MIRA, thermal, multispectral, hyperspectral, SfM).**
Passive Microwave Radiometry (MIRA)
- Both airborne and mobile MIRA methods have potential to provide information on soil moisture, although use may be limited according to site condition (e.g. metal objects and buried services can interfere with signals).

Recommendation – Consideration of MIRA trials at test site(s) to compare with other remote sensing techniques (InSAR, LiDAR, thermal, multispectral, hyperspectral, SfM). Comparison should be made with other surface monitoring techniques, e.g. comparing results against SMD or soil suction results at various trial sites.

Multispectral Imaging
- Free or low-cost satellite data would assist land-cover classification at small-scale
- Airborne or terrestrial (mobile of static) systems would provide greater detail and resolution and could be used for more detailed assessment of assets that may have been previously identified as requiring more detailed assessment or monitoring

Recommendation – Consideration of multispectral trials, at multiple scales (satellite vs airborne vs terrestrial) at test site(s) to compare with other remote sensing techniques (InSAR, LiDAR, MIRA, thermal, multispectral, hyperspectral, SfM).

Hyperspectral Imaging
- Satellite data options are currently limited and unlikely at present to provide sufficient detail for geotechnical asset management
- Airborne or terrestrial (mobile of static) systems would provide greater detail and resolution and could be used for more detailed assessment of assets that may have been previously identified as requiring more detailed assessment or monitoring. Hyperspectral imaging will be expected to provide considerable more detail than multispectral, although at potentially higher cost and challenges with relation to optimum surveying conditions (illumination) and post-processing and delivery of applicable derived datasets.

Recommendation – Consideration of hyperspectral trials at test site(s), at multiple scales (airborne vs terrestrial) to compare with other remote sensing techniques (InSAR, LiDAR, MIRA, thermal, multispectral, SfM). Most applicable to rock slope test sites.

Thermal Scanning
- Airborne or terrestrial methods are expected to be most applicable due to their higher spatial resolution and accuracy. Night-time surveys may prove the most beneficial, in particular in order to identify temperature variation that may be proxy for variation in soil moisture. Thermal surveys in tunnels for monitoring of condition and seepage would also be beneficial.

Recommendation – Consideration of thermal scanning trials at test site(s) to compare with other remote sensing techniques (InSAR, LiDAR, MIRA, multispectral, hyperspectral, SfM).

Structure from Motion (SfM)
- Software processing developments are enabling this technique to be potentially of use, in particular from airborne UAV and terrestrial surveys. The key benefit is to provide low cost 3D point cloud data of physical assets (geotechnical assets or structures). High quality images of structural assets that may provide stability to geotechnical assets (e.g., retaining walls) can also be acquired. Change detection and object recognition techniques could be used between successive surveys to understand asset degradation.

**Recommendation** – Consideration of SfM trials at test site(s) to compare with other remote sensing techniques (InSAR, LiDAR, MIRA, thermal, multispectral, hyperspectral).
5. Stakeholder engagement

Disseminating lessons learned and cross-fertilisation with other relevant initiatives is key to the success of this task.

We have engaged with a number of stakeholders both within Highways England and externally, and will continue to do so in the next phase of work, to ensure that this work is connected appropriately to wider initiatives. A list of stakeholders the project team has engaged with is included in Appendix A.2.

A number of external meetings were held during Phase 1, see Appendix A.1 for full list. Ongoing and/or planned initiatives, both internal and external, have been identified as ones that could bring benefits to this task. These are discussed further in Section 6.

A workshop was held to gather views and input from a wide range of stakeholders (Activity 1.4). This is reported on in Section 5.2.

An additional stakeholder engagement activity was undertaken in the occasion of the 2016 Geological Remote Sensing Group (GRSG) annual conference, which is discussed in Section 5.3.

5.1. Stakeholder consultation

A consultation meeting with Highways England stakeholders representing various groups and disciplines (structures, asset management, AIG) was held on the 11th October 2016 in Birmingham. It became apparent that there are several potential opportunities to tap into ongoing or planned initiatives that are related to the use of remote sensing techniques within Highways England, see Section 6.2.1. Notes from the consultation meeting are included in Appendix A.3 of this report.

Further discussions have also been held with IBI Group, in particular the IBI team responsible for SPaTS vehicle based video imagery and LiDAR data capture and the AVIS software. It is clear that whilst some additional research work has been carried out from this data capture, such as road marking and road sign retro reflectivity studies, there has been no work on researching the data for management of geotechnical assets. There is now a large holding of archive LiDAR and imagery of the network that can be used for this purpose.

5.2. Wider stakeholder workshop

A stakeholder workshop was held on 12th December 2016 in order to present and get feedback from a wide range of stakeholders on research findings from the first phase of work. Attendance included representation from asset owners (Highways England, Network Rail, HS2 and TfL), academia (Imperial College) and suppliers (Atkins, CGG). A range of viewpoints on user requirements, applications and risks/challenges in implementing remote sensing techniques was elicited during the event. A factual account of the workshop is presented in Appendix D.

The workshop sought to determine which remote sensing techniques are currently being used in the industry and for which applications, as well as what future uses were envisioned by the attendees. The results of these inquiries are presented in Figures 5.1 and 5.2 and have been taken into account in developing recommendations for the next phase.
Results show that key applications currently in use are feature recognition, change detection and ground movements. In the future, again change detection and ground movements but also condition monitoring and soil saturation have been identified as the most desirable applications. LiDAR is currently the most widespread used technique. Attendees anticipated that InSAR would play a bigger role in the future.

It was felt that a number of other applications should be included such as asset inventory, monitoring other assets (e.g. drainage, barriers, signs, structures, pavement), incident management, topographic surveys, bathymetry, terrain analysis & DEM generation, considering water ingress, planning site works surveys and
ground investigations. Other techniques suggested by attendees included aerial photography, videography and photogrammetry.

5.2.1. Key findings

Key messages from the workshop were:

- a combination of techniques are expected to be most useful as opposed to use one technique only
- the ability to detect soil moisture and use it as indicator of potential failure in conjunction with other triggers will be very useful in the future
- collaboration and cross-fertilisation with industry and academia will be a strong enabler for innovation and implementation of these techniques in asset management

These findings are further discussed below.

Focussing on user requirements initially, the stakeholders identified several. These broadly fall under two categories: practical and technical requirements.

From a practical standpoint, requirements included the need for techniques to be cost-effective with minimal post-processing effort required.

On the technical side, workshop attendees identified the following requirements:

- High resolution and high frequency
- Repeatable
- Appropriately accurate
- Be able to detect features, and signs of instability
- Be able to cover large area

Based on our research to date and feedback from the stakeholder workshop, a key parameter of interest to monitor is soil moisture content. An increase in soil moisture content is typically associated with slope instability, therefore, monitoring soil moisture content over time may enable land slip precursors to be identified and for the potential resulting slip to be mitigated. In light of this, MIRA would be a key technique to research further. Additionally, soil moisture content can be assessed through changes in vegetation (as a proxy for soil moisture), in which case multispectral imaging would also be a technique for further research.

Finally, the majority of stakeholders were also interested in the ability to remotely monitor surface changes over large swaths of their networks remotely with high resolution and at low cost. InSAR is a technique that shows great promise for this application, though as yet there are relatively limited examples of the application of InSAR for geotechnical asset management.

The workshop participants also discussed the barriers, risks and challenges that would be faced in implementing remote sensing techniques. This was done in breakout discussion groups to allow maximum feedback to be gathered.

Barriers identified included available funding and procurement. It was felt that there is currently no clarity on who would be responsible for funding and how procurement would be organised in an efficient way. In addition, current procurement seems to be governed by technology but the attendees questioned if it should be application-led instead. An application-led approach will be the focus of Phase 2 of this task.

Also identified were barriers regarding data – is the industry prepared to share knowledge and data openly and transparently? Some case studies exist but the cost and issues related to the implementation are not always transparent. This links into
the risk appetite for implementing these techniques, which can be expensive but can also be optimised through using the technique in a range of business streams as well as in geotechnical asset management.

A barrier regarding knowledge and training of personnel was identified but not deemed a key risk. There may be a knowledge gap for developing the most suitable specifications for identified requirements.

5.3. GRSG Annual Conference

The GRSG annual conference was held in London on 7th-9th December 2016. This conference presented and discussed a wide range of remote sensing applications, tools, latest innovations and developments and was attended by academics, suppliers and consulting engineering companies from all over the world.

A poster, shown in Figure 5.3 on the right, was presented at the conference with the aim to raise awareness on this project and to engage with conference participants.

The poster triggered several useful conversations with other participants e.g. we have made contact with representatives of the LiveLand project, a very relevant initiative discussed in more detail in Section 6.2.2.

The conference also provided an excellent opportunity to get updated on recent technological advances, in particular for InSAR and Multispectral Imaging as discussed below.

The Intermittent Small Baseline Subset (ISBAS) technique increases usability of InSAR in rural areas. It can map areas that are only intermittently coherent (i.e. rural areas) compared to areas that are always coherent (i.e. urban).

In addition for InSAR there has been a huge increase in time series data available which is a revolution in data supply compared with early InSAR work. Sentinel-1 radar data is available since 2014 and there are approximately 350 no. Sentinel-1 images are collected of UK per month. These are freely available for all users.

In Multispectral Imaging (which is also freely available) there has been an increase in bands from e.g. from Sentinel-2 – 12bands, 10m, 20m, 60m and ASTER – 3no. VNIR 15m; 6no. SWIR 30m; 5no. TIR 90m. There has also been an increase in data usability and access.
5.4. Recommendations

Stakeholder engagement has proven to be extremely useful during the discovery phase of this task. We have identified and engaged with a considerable number of stakeholders who will be managed as set out in Appendix A.2. It is recommended that the list of stakeholders is reviewed and the appropriate level of engagement agreed at the beginning of next phase. Required attendance at Technical Steering Group review meetings should also be formalised with the Project Sponsor.

In addition to the stakeholders we have engaged with during Phase 1, in the next phase of work we will engage with academics, suppliers and subject matter experts as appropriate. The focus of this second wave of consultations will be discussion on the use of data acquired with identified remote sensing techniques for geotechnical asset management applications.

In the next phase it is recommended that Soft Estate/Environmental Management are consulted, including areas such as contract obligations, management of high risk trees, vegetation as part of reinforced soil solutions, bio-engineering locations, monitoring of landscape commitments and the integrity of noise barriers.
6. Related tasks and relevant initiatives

This section summarises related tasks that this project should align with and relevant initiatives, both internal and external, that have been reviewed as part of this phase of work and that may offer opportunities for collaborations and/or pilots in the next phase and beyond.

6.1. Related tasks

The discovery phase (Phase 1) has included a high level review of related tasks. This was to ensure that this task is aligned with the wider direction of travel of geotechnical research within Highways England.

Highways England is looking to develop a framework to manage the resilience of their geotechnical assets (see Arup AECOM (2016)). Figure 6.1 below shows the line of sight for improving the resilience of Highways England’s geotechnical assets.

![Figure 6.1: Line of sight for improving Highways England’s geotechnical resilience (from task 1-085)](image)

This framework will incorporate:

- findings of task 1-085 Geotechnical Resilience Enhancement Measures i.e. review of vulnerable locations, hazard specific guidance notes and links with resilience management procedures
- geo-hazard mapping undertaken as part of Task 1-062
- knowledge of special geotechnical measures (SGMs) from TTEAR Task 594

Better knowledge of the assets provided by remote sensing would allow an improved resilience to e.g. known ground hazards or severe weather. For example, ground movement changes detected by remote sensing could be related to potential ground hazards at identified vulnerable locations. This combination would allow early warnings of potential issues which could then be integrated into resilience management procedures.

Data captured using remote sensing techniques at regular intervals for change detection could be used to monitor condition by directly feeding into calculation of geotechnical performance indicators.

Also relevant is the Geotechnical Asset Data Improvement Plan which seeks to improve geotechnical data quality across several initiatives including examining approach to AGS data, modelling of earthworks, the ability to exchange and analyse...
data drawn from other infrastructure owners and adopting of common data requirements as well as real time monitoring. This data improvement plan will also have to take into account how to deal with data from remote sensing.

6.2. Review of relevant initiatives

A number of initiatives that are relevant to this task have been reviewed as part of Phase 1.

Highways England’s initiatives are briefly discussed in Section 6.2.1 whilst relevant external projects, predominantly focussed on the application of InSAR, are outlined in Section 6.2.2.

6.2.1. Highways England’s initiatives

The stakeholder consultation undertaken during Phase 1 has highlighted a number of relevant initiatives commissioned/planned by Highways England that could offer opportunities for ‘proof-of-concept’ pilots in the next phase of this project and beyond. Datasets that are about to be procured by Highways England have been listed in Section 3.4. Selected initiatives are discussed further below.

The M40 was flown in 2016 with the Blom AISA FENIX sensor and this dataset has been delivered as a full hyperspectral data cube. It is understood that this dataset is being held in archive by the team at the M40 DBFO and that Highways England now holds a copy. This dataset could be analysed and interpreted in conjunction with other datasets available for the M40 area to investigate applicability of the hyperspectral technique.

At the time of writing, repeat surveys using a UAV platform are planned at A40 Lays Bend, a well-known problem site with historical ground instability, to investigate ground movements. It is understood that discussions are still ongoing with the UAV supplier on which sensor (LiDAR, hyperspectral, thermal imagery or near infrared imagery) will be mounted on the UAV platform. Although this initiative would be very relevant and a good candidate for a proof-of-concept pilot to be undertaken in Phase 2, the timescale of planned survey may not be aligned with that of this task.

It is of interest to note that Highways England owns a drone that has been used to undertake structural survey pilots with a small GoPro camera. The drone is GPS enabled and could potentially carry more than one sensor, but that would shorten the flight time. The drone and a licensed operator could be made available to this project, although risk assessments and tight CAA regulations may limit the scope of pilots.

Highways England Professional and Technical Solutions directorate (PTS) plan to procure an advice note on the safety and legal requirements relating to the use of UAVs.

6.2.2. Other initiatives

Links to the initiative websites are given in the references.

Transport Infrastructure Management (TIM) project

The Transport Infrastructure Management project has investigated the feasibility of using remotely sensed data (InSAR) to monitor the condition of earthworks.

This project is part-funded by the European Space Agency and is being delivered by a consortium that includes – amongst others - the National Physical Laboratory (NPL), CGG and Connect Plus. The project has compiled a large dataset of InSAR data spanning several years and it is hoped that by using this data set with real-world data it will be possible to match the InSAR data to the terrain of the slopes to identify actual defects. The ultimate objective is to allow users to access a national data set via a common interface to enable remote sensing to be used to assess condition. Permanent London Integrated Movement Map (PLIMM) is the ongoing demonstration phase of the TIM project.
There are a number of problems with using InSAR that need to be addressed, namely, the effects of natural, seasonal variations, vegetation coverage and the spatial precision of readings over time.

Discussions have commenced with Dr Elena Barton of NPL to potentially carry out a validation and verification exercise using three or four known sites on the M25 where ground movements have been observed and recorded on Highways England’s geotechnical asset information system (HA GDMS). The exercise will look at the history of the defects on HA GDMS and examine the historical InSAR data to determine whether it reflects the observations.

This exercise would involve liaising with Connect Plus, the managing agent for the M25 DBFO, to ensure that the history of the defects is clearly understood and to obtain a third party, objective assessment.

**LiveLand project**
LiveLand is an ongoing European Space Agency-funded project. Their stated aim is to assist transport operators across in Scotland who face significant challenges in detecting, monitoring and forecasting landslide and subsidence hazards across their networks. Owners and operators of transport infrastructure need to understand these hazards, to better manage their exposure, mitigate risk and improve planning and response to incidents when they occur.

The project plans to examine and develop a number of unique monitoring solutions that will address the requirements of two transport operators in Scotland. These are Network Rail (Scotland) and Transport Scotland. The project will range from regional ground stability measurements captured by satellite InSAR (earth observation) data, to hazard forecasting models using geological and meteorological data, and the development of cost-effective, multi-sensor GNSS devices for in-situ monitoring.

These solutions will provide information on hazard potential and activity along and in proximity to rail and road assets. Once successfully demonstrated in Scotland, LiveLand is expected to expand across the UK, with the potential for further expansion into Europe and beyond.

As part of Phase 2 the project team will liaise with the British Geological Society (BGS), one of the parties involved in undertaking this research, with the aim to identify synergies and opportunities for collaboration.

**InSAR for geotechnical infrastructure: enabling stakeholders to remotely assess environmental risk and resilience**
This NERC funded project brings together Transport Northern Ireland (TNI), Northern Ireland Rail (NIR) and the Department of Enterprise, Trade and Investment (DETI). This project aims to enable them to remotely assess asset risk and resilience using InSAR.

The stakeholders anticipate that the use of InSAR data will help form their strategies for monitoring their geotechnical assets and will feed into the existing GIS based risk assessment methods for their infrastructure assets. It is hoped that InSAR will give a much greater insight into the behaviour of a variety of geohazards that impact on road and rail, will inform their maintenance strategies and lead to more cost effective better targeted maintenance. The project aims to validate InSAR and provide baseline data of ground motion to form the basis of future strategic decisions in regards to geohazards.

We will consult with the BGS who are one of the research partners for the above project.
NERC/Satellite Application Catapult soil moisture workshop
NERC and the Satellite Applications Catapult are organising a workshop on soil moisture retrieval using satellite information, in-situ networks and models at the end of January 2017. The aim of the workshop is to inform on the current state of technology for soil moisture retrieval and identify what is currently possible. In addition it is to facilitate the introduction of people and promote collaboration in this space.

This is another potential and timely opportunity to engage with industry and academia and expand the reach and potential stakeholders for this task.

Collaboration/cross-fertilisation with other asset owners
Many other geotechnical asset owners in the UK have similar issues and are turning to remote sensing to monitor condition and performance of geotechnical assets.

A key message from the stakeholder engagement undertaken in Phase 1 (see Section 5) was the need for collaboration between academia and industry in order to achieve significant advances in the application of remote sensing technologies. It has become apparent that is a strong interest in InSAR and use of UAVs.

Network Rail, for example, is about to commission a series of 3 no. UAV surveys of know problem sites to be undertaken with a monthly frequency. The aim is to demonstrate that data captured during the surveys can be used to detect change.

