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Remote measurement methods for 3-D modeling purposes using BAE Systems' Software

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Abstract: Efficient, accurate data collection from imagery is the key to an economical generation of useful geospatial products. Incremental developments of traditional geospatial data collection and the arrival of new image data sources cause new software packages to be created and existing ones to be adjusted to enable such data to be processed. In the past, BAE Systems' digital photogrammetric workstation, SOCET SET®, met *fin de siècle* expectations in data processing and feature extraction. Its successor, SOCET GXP®, addresses today's photogrammetric requirements and new data sources. SOCET GXP is an advanced workstation for mapping and photogrammetric tasks, with automated functionality for triangulation, Digital Elevation Model (DEM) extraction, orthorectification and mosaicking, feature extraction and creation of 3-D models with texturing. BAE Systems continues to add sensor models to accommodate new image sources, in response to customer demand. New capabilities added in the latest version of SOCET GXP facilitate modeling, visualization and analysis of 3-D features.

Keywords: photogrammetry, 3-D building models, satellite imagery, UAS, feature collection

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1. Introduction

Demand for maps and geographic information has changed over the years. End users, from defense forces through non-defense government agencies and private companies to consumers, enjoy 3-D models for purposes ranging from military situational awareness and mission planning through urban planning and disaster management to tourism and recreation. These models are less straightforward to acquire and create than traditional vector data, with the result that modern, cost-effective methods of data collection, measurement, and editing are critical if user requirements are to be met economically.

This paper focuses on modern methods of geospatial data collection and BAE Systems' software tools for processing imagery and generating of 3-D models. Once imagery or LiDAR has been orientated, the image processing part remains mainly interactive or semi-automated, though we should not forget that the growing range of tools in digital photogrammetric workstations has grown over the past two decades and the measurement of detailed buildings takes a fraction of the time required on analog or analytical workstations. Moreover, the sharing of raw data between the photogrammetric software and modeling packages, such as computer-aided design (CAD) and geographic information system (GIS), has streamlined the creation of intelligent models that go far beyond the simple vector representations of rooflines or footprints that satisfied us for so long. But where will the raw data come from in the near future? And how will we be able to effectively use it for 3-D modeling purposes?

2. Geospatial data collection: from the past to the future

2.1. Airborne image systems

Historically, photogrammetry has been performed with special airborne sensors mounted in a fixed-wing aircraft; the workhorses of the data acquisition segment for nearly a century. Digital sensors have eclipsed film in the present century. Imagery acquired on the ground has been less popular and, indeed, close-range photogrammetry has never been used widely in many countries, such as the U.S., except for very high precision industrial measurement. With today's software, however, the use of handheld images to supplement airborne ones and provide superior texture for the building models than can be acquired from the air has gained some traction. However, the challenges of integrating the two data types have not entirely been overcome: software designed primarily for the traditional airborne case does not always lend itself to terrestrial imagery and the use of both types together is not trivial.

The characteristics and advantages of today's airborne digital sensors have been fully described and discussed elsewhere and are not repeated here (for example, Sandau, 2005). Suffice it to say, today's firms can easily fly photography at practically any resolution between 1 cm and 1 m. The high-performance, specialty sensors are gradually improving and are being challenged by the increased performance of medium-format sensors, used singly or in multiple-sensor configurations. Perhaps more noteworthy has been the growth of oblique imagery, often acquired by camera configurations consisting of one vertical and four obliques in a single mount. The recent acquisition of the Pictometry® parent company, Eagleview Technology®, by Verisk Analytics® underlines the success of this approach. The value of top-quality, high-resolution imagery of sides of buildings extends beyond visual interpretation to the provision of ideal texturing for building models, the frames of which can be measured in the vertical or oblique imagery, or both, monoscopically or stereoscopically, in multiple images – there need be no restriction to just one image pair. Algorithms for texturing models with imagery have been refined, often in the computer vision rather than the photogrammetric community, and modern graphics cards enable the process to go extremely fast.

