AN INTEGRATED WORKFLOW FOR LIDAR / OPTICAL DATA MAPPING FOR SECURITY APPLICATIONS

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ABSTRACT:

This paper elucidates the potential of LiDAR data for information generation for security applications. The study is embedded in the EU Network of Excellence GMOSS. General, security applications cover a large area from infrastructure monitoring (e.g. power stations, pipelines) or border monitoring to less tangible threats like terrorism and civil security / homeland security. It is demonstrated that for those security applications where the birds eye view can generally provide useful information LiDAR data are increasingly a valuable source of information, either stand alone or – preferable – in combination with optical data. The empirical work focuses on the extraction of some buildings and power lines. It is demonstrated that aggregated grid data in form of a DTM and DSM are only partially suitable to extract linear and point-type features such as power lines or small power transformation stations. Detectability clearly depends on the spatial resolution but generally 3D point clouds from first and last pulse information allow more sophisticated object extraction methods.

1. INTRODUCTION

New sensor technology (Laser-, digital line scanners and digital camera systems) allow to acquiring data which support a continuous high-resolution reconstruction of surfaces. For partially translucent surfaces such as forest canopy they can reveal three-dimensional structures. Light detection and ranging (LiDAR) technology provides horizontal and vertical information at high spatial resolutions and vertical accuracies (Zimble et al., 2003). These sensor developments and the increasing possibility to handle huge amounts of high-resolution multipulse data are imperative for the identification and extraction of small objects or very thin linear features. Multipulse LiDAR data produce enormous amounts of raw data to be handled. For instance, in a preliminary study in a forest environment 10 LiDAR pulses per m^2 resulted in point data sets of 1000 to 1200 points for typical mountain forest trees (Blaschke et al., 2004a). Next to the data quantity the ever increasing spatial resolution requires different analysis methodologies. There are basically two main directions to exploit raw LiDAR data and to turn them into directly usable information: a) through the generation of both a DEM (digital elevation model) and a DSM (digital surface model), b) through exploring the point data clouds through 3D point metrics. While the first option is technically mature and well explored – although not simple - (for an overview see Wehr and Lohr, 1999; Thiel and Wehr, 2004) the latter approach is very challenging and no standard procedures exist. Recently, Blaschke et al. (2004a) explored the potential of 3D point metrics for ecological applications in forested environments.
Blaschke and Strobl (2001) argue for classification of homogeneous groups of pixels reflecting our objects of interest in reality. They suggest to delineating relative homogeneous objects based on contextual information in an image on the basis of texture or fractal dimension. Burnett and Blaschke (2003) developed a multiscale segmentation / object relationship modelling (MSS/ORM) methodology translating the objective of homogeneous objects into the multiple scale reality of real world objects. In this paper we apply this methodology to LiDAR data and aim for an operational workflow from raw data to tangible information ready to be imported in GIS and decision support systems. LiDAR mapping is one effective tool in an array of geospatial technologies deployed to assist in disaster applications and response and recovery efforts (including both, natural disasters and man-made hazards). Airborne and ground-based LiDAR instruments are increasingly used in conjunction with traditional mapping tools to support emergency managers. Several applications demonstrated the ability of LiDAR technology to provide critical data and assist in timely and effective emergency response. However, most of these applications are case specific. Secondly, they are extremely data rich and information extraction is computer intensive.
While for instance in forestry many examples exist for the characterization of canopy density, closure and height; or the estimation of biomass and gross-merchantable volume, very few applications seem to be built on automated and transferable procedures. In the next section we illustrate for the example of infrastructure monitoring how difficult it can be to detect features and to classify them accordingly. The paper concludes with some insights on LiDAR for security and monitoring applications, including a short preview of foreseen applications and comments on what further research is required.

2. METHODS AND MATERIAL

2.1 Civil (“homeland”) security applications

Increasingly, LiDAR plays an important role in national security and homeland defence and for a growing number of applications which rely on accurate, timely geospatial data to aid decision-making processes. Geospatial data are a common foundation for analyzing and assessing the vulnerabilities of critical infrastructure for security and natural disaster mitigation. Elevation data provide the critical element necessary for perspective scene visualizations supporting decision-making and are an important input for modelling and simulation analysis. In any scenario, elevation data need to support and augment the full geospatial database. LiDAR is a versatile remote sensing tool that is used in a variety of applications, including elevation data generation, bathymetry, biological agent detection, chemical agent detection, military target acquisition and tracking, and environmental monitoring. It can generate accurate, dense, high-resolution digital terrain models with a faster turnaround time than more traditional mapping technologies. Because it is an active sensor, there are fewer problems with obstruction and shadowing. Still, many problems exist due to the enormous amounts of data being produced. Additionally, LiDAR is relatively new and not many standardized methodologies for the data analysis exist.