The Geotechnical Asset Owners Forum (GAOF) is a grouping that could provide potential collaboration partners in the future. This project should actively engage with this forum to disseminate findings and identify opportunities. Members of the GAOF could be involved in the Technical Steering Group review that will take place in Phase 2.

6.3. Recommendations
It is recommended that cross-fertilisation with related tasks is continued in the next phase to ensure full alignment with Highways England’s wider geotechnical research.

Some synergies with external initiatives have been identified as part of Phase 1. Further consultation will take place to explore opportunities for collaborations/future pilots, potentially using Highways England’s know problem sites as case studies.
7. Conclusions

The following conclusions have been drawn from the various activities undertaken in Phase 1:

- Previous research undertaken by Highways England in the area of remote sensing was highly innovative but was commissioned at a time when remote sensing data resolutions and accuracies had just gone through a step-change in development. Some of the techniques had not reached at the time an adequate level of maturity for implementation. Techniques (such as LiDAR, high resolution digital imagery and InSAR) have now reached a level of maturity and their use is widespread whilst other emerging techniques are now potential candidates for further investigation as detailed in Section 3 and 4.

- Highways England should exploit existing datasets that have been procured primarily for asset inventory and that are not currently used for geotechnical applications. LiDAR and imagery datasets currently being procured through SPaTS framework will have improved coverage and resolution. These datasets show promise e.g. for detecting change or extracting geometry of geotechnical assets.

- Whilst each of the individual techniques has potential to provide some information of value for monitoring geotechnical assets, analysis and interpretation is best undertaken using a combination of techniques and by combining with other datasets.

- The techniques presented in Section 3 (techniques already being procured) and Section 4 (techniques not currently procured, including LiDAR) could all be suitable and should be considered in the next phase of work. Their applicability will vary according to the type and scale of the specific feature that is required to be assessed. The choice of platform and sensor, both for trials and implementation, needs to be tailored to specific user requirements, especially with regard to the type of feature wanting to be captured and the spatial scale of the feature and accuracy requirements.

- The optimal combination will depend not only requirements, but also on cost, value for money and cross-asset application. A cost/benefit analysis for identified remote sensing techniques (or combination of) would help informing investment decisions.

- Change detection, condition monitoring and soil moisture assessment have been highlighted as highly desirable future applications of remote sensing techniques to geotechnical asset management. Remote sensing techniques are very software dependent. The software that can be used for change detection and object recognition should be investigated as part of the Phase 2 work such that potential use cases can be established.

- The stakeholder consultation undertaken in Phase 1 has proven to be extremely useful in discovering synergies and potential opportunities for ‘proof-of-concept’ pilots and/or future trials to include collaboration with a mixed group of end-user (Highways England), consultant (engineer/advisor), academic, and commercial suppliers (survey equipment and data suppliers).

- Collaboration and cross-fertilisation with industry and academia will be a strong enabler for innovation and implementation of these techniques in asset management. The wider stakeholder workshop has highlighted a keen interest in the industry to share knowledge on the application of remote sensing techniques.

- Developments in remote sensing technologies of data collection, post-processing of data, and data-fusion are occurring at a rapid rate. Future
developments of remote sensing are on the horizon, some of which are in military domain and may in future be available for civil applications, such as high altitude drones with near real-time monitoring. The increased availability of datasets (increasingly open source) such as climatic data and satellite imagery is allowing for higher temporal frequency of data collection and dissemination, which will assist monitoring and response to critical events such as extreme weather (flood, extreme rainfall events).

7.1. Recommendations for next steps

The next phase will be application-led and concentrate on the use of acquired data to monitor condition and performance of geotechnical assets. It is recommended that the following activities are undertaken in the next phase of this project:

- **Technical guidance** for the use of the selected techniques will be developed as a joint effort by specialists and experts with the appropriate knowledge of the technical subject, existing processes and implications for end-users. Development of technical guidance notes will be informed by all activities outlined below.

- **Further consultation** will take place to discuss use of selected remote sensing techniques for geotechnical asset management applications. In particular, we will consult with:
  - Highways England stakeholders (cross-discipline) with the aim to confirm requirements, tap into ongoing initiatives, identify existing datasets for proof-of-concept pilots and discuss future trials & pilots
  - BGS and NPL on potential collaborations with the identified relevant initiatives
  - Academics, suppliers and Subject Matter Experts from the Arup AECOM consortium for more focussed discussions on technique applications
  - Managing agents, particularly on user requirements
  - Technical Steering Group to review interim findings and provide technical assurance

It is recommended that the list of stakeholders is reviewed and the appropriate level of engagement agreed at the beginning of next phase. Required attendance at Technical Steering Group review meetings should also be formalised with the Project Sponsor.

- **A cost/benefits analysis** for using one or a combination of remote sensing techniques will be undertaken. Remote sensing techniques can be expensive but the cost could be optimised by identified cross-asset applications for the same datasets. Consideration of value, quantifiable benefits and future possible expansion to the rest of network should inform the selection of techniques (or combination of) to be trialled. A potential output could be a requirement matrix to allow quick comparison of applicability and cost/benefit between techniques.

- **Identify and undertake 'proof-of-concept' pilots.** Discussion will take place with Highways England to identify ‘proof-of-concept’ pilots, which will investigate how existing datasets - currently not used for geotechnical asset management - could be exploited. E.g. LiDAR and imagery datasets stored in AVIS, InSAR dataset from the TIM project or other initiative (see Section 6.2.2) and hyperspectral dataset from M40 DBFO.

- **Design of future trials & pilots.** To inform development of appropriate trials it is recommended to hold further discussion with Highways England according to specific user requirements and choice of appropriate test site(s). For maximum benefit the test site(s) should be chosen for where additional datasets are already available, including ideally instrumented slopes or slopes with a time history of
monitoring records available. Trial sites should be known problem sites where more than one technique can be tested in order to investigate their complementarity and effectiveness. Trials should be undertaken at similar time/season and repeated to allow detection of change. It is recommended that user requirements by Highways England shall also consider how the collected datasets could be of potential use to other Highways England parties, beyond geotechnical asset management. This could influence the specification for any trials and surveys.

- **Integration with Highways England’s existing processes and wider research.** We will ensure that the work undertaken as part of this project is aligned with existing processes and with the wider direction of travel of Highways England’s geotechnical research towards improving the resilience of geotechnical assets. For example, we will consider how remote sensing techniques could be used to detect ground movement changes related to potential ground hazards at identified vulnerable locations. We will assess research findings from Phase 1 against HD 41/15 requirements. We will also consider which remote datasets could be integrated in HA GDMS, and how they can be used for condition assessment across the network. A history of layers would also be of benefit, to be able to see changes over time. Other considerations include how data captured using selected remote sensing techniques could feed into the forthcoming Geotechnical Asset Data Improvement Plan and how they could support derivation of geotechnical performance indicators.
REFERENCES


InSAR for geotechnical infrastructure: enabling stakeholders to remotely assess environmental risk and resilience
http://gtr.rcuk.ac.uk/projects?ref=NE/N013042/1 (accessed December 2016)

LiveLand: https://artes-apps.esa.int/projects/liveland (accessed December 2016)

Satellite Applications Catapult Soil Moisture Workshop,
https://sa.catapult.org.uk/news-events-gallery/events/soil-moisture-workshop/

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References used for the summary sheets:

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http://www.esa.int/About_Us/ESA_Publications/InSAR_Principles_Guidelines_for_SAR_Interferometry_Processing_and_Interpretation_br_ESA_TM-19

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https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/smos/scientific-requirements

LiDAR:


Multispectral Imagery:
European Space Agency (accessed December 2016)
https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/resolutions/spatial


Structure from Motion (SfM):

Hyperspectral Imaging:


BaySpec, Inc., OCI™-F-NIR Hyperspectral Camera, Fact Sheet.
ITRES Research Limited, CASI1500 System, Fact Sheet.

Thermal Scanning:


APPENDIX A – Stakeholder engagement
### Appendix A.1 - Record of external meetings

<table>
<thead>
<tr>
<th>Meeting</th>
<th>Date</th>
<th>Attendance</th>
<th>Purpose</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick-off meeting</td>
<td>23/09/2016</td>
<td>Project Sponsor, project team, Chris Batey</td>
<td>Inception meeting</td>
<td>Notes issued.</td>
</tr>
<tr>
<td>TIM/SPaTS 1-086 liaison</td>
<td>06/10/2016</td>
<td>JC/SC/MRW/Elena Barton (NPL)</td>
<td>Find out about the TIMS project</td>
<td>Potential synergy identified. Elena Barton has been invited to take part to the stakeholder workshop.</td>
</tr>
<tr>
<td>Consultation with Mark Jenkins (IBI)</td>
<td>22/11/16</td>
<td>DS/ÁNB/Mark Jenkins</td>
<td>To discuss IBI's current work on data capture and data management including AVIS and their recent R&amp;D</td>
<td>Agreed IBI would provide previous remote sensing review once approved.</td>
</tr>
<tr>
<td>GRSG International Conference</td>
<td>07/12/2016</td>
<td>JM/GC</td>
<td>A poster was presented at the conference to raise awareness about this project and engage with conference attendees.</td>
<td>Good feedback received. Synergies with LiveLand projects have been identified and will be explored in next phase of work.</td>
</tr>
<tr>
<td>Wider stakeholder workshop</td>
<td>12/12/2016</td>
<td>Project team + 20 stakeholders</td>
<td>Raise awareness about the project and elicit feedback on findings of Phase 1.</td>
<td>See Section 5.3 of this report for details.</td>
</tr>
</tbody>
</table>
Appendix A.2 – List of stakeholders

Stakeholder engagement in the next phase of work will be prioritised on the basis of their power and interest. The stakeholder list included in this Appendix summarises the stakeholder analysis and their power/interest.

- High power, interested people: manage closely, the greatest amount of effort should be put in engaging with this stakeholder group and keep them happy.
- High power, less interested people: keep satisfied with interesting updates but not too frequent.
- Low power, interested people: keep these people adequately informed. These people could be very helpful with the detail of the project.
- Low power, less interested people: monitor and send occasional updates.
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Affiliation</th>
<th>Power</th>
<th>Interest</th>
<th>Action</th>
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</thead>
<tbody>
<tr>
<td>Chris Batey</td>
<td>Highways England (AIG)</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
</tr>
<tr>
<td>Chris Newson</td>
<td>Highways England (Pavement)</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
</tr>
<tr>
<td>David Patterson</td>
<td>Highways England (Geo)</td>
<td>High</td>
<td>High</td>
<td>Manage Closely</td>
</tr>
<tr>
<td>David Wright</td>
<td>Atkins</td>
<td>Low</td>
<td>Low</td>
<td>Monitor</td>
</tr>
<tr>
<td>Dennis Sakufiwa</td>
<td>Highways England (Geo)</td>
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<td>High</td>
<td>Manage Closely</td>
</tr>
<tr>
<td>Elena Barton</td>
<td>NPL</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
</tr>
<tr>
<td>Francis McKeown</td>
<td>Highways England (Structures)</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
</tr>
<tr>
<td>Harry McCormack</td>
<td>CGG</td>
<td>Low</td>
<td>Low</td>
<td>Monitor</td>
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<td>Helen Reeves</td>
<td>BGS</td>
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<td>High</td>
<td>Keep Informed</td>
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<tr>
<td>James Codd</td>
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<td>Manage Closely</td>
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<td>James Lawrence</td>
<td>Imperial College</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
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<tr>
<td>Jim Gallagher</td>
<td>Highways England (Structures)</td>
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<td>High</td>
<td>Keep Informed</td>
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<td>John McRobert</td>
<td>Transport NI</td>
<td>Low</td>
<td>Low</td>
<td>Monitor</td>
</tr>
<tr>
<td>John St Leger</td>
<td>HS2</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
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<td>Lesley Benton</td>
<td>Highways England (Geo)</td>
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<td>Louise Jones</td>
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<td>Madi Sillah</td>
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<td>Mark Jenkins</td>
<td>IBI Group</td>
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<td>Nader Saffary</td>
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<td>Paul Mellon</td>
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<td>Philippa Mason</td>
<td>Imperial College</td>
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<td>Robert Jaffier</td>
<td>Highways England (Operations)</td>
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<tr>
<td>Samantha Godden</td>
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<tr>
<td>Simon Abbott</td>
<td>Network Rail</td>
<td>Low</td>
<td>High</td>
<td>Keep Informed</td>
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Appendix A.3 – Notes from cross-discipline consultation meeting with Highways England stakeholders on 11/11/2016
# Meeting Notes

<table>
<thead>
<tr>
<th>Project title</th>
<th>Highways England – Application of Remote Survey Data for Geotechnical Asset Condition &amp; Performance - SPaTS 1-086</th>
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<tr>
<td>Job number</td>
<td>TBC</td>
</tr>
<tr>
<td>Meeting name and number</td>
<td>Consultation Meeting</td>
</tr>
<tr>
<td>File reference</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>The Cube, Birmingham</td>
</tr>
<tr>
<td>Time and date</td>
<td>10.30 – 12.30 pm, 11 October 2016</td>
</tr>
<tr>
<td>Purpose of meeting</td>
<td>Consult with Highways England on ongoing and planned initiatives related to remote surveys</td>
</tr>
</tbody>
</table>

## Attendance
- Savina Carluccio (Arup)
- Matthew Willis (Arup)
- Christopher Batey (HE AIG)
- Louise Jones (HE AIG)
- James Codd (HE)
- Robert Jaffier (HE Area 9 AM)
- Jim Gallagher (HE – p/t by phone)
- Chris Jenks (Mouchel)
- Charlie Swan (Mouchel)
- Dan Schnurr (Empire Consultants – by phone)

## Apologies
- Dennis Sakufiwa (HE)

## Circulation
- Those attending plus David Patterson

The meeting was called to discuss ongoing and planned remote survey initiatives. These included:

- Robert Jaffier – (HE Asset Manager structures Hertfordshire, Area 9 ‘geotechnical champion’), working with Kier service provider (CJ and CS Mouchel), introduced ideas about doing geotechnical inspections remotely e.g. landslide Bournemouth used as pointing case.

- RJ also discussed a project at A40 Lays Bends. It is a historical landslide site close to Welsh border. Currently there is a UAV supplier “Fly Through” looking at 4 different options: LiDAR, hyperspectral, thermal imagery and near infrared imagery. These will investigate ground movements. Trial in good time for vegetation, David Towel is the contact for Kier. Initial research has found that it would cost approximately £3k per day for LiDAR, and the platform can only carry one sensor at the time. Agreed there is value in carrying out more surveys to be able to detect change. This work driven initially by geotechnical reasons and

Prepared by Grace Campbell
Date of circulation 22/09/2016
work with BGS and Loughborough University as a scoping case as part of monitoring consortium (ALARMS). At the site there will also be ground surveys and monitoring posts.

- This work may not fit into the 1-086 task as the timelines do not match and plus limitations identified in CAA guidelines.

- Composite Drone LiDAR and traditional GPS and total station work is also planned on the M5.

- RJ also noted that there are regulatory constraints for UAV use. Paper by Denis Shapley (Arup) on UAVs recommended.

- Jim Gallagher (structure contact) introduced a scoping study carried out with Chris Armstrong and Denis Shapley. It was majorly impeded by regulation and took 2 years to get some basic surveys done. Denis Shapley has obtained pilot qualification so would be faster to mobilise. The study was carried out at a viaduct in a location difficult to get to and to take photographs and gave very promising results with assessment of corrosion for that structure. There were big safety benefits. A small GoPro camera was used. The drone is GPS enabled so could replicate the path. Further trials may be carried out on A556 and A56 but dependant on a risk assessment. There is the potential to put additional equipment on drone but the weight of equipment may limit the flight time. It was suggested that more photographs could be provided by Denis. The drone could be used in this project and Denis is a trained operator.

- There is an ongoing project to get LiDAR data for the entire network by June 2017. It will potentially prioritise Area 9 (Lays Bend).

- There have been proof-of-concept trials on A4 with the 360 picture complete. M40 DBFO will be flown soon. There is also potentially some hyperspectral data (AISA Eagle unit, done by Blom) for Area 9. ORBIS at Network Rail are using this technique. Contacts for this work in NR include Derek Bell (Project Manager). Hyper-spectral may be useful due to ability to detect algae on top of drains to see if they have been cleaned.

- There will soon be a task brief for new rotary wing surveys available through SPaTS.

- In response to a question from government 3 years ago on the locations of assets a new programme was instigated called AVIS. It surveyed the whole network, routemapper was an interim product as data captured couldn’t be stored in IAM-IS. It was then developed into a web based data viewer with asset inventory, reference to chainage, allowing measurements to be taken. 600 people were trained. The tool was developed with IBI, long term interim measure for IAM-IS. IBI have their own imagery capture vehicle.

- Potential to send people from this project onto a course to get trained in AVIS next week [post meeting note: Grace Campbell and Andy Merritt attended course].

- CB to send reports from previous and documents for currently procured work.

- CB stated that the most important thing is asset inventory rather than condition, asset data capture survey and validation to get commercial datasets and pass on to service providers.

- Other people we may want to consult with are Alan James (Blom operations manager) and Mark Jenkins (IBI) organise meeting via CB/JC

- Mobile mapping ahead in UK – CB went to TRB conference

- As part of a dissemination piece AVIS has been displayed at Highways UK

- Chris J is willing to be contacted and has good experience on field surveys and working with ASC. He has worked with Fly Through previously (e.g. drone Optcopter that can carry up to 7kg and fly for about 30 min). He worked on a possible case study – survey of a
Meeting notes

Highways England – Application of Remote Survey Data for Geotechnical Asset Condition & Performance - SPaTS 1-086

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cliff with a slip surface. Also involved with forensic surveys to find burial sites (resolution of 400 points per square meter). The same method could potentially could pick up tension cracks and bulges e.g. two sites on the M5 (at J7 and J8 there are signs of instability – this project is driven by the need to monitor those sites) and also the aforementioned Lays Bends.

- Constraints noted include that a base station is needed for VRS and GPR to give the 1mm accuracy.
Appendix A.4 – Poster presented at the 2016 Geological Remote Sensing Group annual conference
Overview
Highways England operates, maintains and improves England’s motorways and major (trunk) roads, which amount to almost 7,000 km in length. While this represents only 2 per cent of all roads in England by length, these roads carry a third of all traffic by mileage and two thirds of all heavy goods traffic. About 50,000 geotechnical assets (ie embankments, cuttings and at grade sections) support the road network. These assets are subject to deterioration which, if combined with the impact of severe weather, existing hazards and other external triggers, may result in loss of performance and functionality.