2.2. Satellite imagery

The use of satellite imagery for building modeling was never envisaged when the first earth observation sensors were launched into orbit, but has become feasible as resolutions have increased. Imagery is available from many commercial satellite operators at 1 m resolution or better. The DigitalGlobe® WorldView-3 satellite was launched successfully on 13 August 2014, only six weeks after the launch of the Airbus® SPOT-7 on 30 June 2014. WorldView-3 offers panchromatic imagery at a resolution of 0.31 m and on 11 June 2014, the U.S. Department of Commerce relaxed its restrictions to allow the dissemination of imagery up to 0.25 m resolution panchromatic, 1.0 m multispectral, without resampling, six months after the launch. WorldView-3 has the same eight multispectral bands as WorldView-2, though at the higher resolution of 1.24 m, but these are supplemented by eight short-wave infrared bands (SWIR; 3.7 m) and 12 CAVIS bands (clouds, aerosol, vapor, ice, snow; 30 m).

Recently, however, a different trend has attracted attention. A concept pioneered by the U.K. company, Surrey Satellite Technology®, and its subsidiary DMC International Imaging® (DMCii), both now parts of Airbus, was the use of multiple, lighter, less expensive satellites providing frequent coverage at lower resolution. This practice has blossomed recently, with several companies, such as Skybox Imaging®, Planet Labs® and BlackSky Global in the process of launching and making operational constellations of large numbers of small satellites, ensuring short revisit times and backed up by novel business models designed to attract image purchasers (Anon, 2014; Quinn, 2014). The recent acquisition of Skybox Imaging by Google™ has catapulted these endeavors into the public eye and it is likely that both image-based data products and modeling will benefit from the frequent coverage, albeit at lower resolution. These exciting innovations, however, must be observed in perspective: despite their advantages, they must compete in the marketplace with an endless stream of top-quality, high-resolution imagery from large, established suppliers supported by extensive, powerful processing capabilities and well-developed distribution networks. DigitalGlobe and Airbus, with their well-known constellations, are the examples of this category, but we must not forget Blackbridge®, the Canadian company that purchased the RapidEye constellation in 2011, and the many national satellite operators from countries such as Israel, India and Japan. The latest developments follow an established trend to increasing spatial and spectral resolution, agility, and coverage (Jacobsen, 2011).

Photogrammetrists focused on 3-D modeling perhaps think first of the highest resolution imagery in order to capture small details of, for example, urban streetscapes. But we should not forget the remarkable progress in recent years of orbital synthetic aperture radar (SAR) data and the growing constellations of satellites that provide it, for example Airbus' TerraSAR-X and TanDEM-X, and planned additions to the constellation; RADARSAT; COSMO-SkyMed; and RISAT. Indeed, Surrey Satellite Technology is involved in the development of a constellation of four of its NovaSAR-S modestly priced SAR satellites.

The availability of satellite imagery for 3-D data acquisition is staggering. Resolution is more than adequate for urban modeling, and access to data has become simpler through the satellite operators' websites and numerous data brokers. SWIR and SAR mean that cloud and haze are no longer the death knell of data acquisition. Competitive forces ensure prices fall in real terms.

2.3. Unmanned Aircraft Systems

The flurry of developments and rapidly growing deployment of Unmanned Aircraft Systems (UAS), sometimes called Remotely Piloted Aircraft Systems (RPAS), has taken the photogrammetric world by storm, redolent of the burgeoning of LiDAR some years ago. The torrent of publications, conferences, trade shows, courses and webinars provides ample evidence of the excitement. Legal companies develop UAS-specific practices. Every day new announcements are made, confirming that the available hardware and software solutions are continuously improving.