Within the EU 6th Framework Network of Excellence GMOSS (Global monitoring for Security and Stability) several international research groups investigate to what degree remote sensing can contribute to difficult tasks such as treaty and safety monitoring. Increasingly often it is believed that high-resolution, high-accuracy 3D data form the basis for security information and decision support products (Flood, 2003). Generally, such applications range from line-of-sight and line-of-fire analysis, dispersion modelling of biological, chemical, and radiological weapons, vulnerability analysis, road network analysis, bomb blast modelling, debris removal, casualty estimates, evacuation route determination to e.g. damage visualization for first responders. These are key concerns for agencies responsible for security applications. 3D modelling for creation of virtual cities is probably the most prominent LiDAR application area, in terms of revenue and effort. In part, this is driven by the large number of information products required in such environments. In this paper we concentrate on the relatively simple task of infrastructure monitoring. Still, there are more than enough technical obstacles and semantic/ontological difficulties in feature recognition processes and, subsequently, in defining change. But even the first step, the identification of infrastructure elements in remote sensing data is often hindered by factors such as atmospheric conditions or the interference of different land use classes or objects, respectively. One example is tree crowns overarching roads, pipelines, fences or buildings.

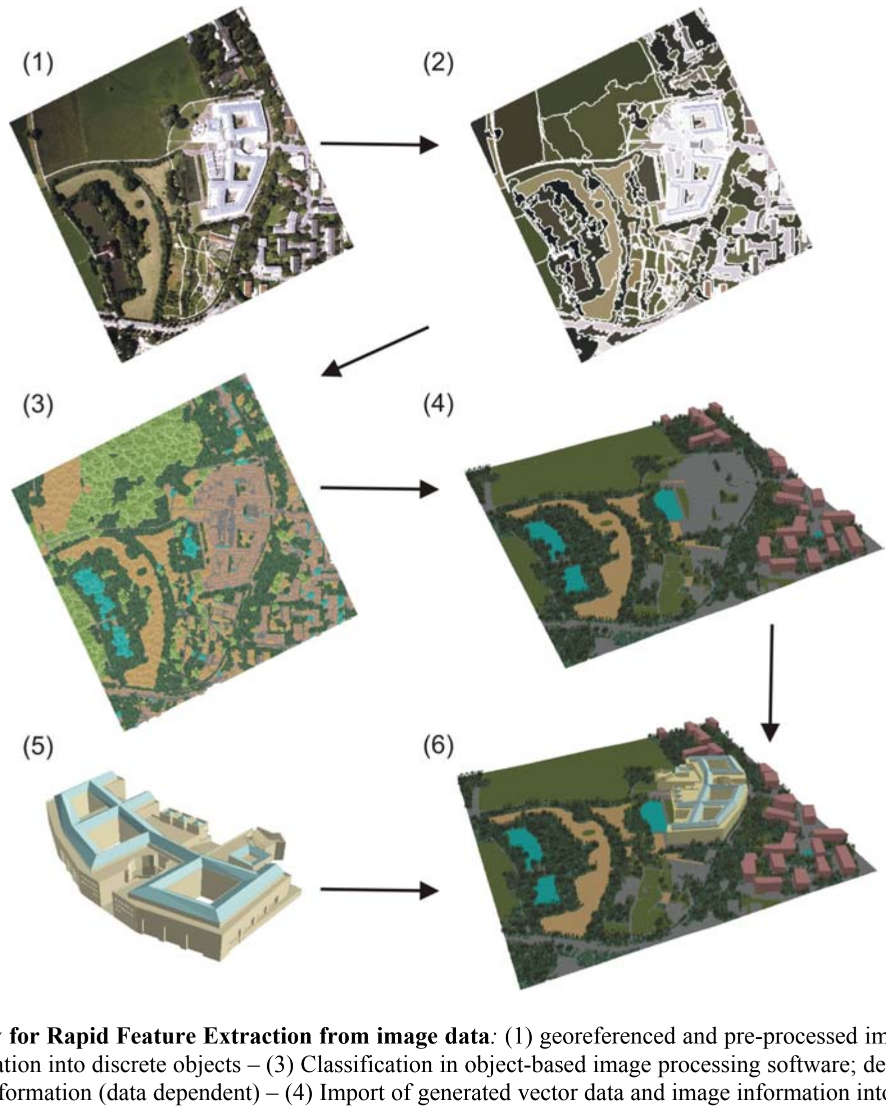

Figure 1. **Workflow for Rapid Feature Extraction from image data***:* (1) georeferenced and pre-processed image data – (2) Image segmentation into discrete objects – (3) Classification in object-based image processing software; derivation of additional object information (data dependent) – (4) Import of generated vector data and image information into a GIS; allocation of 3D textures to surface-like, but in reality low objects (meadow, field, water…..); for tree or forest objects the exported centres of the segments classified as “trees” (or other vegetation objects) are seeding points for 3D tree symbols; simple extrusion of less important 3D objects – (5) Single objects of bigger importance can be constructed in extern CAD-Design Software – (6) 3D Visualization; rendering on the fly

LIDAR technology is increasingly being used to support infrastructure protection. In the U.S., for instance, a new sector called "homeland security" developed basically since the September 11th event and different threat environment is being recognized. Much of the US infrastructure - utility delivery systems for electricity, natural gas, oil, and gas; transportation systems, including national highways, bridges, and tunnels; as well as waterways, dams, airports, harbours, and ports - was built between the 1950s and 1980s. Consequently, there are limited geospatial data available on these assets to support security assessments. Surveying these assets with airborne and ground-based LiDAR is an efficient, cost-effective way to rapidly create the basic geospatial data needed to assist in vulnerability assessments and emergency response planning. In a preceding literature study we found that relatively few empirical studies outside forestry and the 3D reconstruction of buildings for 3D city models rigorously tested the feasibility of LiDAR data.