Context
Over the last 12 years Highways England has been effectively using remote sensing methods to capture geotechnical and other asset data. However, this data collection has been relatively piecemeal and with recent advances in remote sensing technology, a greater variety of sensors, platforms and techniques are available for use, some of which may allow for more efficient geotechnical asset data capture.

The use of remote sensing techniques has an additional benefit of reducing the volume of traditional surveying on foot, lowering the exposure of operatives working adjacent to highways the need for lane-closures to enable safe working practice. Reducing the frequency of lane closures has the further benefit of reducing delays to road users.

Scope of the project
The current research project started in September 2016 and will run until the end of June 2017. It will provide a clear picture of the current status of the remote sensing methods previously and currently used by Highways England to inventory and assess the condition of their geotechnical assets, in addition to summarising the type and extent of data currently acquired. It will also research cutting edge remote sensing techniques that can provide innovative, rapid, and potentially low cost, automated methods for inspecting assets and improving asset knowledge, as well as removing some need for personnel to be physically on the network.

Techniques
Techniques under consideration cover a broad range of sensors, each with a variety of possible platforms (terrestrial, mobile, airborne, UAV and satellite), and include:
- Radar interferometry
- Photogrammetry
- LIDAR
- Multispectral Imaging
- Hyperspectral Imaging
- Passive Microwave Radiometry
- Thermal Scanning
- High resolution aerial photography

Stakeholder engagement & feedback
Highways England and the Arup/AECOM project team welcome feedback from the remote sensing community.

Contact
Highways England (Project Sponsor): James.Codd@highwaysengland.co.uk
Arup/AECOM (Project Team): savina.carluccio@arup.com
APPENDIX B – Activity 1.2 Summary Sheets: remote sensing techniques currently being procured by Highways England
A) LiDAR (Fixed, Rotary Wing and Vehicle Based)

History (LiDAR and Highways England)
LiDAR surveying was first researched for earthworks asset inventory and condition by Highways England between 2000 and 2005. From the results of that initial research, major capture of LiDAR datasets commenced in 2004 under the 5+2 year Nationwide LiDAR Framework Contract, which ran until 2011. Following that a 3 year SPS (Specialist Project Services) Framework, Lot 4, was used to procure LiDAR data between 2012 and 2015. This was replaced in 2016 with the SPaTS (Specialist Professional and Technical Services Framework); which is now used to procure LiDAR data.

Drivers for Procurement
The initial aim of the early research work was to assess the potential for improving the safety, speed and reliability of geotechnical asset inspections. However, it was quickly realised that 3-dimensional terrain models and topographic mapping at 1:1250 scale (from fixed wing) and 1:500 scale (from rotary wing) could be produced from the data. At that time Highways England Major Projects required topographic mapping for ECI on a number of significant motorway widening and improvement schemes and this application became the first driver for procurement. During the SPS Framework some initial research in 2012 showed that a vehicle mounted LiDAR could also be integrated with video surveys. These were being used for large scale asset data capture by the Term Contractors in each Area. It was further recognised by Highways England that this dataset could underpin more cost effective awarding of Area Term Contracts, due to a greater understanding of a wider range of asset inventory and condition.

Partner Consultants/Experts
The original research project and associated further tasks from 2000 to 2008 were led by Arup, who were also then Technical Advisor to the frameworks. IBI have helped lead the development of the vehicle mounted LiDAR solution with Blom, a major LiDAR contractor, who were part of the original GeoSurvey Solutions team on the LiDAR and SPS Frameworks, together with Airbus. CH2M Hill and TRL have collaborated to research, innovate and develop integration of LiDAR to other vehicles which survey the network.

Current Survey Methods and Coverage
Although the earlier frameworks focused on airborne LiDAR data capture to provide rapid topographic mapping for the motorway widening and improvement schemes then underway there is currently less need for this type of survey. The current main method of LiDAR data capture across the network is from the vehicle mounted platform for AIG use on asset inventory. As this is a vehicle mounted platform there are limitations on the data coverage (e.g. along embankments and areas outside the highway boundary). To supplement this dataset additional project based ad-hoc airborne LiDAR data from both rotary wing and fixed wing platforms has been captured. However, at the time of this work, a major airborne rotary wing LiDAR dataset for the whole network is in the process of being procured. This will complement two complete vehicle based LiDAR datasets for the network; captured in 2012-13 and 2015-16.

Data Format
The main format for LiDAR data held in the Highways England data archives is .LAS. This is based on an American Society of Photogrammetry and Remote Sensing (ASPRS)
specification, the current version of which was approved by the ASPRS board in 2011. The format is a binary file format independent of the proprietary manufacturer formats and being non-ASCII allows for effective compression and efficient storage of large LiDAR files. Highways England has LiDAR data in archive which is raw and unprocessed (as captured) and also as ‘classified’ LiDAR data where the points have been classified according to the object that has been scanned by the LiDAR pulses. For example, a common classified LiDAR point cloud held in .LAS format will have points in a ground layer (used for terrain modelling), two or three vegetation layers with points usually classified according to the height of the vegetation, plus additional layers such as LiDAR points on structures or non-ground in areas of particularly dense vegetation. The .LAS files can also be accessed and viewed directly in this format using a variety of viewing software, including the IBI AVIS program used by Highways England.

Data Usage

To date LiDAR data has been used by Highways England for three main applications:

1. Three Dimensional Topographic Mapping
2. Major Asset Inventory (pavement, structures, furniture, etc.)
3. Selected Geotechnical Asset applications

The data has been kept in archive format as described above and this has enabled further use of the LiDAR data captured. For example, along the M1 in several locations, LiDAR data originally procured to create topographic mapping of various sections has been extracted from archive, enabling 3D modelling for smart motorways schemes and for annual vegetation management work. The 3D dataset has also been used for applications such as noise mapping studies. Although the original driver for the early research in 2000-05 was for geotechnical applications it has not really been adopted on a routine basis by Managing Agents and on-foot inspections are still the main method of collecting earthworks condition data. This is not because LiDAR datasets are not suitable for collecting HD41 earthworks inspection data but for reasons such as cost of obtaining the data solely for this purpose, processing and viewing of the data, frequency of survey required as well as familiarity and individual preference for traditional inspection methods. However the way the network is managed is changing and there will be more of an onus on reducing road-side inspections for safety reasons and the potential delays caused by lane-closures and the use of safety vehicles.

LiDAR is also of considerable benefit for areas where steep inaccessible natural slopes border the highway and on-foot inspections are difficult and time consuming.

Conclusions for Geotechnical Asset Condition & Performance

- LiDAR data can be used to determine initial asset geometry, including penetration of vegetation to assess slope at ground level.
- Initial returns in a LiDAR point cloud also provides a certain amount of vegetation feature recognition including the type, density and extents of planting.
- Repeat LiDAR data capture enables assessment of ground movements and a certain level of change detection especially when using archive LiDAR data.
- LiDAR data should be stored in an accessible archive. An extensive campaign should be carried out to inform stakeholders and to increase usage.

<table>
<thead>
<tr>
<th>Description</th>
<th>Positive for Geotechnical Assets</th>
<th>Could be Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle LiDAR</td>
<td>Ease of capture, high resolution &amp; accuracy</td>
<td>Use of data for other applications</td>
</tr>
<tr>
<td>Rotary Wing LiDAR</td>
<td>Extends to highway boundary, accuracy</td>
<td>Capture after major construction</td>
</tr>
<tr>
<td>Fixed Wing LiDAR</td>
<td>Enables wider geotechnical stability assessment</td>
<td>Limited coverage over network</td>
</tr>
</tbody>
</table>
A) Vertical Aerial Imagery (Fixed and Rotary Wing)

History

Vertical aerial imagery was first investigated for its potential application to geotechnical asset inventory and condition assessments by Highways England during the Remote Rapid Assessment research project from 2000 – 2005. This also included research into the use of LiDAR and other remote techniques. Following that work, a network wide ‘off-the-shelf’ vertical aerial imagery dataset was purchased. This was captured from a fixed wing platform and processed as orthophoto tiles at ground resolutions of 25 cm (rural) and 12.5 cm (urban). The initial purchase of the licence for this imagery was in 2004 at the time of the 5+2 year Nationwide LiDAR Framework contract, which ran until 2011. This ‘UK Perspectives’ imagery was obtained from Airbus (then called Infoterra), covered the whole network and was made available to stakeholders via the HA ‘GeoStore’. It was also loaded onto Highways England databases such as HAGDMS, as a viewable layer. This licence arrangement remains in place today. In addition to the off-the-shelf imagery, higher resolution rotary wing vertical aerial orthophoto imagery at 2 cm, 4 cm and 5 cm resolutions was also captured during LiDAR surveys commissioned under the LiDAR Framework. Since 2012 high resolution vertical imagery has been procured under the SPS framework when LiDAR surveys have been commissioned.

Drivers for Procurement

It was clear from the early research work that off-the-shelf vertical aerial imagery added a very helpful visual tool which provided useful information about the highway corridor and surroundings before the widespread availability of satellite image layers in Google Maps, Google Earth and Bing Maps. This could be used to understand site layouts, highway and earthwork geometry, structures, vegetation, furniture, watercourses, safe access and other features before site visits were made or even, at times, to replace site visits. Some low level assessment of earthwork condition also could be made at some locations. The image layer was also used as a base layer in HAGDMS to enable a more visual ‘canvas’ on which geotechnical asset information and work was recorded and stored within HAGDMS. The drivers for the procurement of higher resolution imagery sets were slightly different as these were captured as part of the LiDAR Framework surveys for the producing 1:500 scale three dimensional topographic mapping. The imagery was first processed as an orthophoto and then used in conjunction with the three dimensional LiDAR data by the mapping contractors to generate the topographic mapping – typically for motorway widening or major improvement schemes. The imagery would then be passed through to the GeoStore archive and to HAGDMS. However, as the imagery was captured pre-construction it is largely an archive of the network state before these major schemes, until new high resolution imagery is procured. Another issue is that the imagery covers specific sections of the network and is not a consistent network product. However this has since been recognised and at the time of writing a complete new high resolution imagery layer is being procured for the entire network in early 2017.

Partner Consultants/Experts

The original research project and associated further tasks from 2000 to 2008 were led by Arup, who were also then Technical Advisor to the LiDAR and SPS Frameworks. Airbus were awarded the first off-the-shelf imagery contract in 2004 and this imagery is still being provided today, currently by Info Terra/Astrium. Blom were the main provider of high resolution imagery under the LiDAR and
SPaTS Frameworks, with some imagery also provided by Fugro BKS and Terraimaging.

Current Survey Method and Coverage

Currently, the GeoStore archive can be accessed to obtain aerial imagery via the URL: http://www.geostore.com/highwaysengland/

The HAGDMS system also still contains the GeoPerspectives (formerly UK Perspectives) and historic high resolution imagery layers. Survey data procured since the LiDAR Framework, under the SPS and now SPaTS Frameworks, is also submitted to the archive and available through these two channels.

Data Format

The main format for vertical aerial imagery is an orthophoto which is processed from the overlapping raw imagery and corrected for camera lens and terrain distortions and so can be used as a photographic map. It is delivered, stored and accessed in tiles of 1 km x 1 km or 250 m x 250 m for the higher resolution images. The image format .ECW (Enhanced Compression Wavelet) is a native Intergraph (now part of Hexagon Geospatial) format. The .ECW files can also be accessed and viewed directly in this format using a variety of viewing software, but is also native to the Intergraph engineering software used by the majority of consulting engineers.

Data Usage

To date vertical aerial imagery has been procured by Highways England for:

1. Viewing canvas for the entire network, prior to Google and Microsoft (Bing) maps.
2. Topographic Mapping

The data has been successfully used for both of these major applications and has also been stored in archive format as described above. The off-the-shelf imagery is subject to a refresh programme with updates at less than 3 year intervals across the entire network. It is not known how much vertical aerial imagery is being used ad-hoc outside the core GeoStore and HAGDMS databases. It is likely that many stakeholders use the free Google Maps services as this includes both ‘Earth’ imagery from orthophotos at 25cm resolution and also Google StreetView imagery of the network.

Conclusions for Geotechnical Asset Condition & Performance

- Vertical aerial imagery is a good ‘plan-correct’ base dataset to help visualise features within and outside the highway corridor. Information that can be gained about the geotechnical asset include earthwork location, setting and surrounding features (watercourses, structures, access etc), type, qualitative geometry, vegetation, surface visible drainage and remedial works as well as slope failures.

- Both fixed wing imagery (medium resolution 25 cm and 12.5 cm) and rotary wing imagery (high resolution 4 cm) are available and are provided as tiled ‘orthophotos’ suitable for GIS type use.

- A photogrammetric DTM can be generated from the raw stereo imagery and is used to orthorectify the imagery. The DTM can be used for earthwork geometry.

- Imagery used for both cuttings and embankments.

- Repeat imagery surveys (now often with LiDAR) will enable change detection of asset condition from changes to the geometry in the DTM and visible changes on the image.

<table>
<thead>
<tr>
<th>Description</th>
<th>Positive for Geotechnical Assets</th>
<th>Could be Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Wing Aerial Imagery (25–12.5cm)</td>
<td>Full coverage, off-the-shelf, periodic updates, good visual tool</td>
<td>Understanding how many users have access to Google/Bing maps imagery</td>
</tr>
<tr>
<td>Rotary Wing Aerial Imagery (4cm)</td>
<td>Provides useful information for earthwork condition assessment</td>
<td>Limited coverage over network, but this is being improved in 2017</td>
</tr>
</tbody>
</table>
A) Video Imagery (Vehicle Based)

History
Video imagery captured from vehicles running the highway network were introduced to the trunk road network as part of TRAffic-speed Condition Surveys (TRACS) in 2000. However, the video data set has only been used for quality control of the main scanned pavement data. The first TRACS contract (TRACS1) was undertaken by WDM between 2000 and 2005. This was replaced by the TRACS2 contract in early 2006, which was awarded to Jacobs. The TRACS3 survey contract started in February 2012, and being carried out by Yotta. TRACS4 has been awarded to WDM and is due to start in Spring 2017. Historically, in addition to the main TRACS contracts, a number of the service providers such as Yotta and IBI also offered vehicle based video surveys to Managing Agents and contractors who wished to have their own asset inventory at both the start and end of their Area Term Contracts. These surveys were usually delivered to the Area Teams using the contractors’ own software platforms. Some also provided export from their proprietary software enabling an HAGDMS compliant input. This was the case until approximately 2012 when the 3 year SPS (Specialist Project Services) Framework, Lot 4, was used as Highways England’s main procurement of video imagery from a vehicle which also had a LiDAR sensor fitted. This SPS contract was replaced in 2016 by part of the SPaTS Framework Contract.

Drivers for Procurement
The initial driver for TRACS surveys was to improve the safety, speed and reliability of road pavement condition surveys. In particular, removing visual survey inspectors from the network by using a TRACS specified vehicle. One major output from these surveys was road condition data from a scanner which detected rutting, cracking and the overall ride quality of the road surface. In order to quality control this data and to provide an additional visual reference of the carriageway video data was also specified as a minor dataset. In addition to the TRACS contracts, video data was widely procured by Managing Agents and was rapidly adopted as a primary input of other asset data into the HAPMS database, which also required the input of carriageway inventory. This was the definitive record of non-pavement carriageway assets which the Routine Maintenance Management System (RMMS) Manual required to be recorded in HAPMS. The video data procured outside the TRACS contracts provided a simple technique for all Highways England stakeholders to compare the HAPMS data base with the actual observed road data; enabling audit, update of asset records and the recording of asset inspection and maintenance. During the SPS Framework, video data being captured in conjunction with vehicle based LiDAR data, started to be specified for large scale asset data capture and condition assessment to enable the more effective awarding of Area Term Contracts, through a greater understanding of the range of asset inventory and condition.

Partner Consultants/Experts
The original TRACS research and contract development was led by TRL. This was then followed on with development of the specifications, additional sensors and software by TRL. The Roads Liaison Group commissioned work into the wider adoption of TRACS and SCANNER has been used on local roads since 2005. IBI, in conjunction with Blom, have carried out a number of research and development projects to assess the suitability of LiDAR data for augmenting the video imagery.
Current Survey Method and Coverage

Yotta have finished TRACS3 and the TRACS4 contract will be started by WDM in Spring 2017. GeoSurvey Solutions and CH2M Hill, in conjunction with an IBI sensor package, are undertaking the SPaTS contract. Both contracts require a full annual drive of the Highways England network and it is understood that both datasets are still used mostly for their own specific purpose, under each separate driver for procurement. The mobile mapping dataset procured under SPaTS includes video imagery captured in stereo so that geometric measurement at a certain level of accuracy can be carried out in addition to asset inventory assessment. In addition to these surveys, the HARRIS (Highways Agency Road Research Information System) vehicles, developed in conjunction with TRL, are still used for research and development of the TRACS dataset. For example, during the second (TRACS2) contract, surveys of retro-reflectivity of road markings were carried out using a separate survey vehicle (the TRAffic-speed Assessment of Road Markings Survey – TRAMS). For the TRACS3 contract Yotta developed the Tempest survey vehicle.

Data Format

The main format for video imagery is .JPG still photographic images as the video is in fact a series of still images, typically captured at between 4 and 8 Hz. The images are ‘stacked’ as a video and typically held in a proprietary format as specified in HA DMRB Volume 7, Section 3, Part 2: HD20/08 Data for Pavement Assessment, Chapter 2, Section 2.44, TRACS Video Records. This specification from May 2008 requires a hard disk drive of data per area be provided, but it is not known if this is still the case or whether a more central video access is now available. Contractors all offer an on-line video access system as part of their associated software however each uses a proprietary video storage solution.

Data Usage

To date, the video imagery from vehicle platforms has been procured by Highways England for two applications:

1. Quality control of TRACS surface scanning data for the HAPMS database.
2. Major asset inventory capture and assessment to build asset databases which underpin the Area Contracts.