A recent study by the Boston market research firm Information Gatekeepers Inc., predicted spending on UAS, including the military, to increase from $5 billion in 2013 to $15 billion in 2020, i.e., a tripling in seven years. This is more optimistic than a 2013 study by the Teal Group®, but the investigations predict vibrant growth in both technologies and applications. The Association for Unmanned Vehicle Systems International (AUVSI), an industry organization founded in 1972, is aware of over 3,800 platforms. The regulatory issues surrounding the use of UAVs vary across the world. The Federal Aviation Authority (FAA) in the U.S. continues to wrestle with the issue of integrating UASs into the national airspace. Intriguingly, the flying of model aircraft by hobbyists has been permitted since 1981, subject to certain procedures. The FAA will not meet its deadline of 30 September 2015, for major change but is considering allowing UASs to be flown under certain circumstances for use in agriculture, film making, power line and pipeline inspections, and oil and gas flare stack inspections.

They are flying nevertheless. In 2013, the FAA gave permission for AeroVironment Puma and Insitu Scan Eagle to be flown over Arctic waters to acquire data for BP and ConocoPhillips respectively; and on 10 June 2014, AeroVironment received permission to fly for BP over land, above Alaska's North Slope, for applications including 3-D road mapping, pipeline inspection, volumetrics of gravel pits, monitoring wildlife and ice floes, and helping search and rescue. Suffice it to say, the use of UASs will explode – and regulatory frameworks will less dramatically evolve to match – while defense, agriculture and oil and gas are likely to be leading fields of application; the collection of imagery for urban modeling will become commonplace too. Indeed, numerous UASs are being flown in the U.S. national airspace, exploiting ambiguities over their legality, whilst such flights are perfectly legal and well established in many other countries. Useful review material is readily available (van Blyenburgh, 2014; Colomina and Molina, 2014).

2.4. LiDAR

Just as conventional aerial photography with digital sensors is routine and not examined here in detail, similarly LiDAR is an everyday process to create 3-D models. Once again, there are discernible trends. The pulse rates of the lasers used in LiDAR have been steadily increasing over the years and the scan rates of the system hardware have increased too, so most projects flown today generate point clouds at several points per square meter. Full waveform, as opposed to discrete return, sensors are commonplace and dual-wavelength systems capable of combined onshore and offshore operations have recently been introduced, transforming the marketplace that had been previously characterized by a dearth of offshore systems. At least one LiDAR sensor has been announced that is light enough for use with medium-sized UASs, so LiDAR data collection faces the same disruptive technology as imagery.

Airborne sources are complemented by terrestrial data acquisition, including not only tripod-mounted scanning lasers, but also mobile mapping systems, consisting of road vehicles modified to include LiDAR and multiple cameras. These systems can be driven at normal road speeds and are capable of generating dense point clouds close to the vehicle's route of travel as well as extensive collections of still imagery or video. Though rapid, sophisticated processing of these various LiDAR data types is routine and the software is steadily improving, it could be argued that the automated algorithms used to extract features from terrestrially acquired point clouds have not been fully transitioned to the airborne case, where higher levels of human intervention occur. At the other end of the spectrum are the specialty systems used in industrial measurement, where tripod-mounted scanning lasers are complemented by both handheld and robot-mounted models. Somewhere in between, however, lies the growing range of indoor systems, key for which have been significant improvements in indoor positioning, using technologies such as radio frequency identification (RFID), Wi-Fi and cell phone signals to overcome problems caused by the obstruction of Global Navigation Satellite System (GNSS) signals. Indoor 3-D modeling will be an increasingly requested complement to conventional data capture for multiple applications from military situational awareness to tourism.

2.5. Video

The use of motion imagery, of which full-motion video is a subset, has been commonplace in defense and intelligence for many years and the hemispherical turrets containing video cameras with fast slew and zoom capabilities are a feature of the large military UASs so well known to the public. Photogrammetrically, video is not problematical when considered in simple terms: each of the 30 frames per second is a frame image, geometrically the same as a still image. A greater challenge has been the determination of the metadata necessary to process such images as frame – detailed below. Interestingly, the acquisition of video from satellites has been a discernible trend in the last year or two, an example being Skybox Imaging. Moreover, Surrey Satellite Technology has announced its low-cost, V1C color video imaging satellite.