2.2 Methodology: Workflow for Rapid Feature Extraction from image data

We build on the object-based GIS/remote sensing methodology of Burnett and Blaschke (2003). This multiscale segmentation/object relationship modelling or MSS/ORM is based on GIS objects and/or objects derived from image analysis. Based on the delineation of image objects at several levels, a semantic network is built. This is done using a commercially available, object-oriented, GIS/remote sensing software environment called eCognition. A segmentation algorithm generates objects at several user-defined levels. It generally allows generation of image objects on an arbitrary number of scale-levels, taking into account criteria of homogeneity in colour (reflectance values in a remotely sensed image) and shape. Thereby, a hierarchical network of image objects is generated, in which each object knows its neighbouring objects in the horizontal and vertical direction. The aim of the segmentation is to generate the most meaningful objects possible (for a state of the art overview of segmentation see Blaschke et al. 2004b). This means that the shape of each object should be represented by an image object. This shape, combined with further derivative colour and texture properties, can be used to initially classify the image by classifying the image objects. Thereby, the classes are organized within a class hierarchy. In a second step, additional semantic information can be used to improve the image classification. With respect to the multi-scale behaviour of the objects, a number of small image objects can be aggregated to form larger objects, constructing a semantic hierarchy. Likewise, a large object can be split into a number of smaller objects. The semantic network and modelling approaches built upon it allow for the derivation of geographical models capable of representing both observational data and (higher level) semantic abstractions that can be derived from that data and an external expert knowledge describing the classes. The main difference of this integrated GIS/remote sensing approach is that topological relationships - information on size, orientation, or distribution of objects - are intrinsically obvious and can be used directly in the formulation of rules. Blaschke (2004) provides examples of successful applications of this approach.

In the following examples we apply this approach to discrete return LiDAR data. Most commercial LiDAR systems capture between two and five returns; referred to as multipulse or multiecho capability. Only recently, field projects have reported detailed statistics or analysis based on the number of returns seen in each band or examined the variance of this parameter against e.g. forest canopy type or operational variables.

2.3 Data sets and results

The first example is from the Bavarian Forest National Park, Germany. For a more detailed description of the study area and data sets see Tiede et al. (2004) and Blaschke et al. (2004a). Small-footprint time-of-flight first and last pulse LiDAR data were collected with an average pulse density of 10 pts/m². Date products derived include Digital Surface Model (DSM) and Digital Terrain Model (DTM) with a ground resolution of 0.5 meters. The multi-spectral line-scanner data include 4 channels: B (440-490 nm), G (500-580 nm), R (580-660 nm) and NIR (770-890 nm) with ground resolutions of 0.5 meters. Figure 2 illustrates the extraction of trees and their symbolic near-realistic visualization in a GIS environment.