For the major asset inventory data capture the derived asset data, which is extracted from the video imagery, is held in a number of asset databases. The eventual goal is to hold all data in IAMS - however to date suppliers such as IBI provide access via their proprietary AVIS database. The derived asset condition data from these surveys is also held variously in HAPMS, HAGDMS and HADDMS, however this is not formally undertaken as part of the SPaTS contract.

Conclusions for Geotechnical Asset Condition & Performance

- The video imagery captured from road level is a high quality visual tool from which various features used to assess geotechnical asset condition may be identified – such as vegetation, bare slopes and some drainage. Detection of visible changes over successive surveys should also be possible for some features.
- When used with LiDAR captured from the same vehicle, or when video is captured in stereo, asset geometry can be captured to a limited extent. Cuttings are well covered from a moving vehicle but embankments remain a challenge.

<table>
<thead>
<tr>
<th>Description</th>
<th>Positive</th>
<th>Could be Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACS Video</td>
<td>Extensive coverage of network</td>
<td>Standardised archive format</td>
</tr>
<tr>
<td>SPS/SPaTS Video</td>
<td>High accuracy, resolution, multiple angle</td>
<td>Standardised archive format</td>
</tr>
</tbody>
</table>
APPENDIX C – Activity 1.3 Summary Sheets: remote sensing techniques not currently being procured by Highways England
**TECHNIQUE: Thermal Infrared**

**OVERVIEW**

Thermal infrared (TIR) remote sensing, also called Thermal Scanning or Imaging, is a passive technique that detects emitted infrared radiation with wavelengths of between 8 to 15 µm in the Long Wave Infrared (LWIR) region of the electromagnetic spectrum. TIR detection systems can be mounted on a number of platforms but are most frequently used as an aircraft-mounted (both fixed wing and rotor) or ground-based (hand-held) system, providing real-time information. Thermal imaging is a non-contact, non-invasive and rapid technique for detecting thermal anomalies arising from physical and chemical changes.

**Technique**

Infrared sensors capture information about the chemical and physical properties of the Earth’s surface, which in turn, generate different thermal infrared signatures in digital imagery. Infrared thermography operates by measuring the amount of radiation emitted from an object in the Long-wave infrared (LWIR) range (8–15µm). The measured radiation is a function of the object’s emissivity and temperature, as well as the surrounding weather and atmospheric conditions.

**Figure 1.1** Handheld Thermal Infrared Survey to identify water seepage locations within a transport tunnel. Image Source: http://www.penetradar.com/tunnel---wall-inspection.html

<table>
<thead>
<tr>
<th>Key Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Derives bulk thermal properties of surface materials.</td>
<td>• Resolution is generally lower than optical techniques (for given platform distance from object).</td>
</tr>
<tr>
<td>• Produces overall picture of spatial distribution of surface temperature, identifying thermal anomalies.</td>
<td>• Complex image interpretation esp. change detection if data is collected under different environmental conditions (season, time of day).</td>
</tr>
<tr>
<td>• Differentiates soils with different moisture contents.</td>
<td>• Calibration is challenging due to atmospheric and other effects. Wavelengths used are absorbed readily by atmospheric water.</td>
</tr>
<tr>
<td>• Informs about hydrology, surface water and seepage.</td>
<td>• Potentially costly data acquisition and iterative nature of data filtering.</td>
</tr>
<tr>
<td>• Has potential to identify hazards such as sinkholes and mineshafts through differences in thermal properties of infill materials (or voids) and moisture content.</td>
<td>• Informs only about the top layer (~0.5-1.0m) of surface materials.</td>
</tr>
</tbody>
</table>

**Platforms**

TIR sensors are available on a wide range of platforms including: Satellite, Airborne, UAV and terrestrial.

<table>
<thead>
<tr>
<th>PLATFORM</th>
<th>SENSOR</th>
<th>MEASURE</th>
<th>DATA PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPACE</td>
<td>PASSIVE</td>
<td>CHEMICAL</td>
<td>ORTHO-IMAGE</td>
</tr>
<tr>
<td>AERIAL</td>
<td></td>
<td></td>
<td>POINT CLOUD</td>
</tr>
<tr>
<td>TERRESTRIAL</td>
<td>ACTIVE</td>
<td>PHYSICAL</td>
<td>DEM</td>
</tr>
<tr>
<td>MOBILE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATIONARY</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.2** Summary key, blue shaded boxes indicate the key features that apply to the Thermal scanning technique.
Data Formats

Raw: Thermal infrared radiation intensity

Derived: Thermal conductivity, emissivity and diffusivity

Data Availability/Usage

Data is generally acquired by a commercial data provider. Careful consideration of survey timing is required (night-time, day-time, season etc.). Some TIR data is available through extraction from multispectral or hyperspectral systems. Hand held IR systems are widely available.

Geotechnical Applications

This remote sensing method has many applications and is typically associated with; (1) Agriculture and Environment, (2) Geology and Mining and includes the detection of:

- Geothermal activity (subsurface hydrothermal fluid circulation), hot spring detection
- Vegetation type and geological material

Geological Mapping

ASTER and Landsat satellite data (both include thermal bands) has been used to differentiate between surface outcrops of competent rock, weathered rock and unconsolidated superficial deposits.

Sinkhole and mineshaft location and characterisation

Thermal infrared has been used to identify sinkhole locations by observing relatively warm groundwater at or very near the surface. Abandoned mineshafts have been identified as thermal anomalies.

Identification of Hydrogeological Conditions

Thermal surveys (occasionally as day/night pairs) can inform about:

- Localised high groundwater table,
- Soils of varying moisture contents,
- Regions of water ingress-egress (e.g. springs),
- Leaking drainage structures (culverts, pipes, drains) or buried tanks,
- Thermal cracking of assets and structures,
- Shrink-Swell and plastic deformation.

Performance of Highway Drainage Systems

The technique is capable of identifying leaking highway drainage systems (Figure 1.4) and groundwater flow affecting transport infrastructure through seepages in tunnel linings (Figure 1.1).

Road Condition Assessment

by exploiting a 0.5°C difference between poor and good condition pavements Moropoulou et al (2001) utilised thermography to perform road pavement condition assessment.

Figure 1.3 Thermal Infrared image showing relative surface water temperatures and locations of associated sinkholes. ImageSource:https://www.researchgate.net/figure/269095654_fig3_Fig-3-Remote-thermal-infrared-map-showing-variations-of-surface-temperature-C

Figure 1.4 Airborne Thermal Infrared image of leaking drainage infrastructure. Image Source: http://www.visionmap.com/Imaging_for_HLS_Defense_7C_maritime/168/Pipeline_Monitoring

SUMMARY

Since many physical, chemical, and hydro-mechanical processes are linked to thermal responses through thermodynamic coupling, it is possible to exploit thermal anomalies to detect underlying hydrogeological processes and geotechnical processes.

The information that thermal imaging generates is also of potential use to other asset teams including flood and drainage engineers and bridge/structural engineers.
**TECHNIQUE: Hyperspectral Imaging**

**OVERVIEW**

Hyperspectral imaging systems acquire data across hundreds of discrete portions of the electromagnetic spectrum, as individual narrow wavebands of typically 5-10 nm. In comparison, multispectral datasets are composed of fewer bands (typically 3-15 no.) of relatively large bandwidth (70-400 nm). The greater spectral resolution of hyperspectral datasets thus allows for more detailed analysis and land-cover identification.

The technique has possible application to delineating features within rock slopes that may contribute to rockfall and slope failure. This is due to the technique’s capacity to identify the minerals associated with mechanically weaker zones within the rock mass.

**Technique**

Every material on the earth’s surface reflects light in a characteristic pattern within the electromagnetic spectrum. The manner in which light of different wavelengths is reflected or absorbed by each material is known as its reflectance spectrum. Hyperspectral imaging systems consist of a spectrometer that records spectral information in hundreds of discrete narrow bands (each typically ~5-10 nm) that allows a detailed spectral signature to be derived. Therefore, greater detail on mineral and chemical properties can be deduced than from multispectral systems, allowing for a greater variety of refined land-cover classes to be created.

*Figure 1.1 Example of terrestrial hyperspectral scanning of a rock slope. Hyperspectral data cube (left), hundreds of discrete wavebands allow for detailed spectral signature to be derived, each pixel has a unique pixel spectrum (right); source: http://org.uib.no/cipr/Project/VOG/hyperspectral.htm*

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<thead>
<tr>
<th>Key Benefits</th>
<th>Disadvantages</th>
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<tr>
<td>• Hyperspectral allows for more refined spectral signature and analysis than multispectral</td>
<td>• High data volumes (Tb of data)</td>
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<td>• Land-cover classes can be defined according to spectral signature, including pavement type, pavement condition and soil and vegetation classes.</td>
<td>• Complexity of processing and analysis</td>
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<td>• Generate large and therefore flexible datasets</td>
<td>• Calibration and ground-truthing recommended</td>
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<tr>
<td>• Data can be displayed in a number of outputs</td>
<td>• Availability and cost of survey data</td>
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<tr>
<td>• Can help to determine vegetation types and health, which can then be related to soil moisture or soil type</td>
<td>• Better suited to bare rock/soil areas and arid/semi-arid regions. Applicability to geotechnical asset monitoring in temperate regions would benefit from trials and acquisition of spectral libraries for different land-cover classes</td>
</tr>
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**Platforms**

Platforms include: Satellite (Hyperion EO-1); Airborne (AVIRIS; HyMap); UAV-mounted (SOC710), and; terrestrial mobile or static systems. Spatial resolution varies with distance from object and speed of platform/sensor.

*Figure 1.2 Summary key, blue shaded boxes indicate the key features that apply to the Hyperspectral Imaging technique.*

**Data Formats**

*Raw: A reflection spectra per pixel*

*Derived: False colour composite images; Hyperspectral Cube; land-cover classes by material composition e.g. concrete, tarmac, soil class, soil moisture content mapping.*
Hyperspectral datasets of the UK are not readily available and are generally acquired through a commercial provider as a bespoke survey.

Future planned satellite missions such as the EnMap hyperspectral satellite (30m spatial resolution) could be a beneficial source of low cost or free data. Aerial or terrestrial systems more applicable to geotechnical asset monitoring would likely require bespoke surveys.

The applications of hyperspectral remote sensing techniques all exploit the techniques capacity to map and evaluate characteristics of the Earth’s surface. Hyperspectral remotely sensed data, acquired from airborne systems such as NASA’s Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) have been used to investigate the following Earth properties:

- Geological materials (soil and rock types),
- Urban and developed areas,
- Water resources (depth), maritime and shoreline zones,
- Land use

**Slope Instability** Some slope failures on rock slopes are associated with mechanical degradation, weathering and hydrothermal alteration. A study into the application of hyperspectral imaging as a means of characterising potentially instability-prone rock slopes was carried out by the National Institute for Occupational Safety and Health (NIOSH) in the USA. A key finding was that hyperspectral imaging is capable of identifying in the rock mass:

- Clay-rich alteration zones (mechanically weak layers),
- Arrangements of rock discontinuity sets and,
- Presence of faults, shear surfaces and zones of weakness

The technique has potential for identifying the regions within geotechnical assets that may be more susceptible to instability developing. This is due to the techniques capacity to identify the minerals associated with mechanically weaker zones within the rock mass.

**Define Surface Characteristics of Geotechnical Assets** Hyperspectral imaging can map various land-cover classes and can distinguish vegetation type and health, which can be indicator of underlying moisture content and soil mineralogy or chemistry.

**Pavement Condition Assessment** Hyperspectral airborne systems have been used to map road surface type and condition, including the ability to identify cracking in asphalt road surfaces (Figure 1.3).

**SUMMARY**

Hyperspectral imaging is a remote sensing technique that is rapidly developing, in particular as a tool for geological and land-cover mapping. When expressed as a manipulated false colour composite image the technique has several geotechnical asset applications, including the identification of discontinuity patterns, rock-mass variations and other features within rock slopes that may contribute to an increased landslide susceptibility.

Airborne, UAV and terrestrial (mobile, handheld and tripod) mounted sensors can provide both high spatial resolution and high spectral resolution data, to enable land-cover and material properties to be distinguished and shows promise as a technique to classify, map and monitor changes to geotechnical assets. There are some challenges to overcome, in particular in respect to data handling (volume) and complexities of calibration and processing.
**TECHNIQUE: Light Detection and Ranging (LiDAR)**

**OVERVIEW**

LiDAR is an active remote sensing technique that employs a laser light source and can be operated as a terrestrial, aerial or (limited application) satellite-mounted system. The system is utilised as a topographic mapping tool and is widely applied in the following activities: geological, geomorphological and topographical mapping, archaeological investigation, agriculture and civil/structural engineering.

The technique outputs 3D datasets, called point clouds, that reveal the physical shape of the ground surface, structure, vegetation/trees or other feature.

Airborne LiDAR is currently procured by Highways England for mapping assets and geotechnical asset monitoring. There is potential for greater use of some of the LiDAR data outputs including: reflectance intensity data (for texture and land-cover classification); and RGB point cloud information.

**Technique**

LiDAR, also known as Laser Scanning, functions by a light source transmitting a pulse of laser light at an object and timing the time taken for the returning, reflected light pulse to be detected by a receiver. The two-way travel time of the pulse of laser is measured. From that measurement, the spatial location (XYZ) of the reflected surface is determined. Each point cloud feature also typically includes intensity reflectance data and a coloured RGB point cloud.

By transmitting and recording many pulses of transmitted laser light, and systematically varying the direction in which the pulse is directed, a three-dimensional point cloud of the surrounding landscape is constructed. A typical LiDAR scan may record many tens of thousands of light pulses. Survey data is presented as an XYZ dataset with ‘above ground’ features included. Data filtering permits both data-cleaning and vegetation-stripping, creating both a Digital Surface Model (DSM) top of vegetation and structures, or a ‘bare-earth’ Digital Terrain Model (DTM) with vegetation and structures removed.

**Key Benefits**

- Semi-mature technology with proven high survey results resolution and accuracy, already applied widely for surveying transport infrastructure.
- Flexibility of platforms allows for acquisition of data specific to the application requirement, with terrestrial surveys beneficial for surveying high angle slopes, rock slopes and structures or bridge abutment slopes.
- Multiple outputs are possible (DTM, DSM, 3D surface, point cloud).

**Disadvantages**

- Potentially requires equipment to be positioned on network when surveying.
- Potential minor disruption to road network users.
- High data volumes of raw data.
- Relatively high mobilisation costs of airborne sensors.

**Platforms**

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**Figure 1.1** Point-cloud acquired by vehicle-mounted LiDAR System of a cut slope and overbridge on the M1. Extracted from Highways England AVIS System

**Figure 1.2** Summary Key blue shaded boxes indicate the key features that apply to the LiDAR technique.
**Data Formats**

**Raw:** Point cloud of x,y,z, RGB and reflectance data and full spectra of arrival times.

**Derived:** DTM, DSM, shaded-relief, shaded-elevation, contours, mapped features

**Data Availability/Usage**

Survey data is generally acquired through a commercial provider. Some off-the-shelf archive datasets are available for the UK.

**Geotechnical Applications**

Many applications for LiDAR surveying exist within geotechnical asset management. Airborne rotary and vehicle-based LiDAR is currently implemented by Highways England to visualise their road network within their Asset Visualisation System (AVIS), as well as to characterise and locate visible roadside surface assets (signage and structures).

**Sinkhole Detection & Characterisation** Airborne LiDAR has been used to both locate and characterise sinkholes in Kentucky, USA.

**Engineering Geomorphological Mapping** The British Geological Survey (BGS) analyse airborne LiDAR data to produce engineering geomorphological mapping and cartography. In addition, the BGS monitor coastline recession in areas where geotechnical assets are at risk of becoming structurally compromised.

**Geotechnical earthworks asset management** Data can be used to aid geotechnical asset decision-making by highlighting which assets contain features that render their condition marginal or worse.

**Slope Instability & Ground Deformation** The technique can detect relatively small shallow slope failures and other changes in slope morphology (e.g. spoil placement, excavations etc.).

![Figure 1.4](image1.jpg) Greyscale shaded-relief DEM surface showing earthworks at J29, M25, as well as vegetated areas (LiDAR first return, top of canopy measurements DSM).

**SUMMARY**

LiDAR can be a valuable tool for the geotechnical asset management. The technique provides high resolution, highly versatile data about the landscape in the form of Digital Elevation Models or point cloud. Geotechnical Asset Management applications for the technique include:

- Mapping of transport network and associated assets and adjacent areas.
- Identifying and characterising geohazards such as mass movements, sinkholes and settlement.
- Functionality of earthwork remediation measures.
- Mapping of network geotechnical assets (engineering geomorphological)
- Surface Change Models to identify evolution of geotechnical asset condition.

LiDAR survey results are time-stamped and can be analysed using full waveform analysis. This enables survey results to be interpreted in terms of the principal features of interest. An appropriate example of where this full waveform analysis is valuable is in the identification of vegetation or network assets for automatic classification and removal from digital outputs.
TECHNIQUE: Multispectral Imaging

OVERVIEW
Digital multispectral images capture spectral information across a broad frequency range (0.45–12.50 µm) of the electromagnetic spectrum providing more information about the physical and chemical properties of the materials in a scene than a standard aerial photograph. The technique is passive and relies upon reflected sunlight or thermal emission, therefore, data can only be collected in the daytime (with the exception of thermal) and requires sparse or ideally no cloud cover. Multispectral imaging sensors can be hosted on satellite, aerial, and terrestrial platforms, each of which provides a different spatial resolution.

Technique
A multispectral imaging system comprises at least three or more (up to ~15) radiometer sensors. Each sensor detects reflected electromagnetic radiation from the target scene in a different discrete wavelength range (band) and acquires a digital image formed of pixels each with sub-metre to 100 m resolution. The final multispectral image is comprised of any combination of the individual band images, displayed in standard Red-Green-Blue (RGB) channels.

The red-green-blue (RGB) region of the visible electromagnetic spectrum ranges from 0.7-0.4 µm. The others wavelengths are classified as infrared, including near infrared (NIR), middle infrared (MIR) and far infrared (FIR or thermal), and have wavelengths ranging from 0.7–10 or more µm.

<table>
<thead>
<tr>
<th>Key Benefits</th>
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<tbody>
<tr>
<td>• A broad range of spectral (chemical) information can be used to inventory geotechnical assets and monitor their condition over time</td>
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<tr>
<td>• Published spectral libraries (spectral signatures for common materials) are available</td>
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<td>• Images acquired from different platforms can cover large areas (≥1 km²) and small areas both with relatively high pixel resolution.</td>
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<td>• Some satellite datasets (e.g. Landsat, ASTER, Sentinel-2) are available under free open-data policies</td>
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<tr>
<td>• Multispectral images can be used in combination with other remote sensing data, such as Light Ranging and Detection (LiDAR), and Interferometric Synthetic Aperture Radar (InSAR), to observe changes in asset characteristics over time.</td>
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<tr>
<td>• Imaging repeat time are rapid, e.g. daily</td>
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<th>Disadvantages</th>
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<tr>
<td>• Imaging requires daylight and good weather conditions</td>
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<td>• Ground truthing of the spectral signals is required and takes time</td>
</tr>
<tr>
<td>• The material surface reflectance is detected, there is the potential that this is not representative of the underlying material</td>
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Platforms
Multispectral imaging sensors can be hosted on a range of platforms, including satellite, airborne (UAV, plane, helicopter, helikite), and ground-based (hand-held and tripod).

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Figure 1.1 a) Multispectral image (left) composed of multiple individual image scenes (right), each of a different wavelength; Image source: http://www.ok.ctrl.titech.ac.jp/res/MSI/MSI_e.html. b) Spectral reflectance signals (right) are different for each material in a scene (left); Image source: http://www.livingplanet2013.org/abstracts/849435.htm

Figure 1.2 blue shaded boxes indicate the key features that apply to the multispectral imaging technique.
### Data Availability/Usage

Multispectral images from all platforms are available for commercial use. Some satellite-based images such as those acquired by the European Space Agency (ESA) satellite Sentinel-2 are freely available, though most other satellite multispectral images are priced by scene area, with cost increasing with scene pixel resolution and scene area. Satellite multispectral data are available since the 1970's, though as expected, image spatial resolution and pixel quality has increased with time.

### Geotechnical Applications

In general, multispectral imaging has huge potential to monitor the condition of geotechnical assets. The spectral information can detect different natural or manmade material mineralogy types, and changes in mineralogy over time, which may be related to erosion; detection of vegetation cycles that can indicate soil moisture content.

Lower resolution satellite multispectral images can be used to characterise small map scale regions, to gain a better understanding of regional chemical and physical landscape properties that in turn impact local geotechnical assets. High-resolution aerial and ground-based multispectral imaging can be used to characterise geo-assets on a local scale.

### SUMMARY

Because multispectral imaging provides information about the chemical composition of a material's surface, it can be used to both inventory geo-assets, and to monitor how they change over time. In particular, processes such as weathering for example, because it can change the chemistry of a surface material, can potentially be identified as drivers for asset change, which can provide additional information for asset protection planning and deterioration prevention. In combination with other remote sensing techniques that monitor physical changes at various spatial scales, such as Interferometric Synthetic Aperture Radar (InSAR), multispectral imaging, which can be implemented at various scales and resolutions, has the potential to reveal additional information about both the local-scale asset, and the regional-scale physiographic context of the asset and the processes potentially effecting it.
**OVERVIEW**

Structure from Motion (SfM) is a technique that generates high-resolution digital topography and coregistered texture (colour) from an unstructured set of overlapping photographs taken from varying viewpoints. The technique can therefore overcome many of the cost, time, and logistical limitations of Light Detection and Ranging (LiDAR) and other topographic surveying methods. The digital photos can be collected from both aerial and ground-based platforms and can provide high-density colour x,y,z point clouds and centimetre-resolution digital elevation models (DEMs) in addition to high-resolution photographs.

**Technique**

Like traditional photogrammetry, SfM triangulates among the locations of individual features matched in multiple images to build the geometry, 3D shape and colour of a scene, as well as reconstructing the camera positions and orientations. This is achieved using overlapping photographs (taken with a fixed focal length) from multiple viewpoints. The method uses recent advances in feature-matching algorithms that allow for large changes in scale, perspective, and occlusion, making survey planning for photo acquisition much more straightforward than in traditional photogrammetry.

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### Key Benefits

- Colour (Red-Green-Blue, RGB) x,y,z point cloud
- Centimetre resolution DEMs
- Imaging repeat times are rapid, e.g. daily
- Low cost and easy flexible survey methods relative to other remote sensing methods of generating 3D digital scenes
- Regional to local scale high-resolution data
- Technique overcomes ‘shadow zones’ associated with Light Ranging and Detection (LiDAR) datasets

### Disadvantages

- Processing time required to derive high-density point cloud
- Large volumes of digital photo data required to produce high resolution models
- Surveying is weather dependent
- SfM cannot ‘see through’ vegetation, therefore, accurate ground models of densely vegetated areas are a challenge/ not possible
- Images should ideally be collected at the same time of day under approximately the same environmental conditions

---

### Platforms

Photo datasets are collected using a consumer compact or professional camera and a network of ground control points, GCPs, (points at which the exact geographic co-ordinate and elevation is known). The GCPs allow a true scale and known co-ordinate system to be implemented. Consumer cameras can be mounted on aerial platforms including, Unmanned Automated Vehicles (UAVs), planes, helicopters, helikites, and on ground-based platforms, such as long poles, vehicles, and handheld.

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**Figure 1.1** A 3D Model is built from determining matching pixels in a scene from multiple overlapping camera view angles and positions. Image source: http://www.theia-sfm.org/sfm.html

**Figure 1.2** Summary key, blue shaded boxes indicate the key features that apply to the SfM technique.
Data Formats

Raw: Colour (RGB) point cloud and digital photos.

Resolution: There is a trade-off between the distances of the camera from the survey area. When photographs are taken closer to the ground or feature, the SFM point cloud density and DEM resolution improve at the expense of smaller photograph footprint size and overlap, with a resulting increase in the time taken to survey a given area. Typically, centimetre resolution DEMs can be generated from several hundred photos, or less, of an area or object.

Derived: Centimetre-resolution shaded relief DEMs. Orthorectified (undistorted) high-resolution colour photo mosaics, contour and slope maps.

Data Availability/Usage Formats

SFM datasets are not readily available, they need to be collected for the region of interest determined by the surveyor or client as bespoke surveys. The technique is in the beginning stages of application to geotechnical-related problems.

Geotechnical Applications

SFM generates a combination of high-resolution photos, high-resolution colour point clouds, and 3D surface models of the features of interest. This type of data can be used to assess and monitor the condition of geo-assets such as embankments, cuttings, pavement, and structures over time. Figure 1.3 shows a shaded relief DEM and contour map, derived from an SFM point cloud, showing dry stream channels in a desert landscape.

Figure 1.3 Shaded relief DEM and contour map of dry stream channels in a desert landscape, derived from drone aerial imagery. Image source: https://uas.usgs.gov/

Figure 1.4 presents the capability of SFM to produce a high-density, highly detailed 3D RGB (textured) point cloud of a natural scene such as a rock cutting (as shown, top panel), in addition to the point cloud colour-scaled by elevation (bottom panel).

Figure 1.4 a) SFM ‘textured’ RGB colour point cloud of rock slopes; b) A different view angle of the same rock slope with the point cloud coloured by elevation. Image source: https://uas.usgs.gov/

SUMMARY

SFM is a relatively recent technique that has evolved with recent advances in computer science and algorithm-based digital data processing. The technique shows great potential for application to monitoring the condition of geotechnical assets over time. The raw photo datasets are not readily available but they can be collected at relatively low cost by the user and can cover both large (≥1 km²) and small areas with high spatial resolution. Since this type of data collection would start from the date of the first survey, to detect changes that have happened on longer timescales, the SFM data can be used in conjunction with existing datasets such as LiDAR, or aerial-/satellite-based optical or multispectral imagery.
**OVERVIEW**

A passive microwave radiometer measures electromagnetic energy radiated towards it from a target. In application to geo-asset condition monitoring, MIRA can measure the radiation of moisture in the ground (to depths of several metres) and measure changes in vegetation biomass. Ground moisture levels can be used to assess slope failure potential of earthworks and can potentially determine regions that might be prone to flooding (i.e. areas with a high ground-water table). The microwave radiometer sensor can be mounted on a satellite platforms, in addition to terrestrial mobile, and airborne platforms.

**Technique**

The energy detected by a radiometer at microwave frequencies is the thermal emission from the target itself as well as thermal emission from the sky that arrives at the radiometer after reflection from the target. The thermal emission depends on the product of the target’s absolute temperature and its emissivity, but at microwave frequencies (in contrast to the thermal infrared) it is the change in emissivity rather than the change in temperature that produces most of the significant differences between the various targets. The microwave radiometer sensors can use L, C, and X bands (1.4, 6.8, and 10 GHz), each band is typically sensitive to moisture at soil different depths.

**Key Benefits**

- Water can be accurately detected up to several metres beneath the ground surface
- The technique makes non-intrusive subsurface measurements
- Soil moisture measurements are particularly useful for assessing slope stability and flood potential of earthworks

**Disadvantages**

- Subsurface soil moisture measurements should be ground-truthed particularly in business/safety critical sites.
- In spite of the ground facing sensors, the soil moisture measurements can be effected by radiation signals from other roadside sources such as trees. Measurements are also disturbed by the presence of metal objects above surface or underground.

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**Figure 1.2** Summary key, blue shaded boxes indicate the key features that apply to the MIRA technique.

**Platforms**

MIRA sensors can be mounted on satellite-, aerial- and ground-based platforms. Aerial- and ground-based platform-mounted sensors are most applicable for geo-asset condition monitoring.

**Data Formats**

**Raw:** Brightness temperatures

**Resolution:** The resolution of the soil moisture measurements increase with increasing closeness to the target. Satellite-based sensors typically result in images with a resolution of over 10 kilometres squared, airborne-mounted sensors typically result in images with a resolution of 5 to 10 square...
metres, whereas ground-based mobile platform sensors can produce images with a resolution of one metre squared (at a speed of 5 km/hr).

**Derived:** Calibrated digital images of soil moisture

### Data Availability/Usage

High resolution soil moisture data of an asset needs to be collected by bespoke surveying. There are no country specific or global high-resolution datasets readily available.

![Figure 1.3 Ground-based mobile soil moisture surveying of a levee. Image source © Miramap 2016.](image1.png)

### Geotechnical Applications

The main geotechnical applications of MIRA are for detecting and monitoring changes in vegetation biomass and subsurface soil moisture of earthworks, including embankments, levees, and beneath roads. The latter has shown promising results for assessing the slope stability of assets. Because the technique is non-invasive it is particularly useful to monitor moisture at the base of roads and pavements. This has proven an effective tool for damage prevention and route planning.

![Figure 1.4 A mobile ground-based microwave scanner. Image source © Miramap 2016.](image2.png)

### SUMMARY

The use of ground-based and aerial-mounted passive microwave sensors to assess soil moisture for geotechnical applications is a relatively recent development (last 5 years). Methods are becoming increasingly cost effective and operational. MIRA can provide high-resolution soil moisture data, which is particularly useful for assessing the slope stability of earthworks, and monitoring the flood potential of regions that are known to become saturated with ground water. MIRA soil moisture data should prove particularly useful for asset condition monitoring when analysed in combination with high-resolution data such as digital elevation models and vertical aerial photography derived from other remote sensing techniques, in addition to other non-invasive geophysical techniques, including ground penetrating radar (GPR).
InSAR is a radar imaging technique that uses two or more synthetic aperture radar (SAR) images to detect and measure centimetre- and millimetre-scale surface deformation over time. The technique is active, therefore, imaging is possible in all weather conditions, night and day. Image acquisition repeat times are frequent (1–35 days) so ground surface changes can be monitored on relatively short timescales. The platform upon which the sensor is mounted can be ground-based (GB)-, aerial-, and satellite-based, each provides a different scale of surface observation.

**Technique**

InSAR involves the transmission and reception of radar waves with frequencies roughly in the range of 1–11 Gigahertz (GHz) and corresponding wavelengths of ~1–11 cm. When the radar pulses emitted at two different times indicate a phase shift between the echoes of the two signals, the movement of the backscattering targets, and therefore a surface-deformation or elevation-change map can be derived. ‘Time-series’ (multiple repeat images of the same area made at different times) image processing is a particularly powerful method to increase the resolution and quality of surface change measurements derived from InSAR.

**OVERVIEW**

Figure 1.1 Simplified cartoon showing the basic principals of radar interferometry InSAR; image source: http://volcano.si.edu/volcano.cfm?vn=332020

**Key Benefits**

- Rapid remote surveying of sites with areas measuring thousands of square kilometres with a pixel resolution of about 10 m
- Centimetre- to millimetre- scale changes in the ground surface can be detected in any weather, day or night
- Good quality data available since 1995 (also archive data allows for detection of historical ground movement)
- Sentinel-1 data (with free and open access) available since 2014
- Imaging repeat times are frequent (1–35 days)
- InSAR technique can be integrated with other remote sensing and geophysical monitoring methods

**Disadvantages**

- Requires specialist processing
- Better suited to urban areas with higher density of ‘good’ scatter. Less effective in rural regions, though new data processing techniques are in development and show promising results
- Surface change measurements made in the Line of Sight (LOS) of the Satellite, therefore, potentially the total magnitude or sense of change is not detected or is underestimated

**Platforms**

InSAR sensors can be mounted on satellite-, airborne-, and ground-based stationary platforms. The InSAR technique is the same in each case, with capability to detect centimetre-scale surface change, but the scale of the area observed (satellite footprint) in each case increases with elevation above the target.

**Figure 1.2 Summary key, blue shaded boxes indicate the key features that apply to the InSAR technique.**

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<th>SENSOR</th>
<th>MEASURE</th>
<th>DATA PRODUCT</th>
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<tr>
<td>SPACE</td>
<td>PASSIVE</td>
<td>CHEMICAL</td>
<td>ORTHO-IMAGE</td>
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<tr>
<td>AERIAL</td>
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<td>POINT CLOUD</td>
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<tr>
<td>TERRESTRIAL</td>
<td>ACTIVE</td>
<td>PHYSICAL</td>
<td>DEM</td>
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<td>MOBILE</td>
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<tr>
<td>STATIONARY</td>
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</tbody>
</table>
**Data Formats**

Raw: a greyscale digital SAR image mosaic comprised of a two-dimensional array, formed by columns and rows, of small picture elements (pixels), each of which is associated with a small area of the Earth’s surface. Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered by all the ‘scatterers’ (rocks, vegetation, buildings etc.) within the corresponding pixel.

Resolution: SAR pixel resolution is ≤10 m. Raw data is processed to a number of Levels before analysis and interpretation.

Derived: derived InSAR products include: LOS-Deformation Maps, Deformation Time Series (i.e. a graph of LOS displacements plotted with time); Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and Orthorectified (Detected) Radar Images (ORIs). Each of these data products are highly applicable to monitor the condition of geotechnical assets.

**Data Availability/Usage**

Radar SAR satellite-based imagery has been available since the late 1970s. The majority of good-quality, high-resolution satellite SAR data, however, is available since the last decade or so. Data from the European Space Agency (ESA) Sentinel-1 satellites is freely available for commercial use since 2014. Ground-based and airborne-based InSAR data requires commission of a bespoke commercial survey.

**Geotechnical Applications**

Using the range of sensor platforms, InSAR has been used to successfully detect and monitor elevation change related to various geotechnical issues, including: detection of precursory signals of sinkhole formation; city infrastructure subsidence and uplift (e.g. ground subsidence associated with tunnelling works and groundwater abstraction); swelling and sinking of clay-rich soils; landslide/slope instability monitoring; and also structural deformation of infrastructure.

**SUMMARY**

In more recent years InSAR has become a very powerful tool to monitor surface deformation, over regional (≥1 km²) areas and detect centimetre- to millimetre-scale surface elevation changes in any weather condition, day or night. The image repeat times are frequent (≤35 days) allowing for close monitoring. Raw InSAR data requires several specialist processing steps to generate the final products for interpretation. However, data processing times and potential are rapidly increasing with continuing computer software development.

A key benefit of this technique is that it can be implemented at various spatial scales with the same ability for high-resolution physical surface change detection. In particular, combining observations from InSAR data with other remote sensing data, such as multi-scale multispectral imagery, will provide greater insight as to the combination of physical or and or chemical processes that significantly affect different geo-assets, and at what spatial and temporal scales. Additionally, planned future constellations of InSAR satellites will provide near-real-time imaging capability.
Application of Remote Survey Data for Geotechnical Asset Condition & Performance

Stakeholder Workshop, 12th December 2016
Arup offices, London
Context

Remote sensing technology could play a crucial role in providing a proactive approach to geotechnical asset maintenance and potentially deliver safety and efficiency benefits.

This research project will provide a clear picture of the current status of the remote sensing methods previously and currently used by Highways England to inventory and assess the condition of their geotechnical assets, in addition to summarising the type and extent of data currently acquired. It will also research cutting edge remote sensing techniques that can provide innovative, rapid, potentially low cost and automated methods for inspecting assets and improved asset knowledge, removing some need for personnel to be physically on the network.

The workshop has provided an opportunity to present and get feedback on research findings from the first phase of work from a wide range of stakeholders that included representation from asset owners (Highways England, Network Rail, HS2 and TfL), academia (Imperial College) and suppliers. We heard a range of viewpoints on user requirements, applications and risks/challenges in implementing remote sensing techniques.

The outputs of the workshop are summarised in this report and will inform the selection of the remote survey techniques that will be taken forward in the next phase.
Agenda

Welcome and opening address  James Codd, Highways England

Agenda and objectives  Savina Carluccio, Project team

Presentations on research findings to date  Jason Manning & Dan Schnurr, Project team

Workshop Exercise #1 – User requirements

Report Out

Burst presentation on TIM project  Elena Barton, NPL

Burst presentation on photo based condition monitoring  Mike Devriendt, Arup

Lunch

Workshop Exercise #2 – Barriers, risks and challenges

Report Out

Summary and next steps  Savina Carluccio, Project team

Close
Remote sensing technology could play a crucial role in providing a proactive approach to geotechnical asset maintenance and potentially deliver safety and efficiency benefits.
Workshop overview

The workshop opened with James Codd, Highways England Project Sponsor, giving an overview of the scope and objectives of the project and explaining how it fits within the business’ wider geotechnical asset management. Dan Schnurr, a senior specialist from the project team, presented on the techniques currently procured by Highways England. These include LiDAR (Light Ranging and Detection), Vertical Aerial Imagery and Vehicle Video Imagery.