For the same data set Blaschke et al. (2004a) derived structural 3D information from the original point data set. Figure 3 illustrates the amount of point data per for a typical single forest mountain coniferous tree and attempts to derive structural information from the point clouds. These data sets are difficult to handle and relatively expensive. For this study it was impossible to get similar data sets for the infrastructure studies as described below. This was due to financial restrictions. The potential of small-footprint multipulse LiDAR becomes clear in Figure 3: once a single object is characterised by a large amount of point data a multiplicity of methods exist to derive the feature of interests.

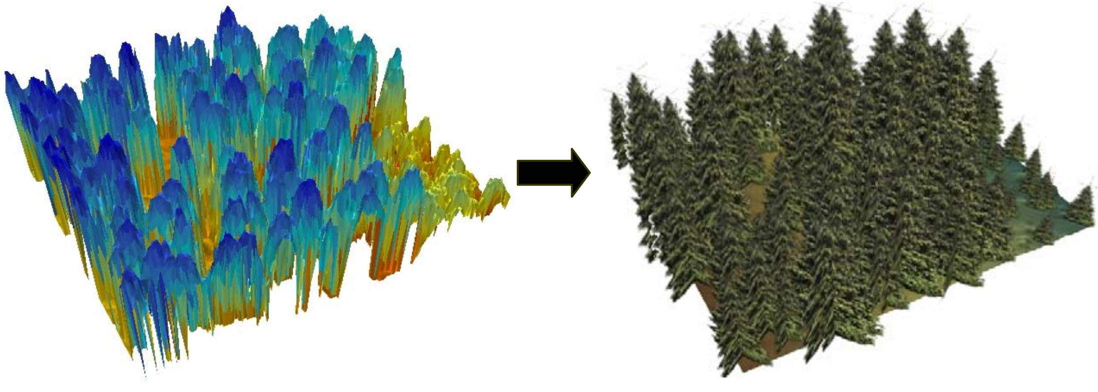

Figure 2. Extraction and visualization of trees from a LiDAR derived DSM and multi-spectral information.

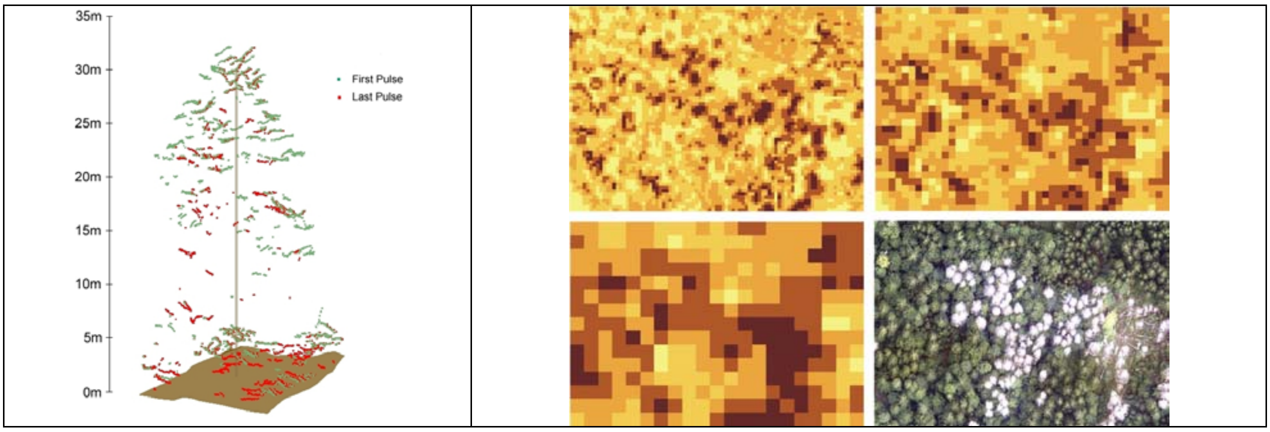

Figure 3. Left: 3d point cloud from both, first and last pulse data falling within the outline polygon of one identified tree. Right: Resulting height standard deviation based on moving windows at three different scales for a forest stand (lower right). Window sizes are 5m (upper left), 10m (upper right), 20m (lower left). Dark colours indicate higher values.

Study 2 covers a small part of the most eastern Austrian province, Burgenland. In this case, only a DSM and a DTM derived from LiDAR data with a ground resolution of 1 m were available but no original LiDAR point data. In addition, CIR and RGB aerial photographs with ground resolution of 0.5 meters were available. Figures 4 - 6 illustrate the results for these data sets for the attempt to extract power lines and small power stations. The figures reveal both the potential of this approach for the features for which the data resolution is fine enough and the failures for the detection of smaller features.

Figure 4. Aerial photograph (top): Power lines not visible, power poles visible. LiDAR DSM (bottom): Bigger power lines and power poles visible, smaller power lines intermittent visible.

Figure 5. Extraction of power lines, power poles and power station in eCognition based on a LiDAR-DSM and spectral information from aerial photographs. Smaller power lines couldn't be extracted.

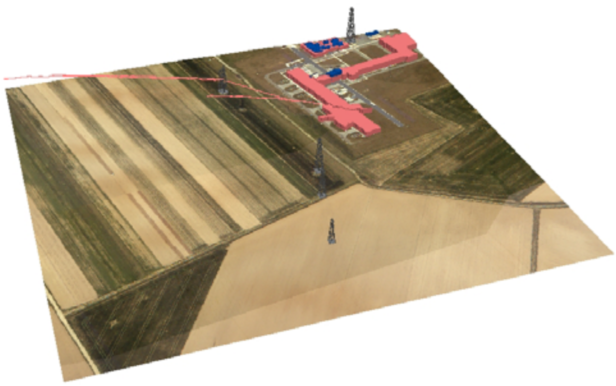

Figure 6. 3D Visualization of extracted objects extruded by LiDAR height information.

The third study is located in the central Danube valley area between the cities of Linz and Wels in Upper Austria. Available are small-footprint time-of-flight LiDAR data. First and last pulse data were collected with an average pulse density < 1 pt/m². RGB aerial photographs with a ground resolution of 0.25 meters are coreferenced. It turns out that for these data sets the extraction of power lines is extremely difficult or nearly impossible. Figure 7 provides some close-up looks for the recognition and classification of power lines and power stations. Very thin power lines overarching young forest are not detectible automatically. This is due to the data resolution. The workflow as such performs well on this data set, too.