Jason Manning, lead specialist from the project team, then presented the techniques investigated to date. These are: Interferometric Synthetic Aperture Radar (InSAR), Structure from Motion (SfM), Multispectral Imaging, Hyperspectral Imaging, Thermal Infrared, Passive Microwave Radiometry and LiDAR (expansion of the current uses). The key benefits and disadvantages of each technique were briefly presented, as well as their current and potential geotechnical applications.

The first breakout session explored the user requirements for the various techniques and what applications, both current and desired.

Burst presentations from Elena Barton (National Physical Laboratory) and Mike Devriendt (Arup) gave an insight into applications of remote monitoring in geotechnical engineering. Elena Barton presented on the use of satellite imagery in transport infrastructure management. Mike Devriendt discussed the applications of photogrammetry and thermal imaging for retaining walls and tunnels.

Following lunch, the second break out session discussed the barriers and challenges that are faced in implementing these techniques. A report out and plenary discussion summarised these concerns but also highlighted opportunities that remote monitoring can provide to geotechnical asset managers.
## Workshop Exercise #1: User Requirements

The first workshop exercise focused on user requirements and applications. The attendees were first asked to fill in the matrix below and answer the questions:

**What techniques are you already using for these applications?** marked with \( \times \) in the example below

**In the future what techniques would you see potential use for these applications?** marked with \( \circ \) in the example below

<table>
<thead>
<tr>
<th>Technique</th>
<th>InSAR</th>
<th>LiDAR</th>
<th>Multispectral Imaging</th>
<th>SIM</th>
<th>Hyperspectral Imaging</th>
<th>MIRA</th>
<th>Thermal Infrared</th>
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<tr>
<td>Ground Movements</td>
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<td>Change Detection</td>
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<td>Condition Monitoring</td>
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<td>Feature Recognition</td>
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<td>Soil Saturation</td>
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<tr>
<td>Other</td>
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</tbody>
</table>
Workshop Exercise #1: User Requirements

Attendees were then asked to pick between 1 and 3 techniques they were most interested in exploring further and answer the following questions.

1. What are your requirements for these remote sensing techniques?

2. Which applications would you use it/them for and why?

3. Name key concerns you have around the technique(s) you identified.

Discussions were aided by group facilitators (James Codd from Highways England, Patrick Cox from AECOM and Jason Manning from Arup) and thoughts were captured on flip charts.
Workshop Exercise #2: Barriers, risks and challenges

In the afternoon the same groups reconvened in order to focus on:

*barriers, risks and challenges that would be faced in implementing remote sensing techniques.*

Discussions were aided by group facilitators and thoughts were captured on flip charts.

The output of these two workshops is summarised on the following pages.
Workshop Exercise #1 - Results

Current and future uses for remote sensing techniques

Results marked on the pro-forma shown on slide 7 have been collated and shown in the above charts.
Workshop Exercise #1 - Results

Other applications for remote sensing techniques

Other applications that were suggested by the attendees included:

- Asset inventory
- Monitoring other assets (eg drainage, barriers, signs, structures, pavement)
- Incident management
- Topographic surveys, bathymetry,
- UAV ground penetrating radar, terrain analysis & DEM generation
- planning site works surveys & ground investigations
- Considering water ingress.

Additional techniques suggested by attendees included aerial photography, videography and photogrammetry.

Other thoughts on specific techniques

- InSAR for ground movement
- SfM change detection i.e. works adjacent to an asset that may affect the asset e.g. construction works etc.
- SfM – High resolution 3D Model of pavement – cracking, fretting (alternative to 3D User surveys)
- MIRA, IR relating to soil moisture deficit
Workshop Exercise #1 - Results

Question 1 - What are your requirements for these remote sensing techniques?

- High resolution and frequency
- Cost-effective
- Repeatability
- Appropriately accurate
- Speed
- Able to cover large areas/liner assets
- Able to detect signs of instability
- Not a lot of post processing
- Feature detection
- More frequent updates on condition – e.g. ride quality
- Early warning of potential movement of pavement
Workshop Exercise #1 - Results

**Question 2 - Which applications would you use it/them for and why?**

- Combining techniques to achieve desired application
- Detecting change that can be correlated with asset condition and performance assessment
- Reducing the requirement for physical inspections
- Geospatial relationship between asset types to allow cross-asset evaluation
- Management of severe weather events
- Moisture detection – 70% geo failures cause by water, drainage
- To monitor existing construction of slopes and other infrastructure assets and a strain warning of any onset of stability
- Detect signs of instability in hazard areas (e.g. backfilled mining)
- Varied depending on analysis of ‘soft’ estate or beneath pavement, around structures etc.
- Detect movement for scour susceptible structures
- Targeting maintenance and other interventions
Workshop Exercise #1 - Results

*Question 3 - Name key concerns you have around the technique(s) you identified.*

- Data manipulation and processing time
- Accuracy
- Repeatability
- Temporal & spatial resolution
- Visualisation
- Cost – especially if combination of multiple techniques required to give usual results
- Ability to distinguish changes of interest from other changes
- End-user misinterpretation
- Access to data
- Features missed
- Effects of vegetation
- Identification of particular textures without ground markers
- Cost/time of interpretation
- Availability and installation
- Losing traditional ‘experience’ from established engineers
Workshop Exercise #2 - Results

Question - Identify **barriers, risks and challenges that would be faced in implementing remote sensing techniques**

**Barriers**

- Information capture and sharing between industry sectors
- Funding – not clear who
- Risk appetite
- Case studies exist but cost and transparency?
- Knowledge access to data gap
- Focus of surveys – should it be on known issues or network wide?
- Writing a specification for requirements
- Empire building within firms
- Internal organisation structure: no central resource organising procurement
- Current procurement governed by technology
- Can be expensive but can optimise through using technique in a range of business streams – wider applications
- The strategy should be to demonstrate that the technique makes a difference

Is the industry prepared to share knowledge and data openly and transparently?
Workshop Exercise #2 - Results

**Question** - Identify barriers, risks and challenges that would be faced in implementing remote sensing techniques

**Risks**

- Being ‘mis-sold’ techniques
- Data confidentiality
- Additional Regulation and Health & Safety
- Liability
- Can of worms. Different results from different firms – why?
- Confidence in contractor survey results
- Data use, limitations and transparency – should not be a “black box”
- Day to day risks – delegated to managing agents
- Expertise to understand new data sets potentially not in-house
- Use of neighbours land
- One property warns of an activation event – e.g. MC, PWP, sinkhole landslide, whereas another doesn’t

---

“While there can be large upfront costs, it comes down to cost benefit analysis – prevention vs intervention”
Workshop Exercise #2 - Results

*Question - Identify barriers, risks and challenges that would be faced in implementing remote sensing techniques*

**Challenges**

- Funding
- Procurement route – supply chain knowledge
- Costs
- Data storage
- Hardware/software specification
- Where to stop with the contractor
- Data ownership
- Time limitations vs capacity
- Writing spec for grading
- Processing and visualisation should be automated and available readily to the user (science must be mature)
- Seasonal variation – e.g. no vegetation in winter

**Opportunities**

- Remote Sensing to improve Health & Safety
- Remote Sensing to support KPIs
- Collaboration between industry and academia
- Open sourcing and data (National Data Sets)
- Combining data sets
- In-house collaboration for data collection
- Successful Remote Sensing case studies to support successful trading

“There may be many challenges but there are just as many opportunities”
# Appendix A: Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Institution</th>
</tr>
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<tbody>
<tr>
<td>Áine</td>
<td>Ni Bhreasail</td>
<td>Arup</td>
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<tr>
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<td>AECOM</td>
</tr>
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<td>Dan</td>
<td>Schnurr</td>
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<tr>
<td>Michael</td>
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</table>
Appendix B: Presentations
Close range photo based condition monitoring

Highways England Application of Remote Survey Data for Geotechnical Asset Condition & Performance

12 December 2016

Mike Devriendt
Associate Director, Arup London
michael.devriendt@arup.com
+44 20 7755 2163

1. Techniques – reconstruction (immersive)

- Removing subjectivity and automating condition inspection
- Photos taken to acquire high quality images of ‘hard’ surfaces,
- Retaining walls, tunnels, bridges ✔ earthworks ❌
1. Techniques – reconstruction (CAD based)

Mesh / point cloud is generated from just photos

For curved surfaces (e.g. tunnel), can present as 2D planar surface...

useful for change detection work

1. Techniques – reconstruction (IR)

Use of IR camera technology

- Can also develop 3D infra red models too
- Dark areas represent lower temperature where there are damp patches (leakage)
- Useful for retaining walls and tunnels
1. Techniques – object recognition

Cracks and panel joints identified
2. Photos at speed

- Objective to avoid closing road / railway to carry out inspection
- Good lighting conditions, photos could be taken up to 20 to 30mph without significant photo quality degradation
- Higher speeds, need to get specialist kit. Strobe light triggered burst photography & very fast shutter speed £££

3. Standards

- Can we train object recognition to spot a range of features?
- How reliable are they at doing this?
- Can we auto-populate the inspection forms?

- Are HA / HE standards able to accommodate new technology?
- Do they inhibit uptake of new techniques?

Structural condition, only one factor in retaining wall's performance
InSAR for geotechnical infrastructure:
Enabling stakeholders to remotely assess environmental risk and resilience
[2016-2017]

QUB & BGS Team

12th December 2016, London, UK
Remote Sensing for Geotechnical Asset Management Workshop

Project Team

Dr David Hughes (PI & Coordinator)
Dr Jenny McKinley
Dr Shane Donohue
Mr Conor Graham

Funded via NERC grant NE/N013018/1

Dr Francesca Cigna (PI)
Dr Vanessa Banks
Mr Kieran Parker
Mr Alex Donald

Funded via NERC grant NE/N013042/1
Objective

To analyse the benefits of using satellite radar interferometry (InSAR) to remotely assess risk to infrastructure associated with ground movements (landslides and mining-related)

Crown hole collapse at abandoned Maidenmount salt mine in Carrickfergus 2001. The collapse generated a hole >100 m in diameter with 8 m vertical displacement

Debris from landslides along the Antrim Coast Road, Northern Ireland

Multi-temporal InSAR

InSAR processing of 20+ scenes allows us to extract reflective targets and measure their motion

Average motion rate (precision up to ~0.1 mm/yr)

Motion time-series (precision up to ~1 mm)
ERS-1/2 and ENVISAT data coverage

69 ERS-1/2 scenes
25m resolution
desc orbits (Track 266)

40 ENVISAT scenes
25m resolution
desc orbits (Track 37)

19 ENVISAT scenes
25m resolution
asc orbits (Track 101)

Land covered: > 3,000 km²

Test sites: Throne Bend, Straidkilly, Bangor line, and Carrickfergus
+ other portions of rail and road networks along the Antrim coast
→ potential to extend the assessment to other sites
InSAR results overview

Velocity Classification
- 5 (≤ -5.0 mm/yr)
- 4 (-4.99 - -3.0 mm/yr)
- 3 (-2.99 - -1.5 mm/yr)
- 2 (-1.49 - 1.5 mm/yr)
- 1 (>1.501 mm/yr)

Velocity is an average in mm per year over the entire 1992-2000 monitoring period.

Newtownards

Up to 5-10 mm/year land subsidence likely induced by groundwater abstraction.
Fair Head

Motion observed in areas affected by landsliding along the Antrim Coast

High resolution UAV surveying

Maidenmount salt mine, 2016
Next steps

• Comparison of InSAR results with monitoring data (groundwater level/abstraction records, levelling data, GPS data, LiDAR elevation models)

• Analysis of more recent ENVISAT 2002-2010 data

• Cover areas at risk with UAV (high resolution local data)
Appendix C: Posters
History of Highways England Use

Vertical aerial imagery was first investigated for its potential application to geotechnical asset inventory and condition assessments by Highways England during the Remote Rapid Assessment research project from 2000–2005. This also included research into the use of LiDAR and other remote techniques. Following that work, a network-wide ‘off-the-shelf’ vertical aerial imagery dataset was purchased. This was captured from a fixed wing platform and processed as orthophoto tiles at ground resolutions of 25 cm (rural) and 12.5 cm (urban). The initial purchase of the licence for this imagery was in 2004 at the time of the 5+2 year Nationwide LiDAR Framework contract, which ran until 2011. This ‘UK Perspectives’ imagery was obtained from Airbus (then called Infoterra), covered the whole network and was made available to stakeholders via the HA ‘GeoStore’. It was also loaded onto Highways England databases such as HAGDMS, as a viewable layer. This licence arrangement remains in place today. In addition to the off-the-shelf imagery, higher resolution rotary wing vertical aerial orthophoto imagery at 2 cm, 4 cm and 5 cm resolutions was also captured during LiDAR surveys commissioned under the LiDAR Framework. Since 2012 high resolution vertical imagery has been procured under the SPS framework when LiDAR surveys have been commissioned.

Drivers for Procurement

It was clear from the early research work that off-the-shelf vertical aerial imagery added a very helpful visual tool which provided useful information about the highway corridor and surroundings before the widespread availability of satellite image layers in Google Maps, Google Earth and Bing Maps. This could be used to understand site layouts, highway and earthwork geometry, structures, vegetation, furniture, watercourses, access and other features before site visits were made or even, at times, to replace site visits. Some low level assessment of earthwork condition also could be made at some locations. The image layer was also used as a base layer in HAGDMS to enable a more visual ‘canvas’ on which geotechnical asset information and work was recorded and stored within HAGDMS. The drivers for the procurement of higher resolution imagery sets were slightly different as these were captured as part of the LiDAR Framework surveys for the producing 1:500 scale three dimensional topographic mapping. The imagery was first processed as an orthophoto and then used in conjunction with the three dimensional LiDAR data by the mapping contractors to generate the topographic mapping – typically for motorway widening or major improvement schemes. The imagery would then be passed through to the GeoStore archive and to HAGDMS. However, as the imagery was captured pre-construction it is largely an archive of the network state before these major schemes, until new high resolution imagery is procured. Another issue is that the imagery covers specific sections of the network and is not a consistent network product. However this has since been recognised and at the time of writing a complete new high resolution imagery layer is being procured for the entire network in early 2017.

Partner Consultants

The original research project and associated further tasks from 2000 to 2008 were led by Arup, who were then Technical Advisor to the LiDAR and SPS Frameworks. Airbus were awarded the first off-the-shelf imagery contract in 2004 and this imagery is still being provided today. Blom were the main provider of high resolution imagery under the LiDAR and SPS Frameworks, with some imagery also provided by Fugro BKS and TerraImaging.

Data formats

The main format for vertical aerial imagery is an orthophoto which is processed from the overlapping raw imagery and corrected for camera lens and terrain distortions and so can be used as a photographic map. It is delivered, stored and accessed in tiles of 1 km x 1 km or 250 m x 250 m for the higher resolution images. The image format .ECW (Enhanced Compression Wavelet) is a native Intergraph (now part of Hexagon Geospatial) format. The .ECW files can also be accessed and viewed directly in this format using a variety of viewing software, but is also native to the Intergraph engineering software used by the majority of consulting engineers.

Data usage

To date vertical aerial imagery has been procured by Highways England for:

1. Viewing canvas for the entire network, prior to Google and Microsoft (Bing) maps.
2. Topographic Mapping

The data has been successfully used for both of these major applications and has also been stored in archive format as described above. The off-the-shelf imagery is subject to a re-fresh programme with updates at less than 3 year intervals across the entire network. It is not known how much vertical aerial imagery is being used ad hoc outside the core GeoStore and HAGDMS databases. It is likely that many stakeholders use the free Google Maps services as this includes both ‘Earth’ imagery from orthophotos at 25 cm resolution and also Google StreetView imagery of the network.

Current Survey Method

Currently, the GeoStore archive can be accessed online to obtain aerial imagery. The HAGDMS system also still contains the GeoPerspectives (formerly UK Perspectives) and historic high resolution imagery layers. Survey data procured since the LiDAR Framework, under the SPS and now SPAiT Frameworks, is also submitted to the archive and available through these two channels.

Recommendations

• Vertical aerial imagery is a good ‘plan-correct’ base dataset to help visualise features within and outside the highway corridor. Information that can be gained about the geotechnical asset include earthwork location, setting and surrounding features (watercourses, structures, access etc), type, qualitative geometry, vegetation, surface visible drainage and remedial works as well as slope failures.
• Both fixed wing imagery (medium resolution 25 cm and 12.5 cm) and rotary wing imagery (high resolution 4 cm) are available and are provided as tiled ‘orthophotos’ suitable for GIS type use.
• A photogrammetric DTM can be generated from the raw stereo imagery and is used to orthorectify the imagery. The DTM can be used for earthwork geometry.
• Imagery used for both cuttings and embankments.
• Repeat imagery surveys (now often with LiDAR) will enable change detection of asset condition from changes to the geometry in the DTM and visible changes on the image.
History of Highways England Use

LiDAR surveying was first researched for earthworks asset inventory and condition by Highways England between 2000 and 2005. From the results of that initial research, major capture of LiDAR datasets commenced in 2004 under the 5+2 year Nationwide LiDAR Framework Contract, which ran until 2011. Following that a 3 year SPS (Specialist Project Services) Framework, Lot 4, was used to procure LiDAR data between 2012 and 2015. This was replaced in 2016 with the SPaTS (Specialist Professional and Technical Services Framework); which is now used to procure LiDAR data.

Current Survey Method

Although the earlier frameworks focused on airborne LiDAR data capture to provide rapid topographic mapping for the motorway widening and improvement schemes then underway there is currently less need for this type of survey. The current main method of LiDAR data capture across the network is from the vehicle mounted platform for AIG use on asset inventory. As this is a vehicle mounted platform there are limitations on the data coverage (e.g. along embankments and areas outside the highway boundary). To supplement this dataset additional project based ad-hoc airborne LiDAR data from both rotary wing and fixed wing platforms has been captured. However, at the time of this work, a major airborne rotary wing LiDAR dataset for the whole network is in the process of being procured. This will complement two complete vehicle based LiDAR datasets for the network; captured in 2012-13 and 2015-16.