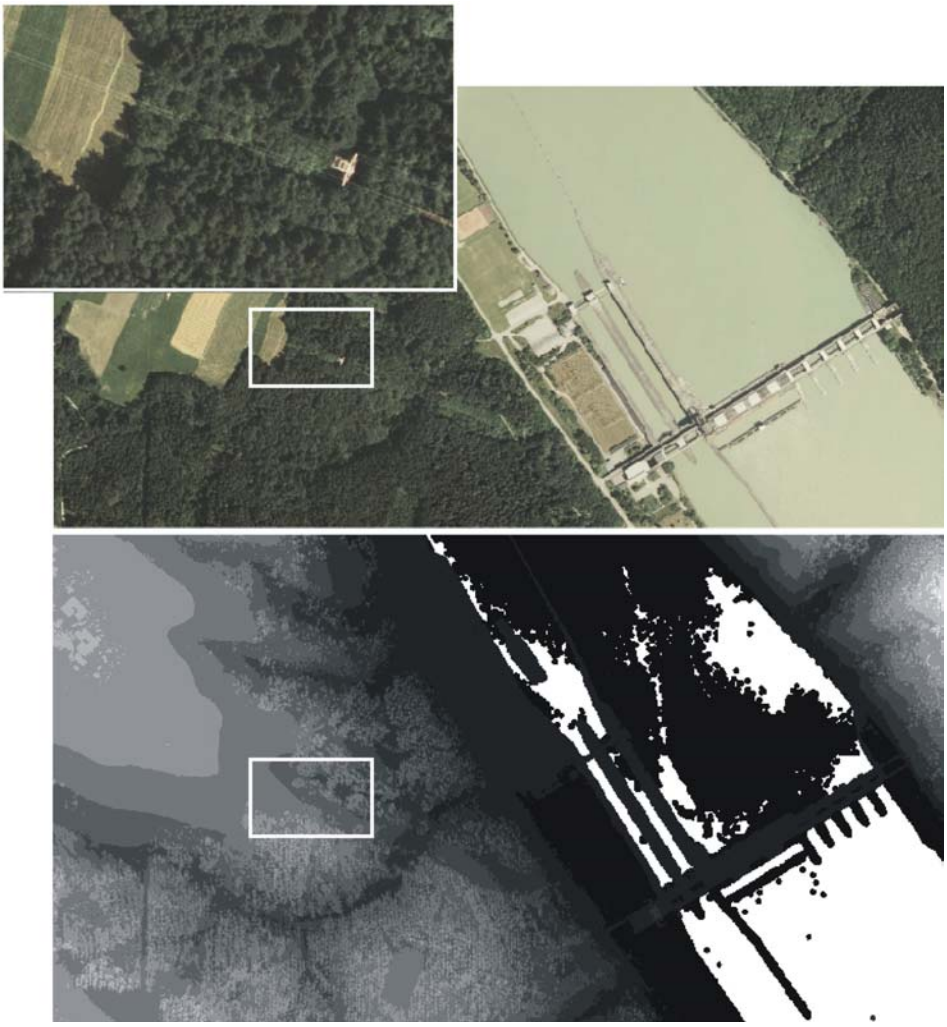

Figure 7. RGB aerial photographs (top): Power lines visible (see zoom window). LiDAR data (bottom): Pulse density too coarse to detect power lines.

3. DISCUSSION

The empirical studies testified that the workflow suggested is operational. Secondly, the general hypothesis that LiDAR data are suitable to generate 3d objects was testified to a great extent. More specific, LiDAR data exhibit a large potential for security applications. Still, it turned out that huge differences appear depending on the kind of data set used and their respective resolutions. Unlike optical data, we have not only to obey spatial resolutions of resulting raster data used in the applications but also to differentiate between LiDAR specific characteristics. We distinguish between a) original multiecho, small footprint discrete return LiDAR data, b) original multiecho, large footprint discrete return LiDAR data, c) aggregated LiDAR data in form of rasters, and d) DSM and DEM data sets derived from LiDAR data.

The work in this paper and related studies (Tiede et al., 2004; Blaschke et al., 2004a) was mainly restricted to the use of discrete return LiDAR data in combination with multispectral data. The approach is not limited to conventional image data. With new technologies it is possible to get an even faster and more exact continuous high resolution representation of the surface and additional three-dimensional structure information directly into 3D Visualization. Future technical development will likely manifest itself in sophisticated sensor fusion (combining digital imagery and hyperspectral data with LIDAR data), improved sampling techniques (full waveform capture, multiwavelength capabilities, and flash LIDAR illumination), autonomous vehicle platforms, satellite platforms, and even advanced concepts such as synthetic aperture LiDAR. We are already seeing more and more LIDAR projects are conducted with integrated digital cameras or in support of other geospatial data acquisition. Powerful sensor systems have become available or even mature and have been already employed in practice for man-made object extraction. These include airborne laser scanning, airborne interferometric SAR, airborne multispectral and hyperspectral scanners with up to 250 spectral bands, high-resolution (<1 m) satellite optical sensors, as well as digital photogrammetric cameras.

However, operational data processing can currently not keep up with these increasing possibilities and escalating amounts of data. We need operational work flows for rapid information update of GIS data bases. In this paper, we discussed a workflow which is nearly operational. Due to the enormous amounts of data we had to restrict our studies to subsets. In this sense, operational end-user operations are not yet available but are at the horizon. The extraction of objects from images has undergone rapid development in the last decade. In addition to the "new" LiDAR data, aerial photogrammetry is a field of particular interest. The combination of LiDAR data and aerial images is regarded to be an excellent data source for a number of applications such as topographic mapping, environmental modelling and monitoring and urban and regional planning.

New security demands are changing how we use LiDAR technology and integrate it with other mapping tools. Future developments must address the underlying need for a full geospatial solution. While in the US great efforts and financial resources are devoted to "security" – homeland security in the US - in Europe comparable efforts are only starting recently. A recent book by Cutter et al. (2003) "The Geographical Dimensions of Terrorism" sees geospatial data and technologies infrastructure research as a top research priority. Response times and logistical drivers related to security and defence will require that the delay from data acquisition to information product be reduced, creating near-real-time mapping solutions. Operational platform choices will need to be broadened to meet military and surveillance requirements. LIDAR mapping will develop further significantly within the next years. The need for data-rich environments with real-time responsiveness will drive sensor development. This means, in the future, we may be working in a seamlessly integrated data-collection environment (elevation, imagery, and spectral information), working with sophisticated information retrieval tools (direct spectral classification and waveform analysis), and working in a near-real-time environment.

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