Drivers for Procurement

The initial aim of the early research work was to assess the potential for improving the safety, speed and reliability of geotechnical asset inspections. However, it was quickly realised that 3-dimensional terrain models and topographic mapping at 1:1250 scale (from fixed wing) and 1:500 scale (from rotary wing) could be produced from the data. At that time Highways England Major Projects required topographic mapping for ECI on a number of significant motorway widening and improvement schemes and this application became the first driver for procurement. During the SPS Framework some initial research in 2012 showed that a vehicle mounted LiDAR could also be integrated with video surveys. These were being used for large scale asset data capture by the Term Contractors in each Area. It was further recognised by Highways England that this dataset could underpin more cost effective awarding of Area Term Contracts, due to a greater understanding of a wider range of asset inventory and condition.

Partner Consultants

The original research project and associated further tasks from 2000 to 2008 were led by Arup, who were also then Technical Advisor to the framework. IBI have been involved in the development of the vehicle mounted LiDAR solution with Blom, a major LiDAR contractor, who were part of the original GeoSurvey Solutions team on the LiDAR and SPS Frameworks, together with Airbus. CH2M Hill and TRL have collaborated to research, innovate and develop integration of LiDAR to other vehicles which survey the network.

Data usage

To date LiDAR data has been used by Highways England for three main applications:

1. Three Dimensional Topographic Mapping
2. Major Asset Inventory (pavement, structures, furniture, etc.)
3. Selected Geotechnical Asset applications

The data has been kept in archive format as described above and this has enabled further use of the LiDAR data captured. For example, along the M1 in several locations, LiDAR data originally procured to create topographic mapping of various sections has been extracted from archive, enabling 3D modelling for smart motorways schemes and for annual vegetation management work. The 3D dataset has also been used for applications such as police mapping studies. Although the original driver for the early research in 2000/05 was for geotechnical applications it has not really been adopted on a routine basis, by Managing Agents and QP foot inspections are still the main method of collecting earthworks condition data. This is not because LiDAR datasets are not suitable for collecting HD-41 earthworks inspection data but for reasons such as cost of obtaining the data solely for this purpose, processing and viewing of the data, frequency of survey required as well as familiarity and individual preference for traditional inspection methods. However the way the network is managed is changing and there will be more of an onus on reducing road-side inspections for safety reasons and the potential delays caused by lane closures and the use of safety vehicles.

LiDAR is also of considerable benefit for areas where steep inaccessible natural slopes border the highway and on-foot inspections are difficult and time consuming.

Data formats

The main format for LiDAR data held in the Highways England data archives is .LAS. This is based on an American Society of Photogrammetry and Remote Sensing (ASPRS) specification, the current version of which was approved by the ASPRS board in 2011. The format is a binary file format independent of the proprietary manufacturer formats and being non-ASCII allows for effective compression and efficient storage of large LiDAR files. Highways England has LiDAR data in archive which is raw and unprocessed (as captured) and also as ‘classified’ LiDAR data where the points have been classified according to the object that has been scanned by the LiDAR pulses. For example, a common classified LiDAR point cloud held in .LAS format will have points in a ground layer (used for terrain modelling), two or three vegetation layers with points usually classified according to the height of the vegetation, plus additional layers such as LiDAR points on structures or non-ground in areas of particularly dense vegetation. The .LAS files can also be accessed and viewed directly in this format using a variety of viewing software, including the IBI AVIS program used by Highways England.

Recommendations

- LiDAR data can be used to determine initial asset geometry, including penetration of vegetation to assess slope at ground level.
- Initial returns in a LiDAR point cloud also provides a certain amount of vegetation feature recognition including the type, density and extents of planting.
- Repeat LiDAR data capture enables assessment of ground movements and a certain level of change detection especially when using archive LiDAR data.
- LiDAR data should be stored in an accessible archive. An extensive campaign should be carried out to inform stakeholders and to increase usage.
History of Highways England Use

Video imagery captured from vehicles running the highway network were introduced to the trunk road network as part of TRAffic-speed Condition Surveys (TRACS) in 2000. However, the video data set has only been used for quality control of the main scanned pavement data. The first TRACS contract (TRACS1) was undertaken by WDM between 2000 and 2005. This was replaced by the TRACS2 contract in early 2006, which was awarded to Jacobs. The TRACS3 survey contract started in February 2012, and being carried out by Yotta. TRACS4 has been awarded to WDM and is due to start in Spring 2017. Historically, in addition to the main TRACS contracts, a number of the service providers such as Yotta and IBI also offered vehicle based video surveys to Managing Agents and contractors who wished to have their own asset inventory at both the start and end of their Area Term Contracts. These surveys were usually delivered to the Area Teams using the contractors’ own software platforms. Some also provided export from their proprietary software enabling an HAGDMS compliant input. This was the case until approximately 2012 when the 3 year SPS (Specialist Project Services) Framework, Lot 4, was used as Highways England’s main procurement of video imagery from a vehicle which also had a LiDAR sensor fitted. This SPS contract was replaced in 2016 by part of the SPaTS Framework Contract.

Drivers for Procurement

The initial driver for TRACS surveys was to improve the safety, speed and reliability of road pavement condition surveys. In particular, removing visual survey inspectors from the network by using a TRACS specified vehicle. One major output from these surveys was road condition data from a scanner which detected rutting, cracking and the overall ride quality of the road surface. In order to quality control this data and to provide an additional visual reference of the carriageway video data was also specified as a minor dataset. In addition to the TRACS contracts, video data was widely procured by Managing Agents and was rapidly adopted as a primary input of other asset data into the HAPMS database, which also required the input of carriageway inventory. This was the definitive record of non-pavement carriageway assets which the Routine Maintenance Management System (RMMS) Manual required to be recorded in HAPMS. The video data procured outside the TRACS contracts provided a simple technique for all Highways England stakeholders to compare the HAPMS database with the actual observed road data; enabling audit, update of asset records and the recording of asset inspection and maintenance. During the SPS Framework, video data being captured in conjunction with vehicle based LiDAR, started to be specified for large scale asset data capture and condition assessment to enable the more effective awarding of Area Term Contracts, through a greater understanding of the range of asset inventory and condition.

Partner Consultants

The original TRACS research and contract development was led by TRL. This was then followed on with development of the specifications, additional sensors and software by TRL. The Roads Liaison Group commissioned work into the wider adoption of TRACS and SCANWER has been used on local roads since 2005. IBI, in conjunction with Blom, have carried out a number of research and development projects to assess the suitability of LiDAR data for augmenting the video imagery.

Recommendations

• The video imagery captured from road level is a high quality visual tool from which various features used to assess geotechnical asset condition may be identified – such as vegetation, bare slopes and some drainage. Detection of visible changes over successive surveys should also be possible for some features.
• When used with LiDAR captured from the same vehicle, or when video is captured in stereo, asset geometry can be captured to a limited extent. Cuttings are well covered from a moving vehicle but embankments remain a challenge.

Data usage

To date, the video imagery from vehicle platforms has been procured by Highways England for two applications:
1. Quality control of TRACS surface scanning data for the HAPMS database.
2. Major asset inventory capture and assessment to build asset databases which underpin the Area Contracts.

For the major asset inventory data capture, the derived asset data, which is extracted from the video imagery, is held in a number of asset databases. The eventual goal is to hold all data in IAMS - however to date suppliers such as IBI provide access via their proprietary AVIS database. The derived asset condition data from these surveys is also held variously in HAPMS, HAGDMS and HADDMS. However this is not formally undertaken as part of the SPaTS contract.

Current Survey Method

Yotta have finished TRACS3 and the TRACS4 contract will be started by WDM in Spring 2017. GeoSurvey/Solutions and CH2M Hill, in conjunction with an IBI sensor package, are undertaking the SPaTS contract. Both contracts require a full annual drive of the Highways England network and it is understood that both datasets are still used mostly for their own specific purpose, under each separate driver for procurement. The mobile mapping dataset procured under SPaTS includes video imagery captured in stereo so that geometric measurement at a certain level of accuracy can be carried out in addition to asset inventory assessment. In addition to these surveys, the HARRIS (Highways Agency Road Research Information System) vehicles, developed in conjunction with TRL, are still used for research and development of the TRACS dataset. For example, during the second TRACS2 contract, surveys of retro-reflectivity of road markings were carried out using a separate survey vehicle (the TRAffic-speed Assessment of Road Markings Survey – TRAMS). For the TRACS3 contract Yotta developed the Tempest survey vehicle.

Data formats

The main format for video imagery is .JPG still photographic images as the video is in fact a series of still images, typically captured at between 4 and 8 Hz. The images are ‘stretched’ as a video and typically held in a proprietary format as specified in HADAPR Volume 7, Section 3, Part 2 HW200/08 Data for Pavement Assessment, Chapter 2, Section 2.44, TRACS Video Records. This specification from May 2008 requires a hard disk drive of data per area be provided, but it is not known if this is still the case or whether a more central video access is now available. Contractors all offer an on-line video access system as part of their associated software however each uses a proprietary video storage solution.

Figure 1 SPaTS survey vehicle

Figure 2 TRACS survey vehicle
Overview

LiDAR is an active remote sensing technique that makes use of a laser light source and, can be operated as a terrestrial, aircraft-, or satellite-mounted system.

The system is utilised as a topographic mapping tool and is widely applied in the following activities: geological and topographical mapping, archaeological investigation, agriculture and, civil and structural engineering.

The technique outputs 3D datasets, called point clouds; that reveal the nature of the ground surface, structure or feature.

LiDAR is a valuable tool for the geotechnical asset condition management. The technique provides high resolution, highly versatile data about the landscape in the form of Digital Elevation Models or point cloud.

Geotechnical Asset Management applications for the technique include:

- Mapping of transport network and associated assets.
- Identifying and characterising geohazards such as mass movements, sinkholes and settlement.
- Functionality of earthwork remediation measures.
- Mapping of network geotechnical assets (engineering geomorphological).
- Surface Change Models to identify evolution of geotechnical asset condition.

LiDAR survey results are time-stamped and can be fully analysed using full waveform analysis. This enables survey results to be interpreted in terms of the principal features of interest. An appropriate example of where this full waveform analysis is valuable is in the identification of vegetation or network assets for automatic classification and removal from digital outputs.

Technique

LiDAR, also known as Laser Scanning, functions by a light source transmitting a pulse of laser light at an object and timing the time taken for the returning, reflected light pulse to be detected by a receiver. The two-way travel time of the pulse of laser is measured. From that measurement, the spatial location (XYZ) of the reflected surface is determined. Each point cloud feature also typically includes intensity reflectance data and a coloured RGB point cloud.

By transmitting and recording many pulses of transmitted laser light, and systematically varying the direction in which the pulse is directed, a three-dimensional point cloud of the surrounding landscape is constructed. A typical LiDAR scan may record many tens of thousands of light pulses. Survey data is presented as an XYZ dataset with ‘above ground’ features included. Data filtering permits both data-cleaning and vegetation-stripping, creating both a Digital Surface Model (DSM) top of vegetation and structures, or a ‘bare-earth’ Digital Terrain Model (DTM) with vegetation and structures removed.

Key Benefits

- Semi mature technology with proven high survey results resolution and accuracy, already applied widely for surveying transport infrastructure.
- Flexibility of platforms allows for acquisition of data specific to the application requirement, with terrestrial surveys beneficial for surveying high angle slopes, rock slopes and structures or bridge abutment slopes.
- Multiple outputs are possible (DTM, DSM, 3D surface, point cloud)

Disadvantages

- Potentially requires equipment to be positioned on network when surveying.
- Potential minor disruption to road network users.
- High data volumes of raw data.
- Relatively high mobilisation costs of airborne sensors.

Data formats

Raw:
- Point cloud of x,y,z, RGB and reflectance data and full spectra of arrival times.

Derived:
- DSM, DEM, shaded relief, shaded-elevation, contours, mapped features

Available/usage

Survey data is generally acquired through a commercial provider. Some off-the-shelf archive datasets are available for the UK.

Geotechnical applications

Many applications for LiDAR surveying exist within geotechnical asset management. Vehicle-based LiDAR is currently implemented by Highways England to visualise their road network within their Asset Visualisation System (AVS), as well as to characterise and locate all assets (signage and structures).

- Sinkhole Detection & Characterisation: airborne LiDAR has been used to both locate and characterise sinkholes in Kentucky, USA.
- Engineering Geomorphological Mapping: The British Geological Survey (BGS) analyse airborne LiDAR data to produce engineering geomorphological mapping and cartography. In addition, the BGS monitor coastline recession in areas where geotechnical assets are at risk of becoming structurally compromised.
- Geotechnical earthworks asset management: Data can be used to aid geotechnical asset decision-making by highlighting which assets contain features that render their condition marginal or worse.
- Slope Instability & Ground Deformation: The technique can detect relatively small shallow slope failures and other changes in slope morphology (e.g. spoil placement, excavations etc.).

In 2004, the Highways Agency successfully trialled rotor-based LiDAR to monitor slope remediation practices, by comparing two repeat LiDAR surveys, of an engineered slope on London’s M25 Motorway. The trial highlighted LiDAR’s capacity to quantify temporal variations (surveys performed 2001 and 2002) in geotechnical asset slopes. See other LiDAR poster.
TECHNIQUE: Hyperspectral Imaging

Overview

Hyperspectral imaging systems acquire data across hundreds of discrete portions of the electromagnetic spectrum, as individual narrow wavebands of typically 5-10 nm. In comparison, multispectral datasets are composed of fewer bands (typically 3-15 no.) of relatively large bandwidth (70-400 nm). The greater spectral resolution of hyperspectral datasets thus allows for more detailed analysis and land-cover identification.

The technique has possible application to delineating features within rock slopes that may contribute to rockfall and slope failure. This is due to the technique’s capacity to identify the minerals associated with mechanically weaker zones within the rock mass.

Hyperspectral imaging is a remote sensing technique that is rapidly developing, in particular as a tool for geological and land-cover mapping. When expressed as a manipulated false colour composite image the technique has several geotechnical asset applications, including the identification of discontinuity patterns, rock-mass variations and other features within rock slopes that may contribute to an increased landslide susceptibility.

Airborne, UAV and terrestrial (mobile, handheld and tripod) mounted sensors can provide both high spatial resolution and high spectral resolution data, to enable land-cover and material properties to be distinguished and shows promise as a technique to classify, map and monitor changes to geotechnical assets. There are some challenges to overcome, in particular in respect to data handling (volume) and complexities of calibration and processing.

Technique

Every material on the earth’s surface reflects light in a characteristic pattern within the electromagnetic spectrum. The manner in which light of different wavelengths is reflected or absorbed by each material is known as its reflectance spectrum. Hyperspectral imaging systems consist of a spectrometer that records spectral information in hundreds of discrete narrow bands (each typically ≈ 5-10 nm) that allows a detailed spectral signature to be derived. Therefore, greater detail on mineral and chemical properties can be deduced than from multispectral systems, allowing for a greater variety of refined land-cover classes to be created.

Key Benefits

- Hyperspectral allows for more refined spectral signature and analysis than multispectral
- Land-cover classes can be defined according to spectral signature, including pavement type, pavement condition and soil and vegetation classes.
- Generate large and therefore flexible datasets
- Data can be displayed in a number of forms
- Can help to determine vegetation types and health, which can then be related to soil moisture or soil type

Disadvantages

- High data volumes (Tb of data)
- Complexity of processing and analysis
- Calibration and ground-truthing recommended
- Availability and cost of survey data
- Better suited to bare rock/salt areas and arid/sans and regions, Applicability to geotechnical asset monitoring in temperate regions would likely require bespoke surveys.
- False colour composite image the rock mass.

Platforms

Platforms include: Satellite (Hypercube EQ-1), Airborne (AVIRIS; HyMap; UAV-mounted, EOSS/Geometrics, HyMap), and terrestrial or static systems. Spatial resolution varies with distance from object and speed of platform/sensor.

Data availability/usage

Hyperspectral datasets of the UK are not readily available and are generally acquired through a commercial provider as a bespoke survey.

Future planned satellite missions such as the EmMap hyperspectral satellite (30m spatial resolution) could be a beneficial source of low cost or free data. Aerial or terrestrial systems more applicable to geotechnical asset monitoring would likely require bespoke surveys.

Data formats

Raw: A reflection spectra per pixel
Derived: False colour composite images; Hyperspectral Cube: land-cover classes by material composition e.g. concrete, tarmac, soil class, soil moisture content mapping

Geotechnical applications

The applications of hyperspectral remote sensing techniques all exploit the techniques capacity to map and evaluate characteristics of the Earth’s surface. Hyperspectral remotely sensed data, acquired from airborne systems such as NASA’s Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) have been used to investigate the following Earth properties:

- Geological materials (soil and rock types)
- Urban and developed areas
- Water resources (depth), magnitude and shoreline zones
- Land use

Slope Instability Some slope failures on rock slopes are associated with mechanical degradation, weathering and hydrothermal alteration. A study into the application of hyperspectral imaging as a means of characterising potentially instability-prone rock slopes was carried out by the National Institute of Occupational Safety and Health (NIOSH) in the USA. A key finding was that hyperspectral imaging is capable of identifying in the rock mass:

- Clay-rich alteration zones (mechanically weak layers),
- Arrangements of rock discontinuity sets and,
- Presence of faults, shear surfaces and zones of weakness

The technique has potential for identifying the regions within geotechnical assets that may be more susceptible to instability developing. This is due to the techniques capacity to identify the minerals associated with mechanically weaker zones within the rock mass.

Define Surface Characteristics of Geotechnical Assets

Hyperspectral imaging can map various land-cover classes and can distinguish vegetation types and health, which can be indicator of underlying moisture content and soil mineralogy or chemistry.

Pavement Condition Assessment

Hyperspectral airborne systems have been used to map road surface type and condition, including the ability to identify cracking in asphalt road surfaces (Figure 3).
Overview
Thermal infrared (TIR) remote sensing, also called Thermal Scanning or Imaging, is a passive technique that detects emitted infrared radiation with wavelengths of between 8 to 15 µm in the Long Wave Infrared (LWIR) region of the electromagnetic spectrum. TIR detection systems can be mounted on a number of platforms but are most frequently used as an aircraft-mounted (both fixed wing and rotor) or ground-based (hand-held) system, providing real-time information. Thermal imaging is a non-contact, non-invasive and rapid technique for detecting thermal anomalies arising from physical and chemical changes. Since many physical, chemical, and hydro-mechanical processes are linked to thermal responses through thermodynamic coupling, it is possible to exploit thermal anomalies to detect underlying hydrogeological processes and geotechnical processes.

The information that thermal imaging generates is also of potential use to other asset teams including flood and drainage engineers and bridge/structural engineers.

Technique
Infrared sensors capture information about the chemical and physical properties of the Earth’s surface, which in turn, generate different thermal infrared signatures in digital imagery. Infrared thermography operates by measuring the amount of radiation emitted from an object in the Long-wave infrared (LWIR) range (8–15µm). The measured radiation is a function of the object’s emissivity and temperature, as well as the surrounding weather and atmospheric conditions.

Platforms
TIR sensors are available on a wide range of platforms including: Satellite, Airborne, UAV and terrestrial.

Key Benefits
- Derives bulk thermal properties of surface materials.
- Produces overall picture of spatial distribution of surface temperature, identifying thermal anomalies.
- Differentiates soils with different moisture contents.
- Informs about hydrology, surface water and seepage.
- Has potential to identify hazards such as sinkholes and mine shafts through differences in thermal properties of infill materials (or voids) and moisture content.

Disadvantages
- Resolution is generally lower than optical techniques (for given platform distance from object).
- Complex image interpretation esp. change detection if data is collected under different environmental conditions (seasons, time of day).
- Calibration is challenging due to atmospheric and other effects. Wavelength/plank are absorbed readily by atmospheric water.
- Potentially costly data acquisition and iterative nature of data filtering.
- Informs only about the top layer (~0.5-1.0m) of surface materials.

Data formats
Raw:
Thermal infrared radiation intensity
Derived:
Thermal conductivity, emissivity and diffusivity.

Data availability/usage
Data is generally acquired by a commercial data provider. Careful consideration of survey timing is required (night-time, day-time, season etc.). Some TIR data is available through extraction from multispectral or hyperspectral systems. Hand held IR systems are widely available.

Geotechnical applications
This remote sensing method has many applications and is typically associated with: (1) Agriculture and Environment, (2) Geology, and Mining and include the detection of:
- Geothermal activity (subsurface hydrothermal fluid circulation),
- Vegetation type and geological material and,
- Geological Mapping of Geotechnical Assets (Satellite TM Thermal Infrared (TIR, Band 6) data has been used to differentiate between surface outcrops of competent rock, weathered rhyolite and unconsolidated head deposits.
- Identification of Hydrogeological Conditions in addition, performing day/night survey pairs can inform about:
  - Localised high groundwater,
  - Soils of varying moisture contents,
  - Regimes of water ingress-egress (e.g. springs) and,
  - Leaking drainage structures (culverts, pipes, drains) or buried tanks.
- Thermal cracking of geotechnical assets and,
- Shrink-Swell and plastic deformation material properties.

Performance of Highway Drainage Systems: The technique is capable of identifying leaking highway drainage systems (Figure 1.4) and groundwater flow affecting transport infrastructure through seepages in tunnel linings (Figure 1.1).

Road Condition Assessment by exploiting a 0.5 ° C difference between poor and good condition pavements. Moropoulou et al. (2001) utilised thermography to perform road pavement condition assessment.
Overview

InSAR is a radar imaging technique that uses two or more synthetic aperture radar (SAR) images to detect and measure centimetre- and millimetre-scale surface deformation over time. The technique is active, therefore, imaging is possible in all weather conditions, night and day. Image acquisition repeat times are frequent (1–35 days) so ground surface changes can be monitored on relatively short timescales. The platform upon which the sensor is mounted can be ground-based (GB), aerial, and satellite-based, each provides a different scale of surface observation.

In more recent years InSAR has become a very powerful tool to monitor surface deformation, over regional (~2 km²) areas and detect centimetre- to millimetre-scale surface elevation changes in any weather condition, day or night. The image repeat times are frequent (≤35 days) allowing for close monitoring. Raw InSAR data requires several specialist processing steps to generate the final products for interpretation. However, data processing times and potential are rapidly increasing with continuing computer software development.

A key benefit of this technique is that it can be implemented at various spatial scales with the same ability for high-resolution physical surface change detection. In particular, combining observations from InSAR data with other remote sensing data, such as multi-scale multispectral imagery, will provide greater insight as to the combination of physical or and or chemical processes that significantly affect different geo-assets, and at what spatial and temporal scales. Additionally, planned future constellations of InSAR satellites will provide near-real-time imaging capability.

Technique

InSAR involves the transmission and reception of radar waves with frequencies roughly in the range of 1–11 Gigahertz (GHz) and corresponding wavelengths of ~1–11 cm. When the radar pulses emitted at two different times indicate a phase shift between the echoes of the two signals, the movement of the backscattering targets, and therefore a surface-deformation or elevation-change map can be derived. ‘Time-series’ (multiple repeat images of the same area made at different times) imaging processing is a particularly powerful method to increase the resolution and quality of surface change measurements derived from InSAR.

Key Benefits

• Rapid remote surveying of sites with areas measuring thousands of square kilometres with a pixel resolution of about 10 m.
• Centimetre- to millimetre-scale changes in the ground surface can be detected in any weather, day or night.
• Good quality data available since 1995 (also archive data allows for detection of historical ground movement).
• Sentinel-1 data and ‘repeat-pass’ (with free and open access) available since 2014.
• Imaging repeat times are frequent (1–35 days).
• InSAR technique can be integrated with other remote sensing and geophysical monitoring methods.

Disadvantages

• Requires specialist processing.
• Better suited to urban areas with higher density of ‘good’ scatter. Less effective in rural regions, though raw data processing techniques are in development and show promising results.
• Surface change measurements made in the Line of Sight (LOS) of the Satellite, therefore, only quantify the total magnitude or sense of change is not detected or is underestimated.

Platforms

InSAR sensors can be mounted on satellite-, airborne-, and ground-based stationary platforms. The InSAR technique is the same in each case, with capability to detect centimetre-scale surface change, but the scale of the area observed (satellite footprint) in each case increases with elevation above the target.

Data availability/usage

Radar SAR satellite-based imagery has been available since the late 1970s. The majority of good quality, high-resolution satellite SAR data, however, is available until the last decade or so. Data from the European Space Agency (ESA) Sentinel-1 satellites is freely available for commercial use since 2014. Ground-based and airborne-based InSAR data requires commission of a bespoke commercial survey.

Geotechnical applications

Using the range of sensor platforms, InSAR has been used to successfully detect and monitor elevation change related to various geotechnical issues, including: detection of precursory signals of sinkhole formation; city infrastructure/subsidence and uplift (e.g. ground subsidence associated with tunnelling works and groundwater abstraction); swelling and sinking of clay-rich soils; landside/slope instability monitoring; and also structural deformation of infrastructure.

Data formats

Raw: a greyscale digital SAR image mosaic comprised of a two-dimensional array, formed by columns and rows, of small picture elements (pixels), each of which is associated with a small area of the Earth’s surface. Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered by all the ‘scatterers’ (rocks, vegetation, buildings etc.) within the corresponding pixel.

Resolution: SAR pixel resolution is ≤10 m. Raw data is processed to a number of Levels before analysis and interpretation.

Derived: derived InSAR products include: LOS-Deformation Maps, Deformation Time Series (i.e. a graph of LOS displacements plotted with time), Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and Orthorectified (Detected) Radar Images (ORIs). Each of these data products are highly applicable to monitor the condition of geotechnical assets.
Overview

Digital multispectral images capture spectral information across a broad frequency range (0.45–12.50 µm) of the electromagnetic spectrum providing more information about the physical and chemical properties of the materials in a scene than a standard aerial photograph. The technique is passive and relies upon reflected sunlight or thermal emission, therefore, data can only be collected in the daytime (with the exception of thermal) and requires sparse or ideally no cloud cover. Multispectral imaging sensors can be hosted on satellite, aerial, and terrestrial platforms, each of which provides a different spatial resolution.

Because multispectral imaging provides information about the chemical composition of a materials surface, it can be used to both inventory geo-assets, and to monitor how they change over time. In particular, processes such as weathering for example, because it can change the chemistry of a surface material, can potentially be identified as drivers for asset change, which can provide additional information for asset protection planning and deterioration prevention. In combination with other remote sensing techniques that monitor physical changes at various spatial scales, such as Interferometric Synthetic Aperture Radar (InSAR), multispectral imaging, which can be implemented at various scales and resolutions, has the potential to reveal additional information about both the local-scale asset, and the regional-scale physiographic context of the asset and the processes potentially effecting it.

Technique

A multispectral imaging system comprises at least three or more (up to 15) radiometer sensors. Each sensor detects reflected electromagnetic radiation from the target scene in a different discrete wavelength range (band) and acquires a digital image formed of pixels each with sub-metre to 100 m resolution. The final multispectral image is comprised of any combination of the individual band images, displayed in standard Red-Green-Blue (RGB) channels.

The red-green-blue (RGB) region of the visible electromagnetic spectrum ranges from 0.7-0.4 µm. The others wavelengths are classified as infrared, including near infrared (NIR), middle infrared (MIR) and far infrared (FIR or thermal), and have wavelengths ranging from 0.7–10 or more µm.

Key Benefits

- A broad range of spectral (chemical) information can be used to inventory geotechnical assets and monitor their condition over time.
- Published spectral libraries (spectral signatures for common materials) are available.
- Images acquired from different platforms can cover large areas (¢1 km²) and small areas both with relatively high pixel resolution.
- Some satellite datasets (e.g. Landsat, ASTER, Sentinel-2) are available under free open-data policies.
- Multispectral images can be used in combination with other remote sensing data, such as Light Ranging and Detection (LiDAR), and Interferometric Synthetic Aperture Radar (InSAR), to observe changes in asset characteristics over time.
- Imaging repeat time is rapid, e.g. daily.

Disadvantages

- Imaging requires daylight and good weather conditions.
- Ground truthing of the spectral signals is required and takes time.
- The material surface reflectance is detected, there is the potential that this is not representative of the underlying material.

Data formats

**Raw:**
- Individual spectral (reflectance) band images that can be displayed in any combination using RGB as a multispectral image.

**Resolution:**
- Band pixel resolution varies depending on wavelength. Typically, short wavelengths have higher pixel resolution (sub-metre to 30 m), longer wavelengths, e.g. thermal bands have lower pixel resolution (30–100 m). The lower resolution pixel images are typically resampled to a higher resolution (≤30 m) using the higher resolution bands.

**Derived:**
- Multispectral image processing produces various mineral and vegetation indices, including band ratios and normalized differences (ND), which are derived from the individual RGB and NIR spectral bands. Additionally images can be ‘classified’ to highlight specific types of land cover areas by differentiating the variation of spectral signatures in the image.

Platforms

Multispectral imaging sensors can be hosted on a range of platforms, including satellite, airborne (UAV, plane, helicopter, helikite), and ground-based (hand-held and tripod).

Technique: Multispectral Imaging

Data availability/usage

Multispectral images from all platforms are available for commercial use. Some satellite based images such as those acquired by the European Space Agency (ESA) and satellite Sentinel-2 are freely available, though most other satellite multispectral images are priced by scene size, with cost increasing with scene pixel resolution and scene area. Satellite multispectral data are available since the 1970’s, though as expected image spatial resolution and pixel quality has increased with time.

Geotechnical applications

In general multispectral imaging has huge potential to monitor the condition of geotechnical assets. The spectral information can detect different natural or manmade material mineralogy types, and changes in mineralogy over time, which may be related to erosion; detection of vegetation cycles that can indicate soil moisture content.

Lower resolution satellite multispectral images can be used characterise small map scale regions, to gain a better understanding of regional chemical and physical landscape properties that can impact local geotechnical assets. High-resolution aerial and ground-based multispectral imaging can be used to characterise geo-assets on a local scale.

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Figure 1: Multispectral image (left), composed of multiple individual image scenes (right), each of a different wavelength. In this example, red is green is blue (RGB). Individual RGB bands indicate the key features that apply to the underlying material.

Figure 2: Blue shaded boxes indicate the key features that apply to the multispectral imaging technique.
Overview

Structure from Motion (SfM) is a technique that generates high-resolution digital topography and co-registered texture (colour) from unstructured sets of overlapping photographs taken from varying viewpoints. The technique can therefore overcome many of the cost, time, and logistical limitations of Light Detection and Ranging (LiDAR) and other topographic surveying methods. The digital photos can be collected from both aerial and ground-based platforms and can provide high-density colour x,y,z point clouds and centimetre-resolution digital elevation models (DEMs) in addition to high-resolution photographs.

SfM is a relatively recent technique that has evolved with recent advances in computer science and algorithm-based digital data processing. The technique shows great potential for application to monitoring the condition of geotechnical assets over time. The raw photo datasets are not readily available but can be collected at relatively low cost by the user and can cover both large (≥1 km²) and small areas with high spatial resolution. Since this type of data collection would start from the date of the first survey, to detect changes that have happened on longer timescales, the SfM data can be used in conjunction with existing datasets such as LiDAR, or aerial-/satellite-based optical or multispectral imagery.

Technique

Like traditional photogrammetry, SfM triangulates among the locations of individual features matched in multiple images to build the geometry, 3D shape and colour of a scene, as well as reconstructing the camera positions and orientations. This is achieved using overlapping photographs (taken with a fixed focal length) from multiple viewpoints. The method uses recent advances in feature-matching algorithms that allow for large changes in scale, perspective, and occlusion, making survey planning for photo acquisition much more straightforward than in traditional photogrammetry.

Photo datasets are collected using a consumer compact or professional camera and a network of ground control points, GCPs, (points at which the exact geographic co-ordinate and elevation is known). The GCPs allow a realistic registration of the photographs taken from varying viewpoints. The technique can therefore overcome ‘shadow zones’ associated with Light Ranging and Detection (LiDAR) datasets.

Key Benefits

- Colour (Red-Green-Blue, RGB) x,y,z point cloud
- Centimetre resolution DEMs
- Imaging repeat times are rapid, e.g. daily
- Low cost and easy flexible survey technique

Disadvantages

- Processing time required to derive high-density point cloud
- Large volumes of digital photo data required to produce high resolution models
- Surveying is weather dependent
- SfM cannot “see through” vegetation, therefore, actual ground models of densely vegetated areas are a challenge not possible
- Images should ideally be collected at the same time of day under approximately the same environmental conditions

Platforms

Consumer cameras can be mounted on aerial platforms including Unmanned Automated Vehicles (UAVs), planes, helicopters, hexacots, and on ground-based platforms, such as long poles, vehicles, and hand-held.

Data availability/usage

SfM datasets are not readily available, they need to be collected for the region of interest determined by the surveyor or client as bespoke surveys. The technique is in the beginning stages of application to geotechnical-related problems.

Data formats

Raw:
- Colour (RGB) point cloud and digital photos.

Resolution: There is a trade-off between the distances of the camera from the survey area. When photographs are taken closer to the ground or feature, the SfM point cloud density and DEM resolution improve at the expense of smaller photograph footprint size and overlap, with a resulting increase in the time taken to survey a given area. Typically, centimetre resolution DEMs can be generated from several hundred photos, or less, of an area or object.

Derived:
- Centimetre-resolution shaded relief DEMs. Orthorectified (undistorted) high-resolution colour photo mosaics, contour and slope maps.
Overview

A passive microwave radiometer measures electromagnetic energy radiated towards it from a target. In application to geo-asset condition monitoring, MIRA can measure the radiation of moisture in the ground (to depths of several metres) and measure changes in vegetation biomass. Ground moisture levels can be used to assess slope failure potential of earthworks and can potentially determine regions that might be prone to flooding (i.e. areas with a high ground-water table). The microwave radiometer sensor can be mounted on a satellite platforms, in addition to terrestrial mobile, and airborne platforms.

The use of ground-based and aerial-mounted passive microwave sensors to assess soil moisture for geotechnical applications is a relatively recent development (last 5 years). Methods are becoming increasingly cost effective and operational. MIRA can provide high-resolution soil moisture data, which is particularly useful for assessing the slope stability of earthworks, and monitoring the flood potential of regions that are known to become saturated with ground water. MIRA soil moisture data should prove particularly useful for asset condition monitoring when analysed in combination with high-resolution data such as digital elevation models and vertical aerial photography derived from other remote sensing techniques, in addition to other non-invasive geophysical techniques, including ground penetrating radar (GPR).

Technique

The energy detected by a radiometer at microwave frequencies is the thermal emission from the target itself as well as thermal emission from the sky that arrives at the radiometer after reflection from the target. The thermal emission depends on the product of the target’s absolute temperature and its emissivity, but at microwave frequencies (in contrast to the thermal infrared) it is the change in emissivity rather than the change in temperature that produces most of the significant differences between the various targets. The microwave radiometer sensors can use L, C, and X bands (1.4, 6.8, and 10 GHz), each band is typically sensitive to moisture at soil different depths.

Key Benefits

- Water can be accurately detected up to several metres beneath the ground surface
- The technique makes non-intrusive subsurface measurements
- Soil moisture measurements are particularly useful for assessing slope stability and flood potential of earthworks

Disadvantages

- Subsurface soil moisture measurements should be ground-truthed particularly in business safety critical sites.
- In spite of the ground facing sensors, the soil moisture measurements can be affected by radiation signals from other roadside sources such as trees. Measurements are also disturbed by the presence of metal objects above surface or underground.

Data availability/usage

High resolution soil moisture data of an asset needs to be collected by bespoke surveying. There are no country specific or global high-resolution datasets readily available.

Geotechnical applications

The main geotechnical applications of MIRA are for detecting and monitoring changes in vegetation biomass and subsurface soil moisture of earthworks, including embankments, levees, and beneath roads. The latter has shown promising results for assessing the slope stability of assets. Because the technique is non-invasive it is particularly useful to monitor moisture at the base of roads and pavements. This has proven an effective tool for damage prevention and route planning.

 Platforms

MIRA sensors can be mounted on satellite-, aerial- and ground-based platforms. Aerial- and ground-based platform-mounted sensors are most applicable for geo-asset condition monitoring.
APPENDIX E – Task orders for LiDAR surveys procured between 2004 and 2010
<table>
<thead>
<tr>
<th>Task Order No.</th>
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<th>Date</th>
<th>Long Date Price of Remuneration</th>
<th>Price of Compensation</th>
<th>Current Lump Sum Price (C.S.)</th>
<th>Status of Task Order / Estimation %</th>
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