3. Geospatial data processing using SOCET GXP v4.1

The data processing software world reflects the evolution of data sources sketched above. BAE Systems' product for geospatial data processing, SOCET GXP v4.1, has been enhanced to meet current requirements arising from these developments.

3.1. SOCET GXP: Photogrammetry

The SOCET GXP software package is the successor to SOCET SET – the meritorious digital photogrammetric workstation (Walker, 2007). The project began in 2002 and it took 10 years to introduce a version that could authoritatively be described as SOCET SET's replacement. SOCET GXP was more than a routine rewrite, however, and much has been written on the development and advantages of the intuitive user interface. A new triangulation capability was developed for frame images. At the same time, the range of sensor models continued to grow and exceeds 50: among the recent additions are Pléiades, SPOT 6, Landsat 8, the Terrain Mapping Camera on Chandrayaan-1, and LiDAR. Sensor models have also been added to accommodate the complex data for COSMO-SkyMed, RADARSAT-2 and TerraSAR-X; RISAT-2, RISAT-1, KOMPSAT-3 and SkySat are in development.

Considerable work was done to enhance the well-documented capability for automatic generation of digital surface and elevation models from multiple images. Next Generation Automatic Terrain Extraction (NGATE), a module introduced in 2006, was replaced by the Automatic Spatial Modeler (ASM). NGATE led the way in providing matching on every pixel – a host of software products based on semi-global matching followed. ASM included sharper building edges and improved accuracy around high buildings, greater felicity with oblique imagery and better performance with repeating patterns, for example on roofs.

A new capability was added, Automatic Feature Extraction (AFE), where elevation data is used to identify and remove buildings and nearby trees from surface models. These developments continue and a current focus is on implementing the algorithms on general purpose graphics processing units (GPUs), certainly the least expensive route to high performance in modern workstation computing (Zhang, 2014). The resulting very dense elevation data sets, together with the growth of LiDAR since the mid-1990s, have given rise to extensive capabilities for visualizing and manipulating large point clouds. Ongoing work includes LiDAR equivalents to the photogrammetric process of automatic point matching: once the algorithms to find corresponding points in multiple LiDAR strips are optimized, the sensor models already developed for LiDAR can be fully exploited (Walker, 2013). A parallel development has been the introduction of a new elevation database capable of storing true 3-D point clouds, allowing, for example, multiple points with different Z values for the same XY location, and providing very high performance in manipulating the data.

Work is almost complete on the automatic registration of video imagery based on frame-to-frame and frame-to-reference matching and the use of a Kalman filter continuously to update sensor model parameters (Taylor and Settergren, 2012). Recent developments include the use of a Fourier-based matching called Enhanced Phase Correlation, developed by another group in BAE Systems for a specific customer, in harness with Oriented FAST and Rotated BRIEF (ORB) (Rublee *et al*., 2011), a matcher from the SIFT family.

The current version is SOCET GXP v4.1 and the latest capabilities include: datums, ellipsoids, and coordinate systems for mapping extraterrestrial bodies such as the Moon and Mars (intriguingly, this enhancement also provides local space rectangular systems, as used, for example, in industrial measurement or small construction projects); the generation of reference imagery in certain U.S. government formats; ClearFlite® functionality for mapping obstructions near airfields; sensor models, as mentioned above; improved performance in elevation data processing, including the use of GPUs for graphics; more efficacious interfacing to Esri® geodatabases; faster processing of frame imagery, for example for triangulation, and the export of results to PATB and BLUH; better, faster texturing, especially of buildings; direct connection to GXP Xplorer, a server-based solution for catalog, search and discovery, with display of search results inside the SOCET GXP Multiport; improved display of point clouds, imagery and vector data, for 3-D viewing; Esri Multipatch support; incremental improvements to spectral capabilities, which are now integral with geometric – a recent addition has been Ehlers fusion pan sharpening; and more options on export to Google Earth. BAE Systems is working with Cardinal Systems® to interface the popular VrOne product for feature collection and editing to SOCET GXP. BAE Systems resells the OrthoVistaXtreme products from Stellacore Solutions for generating aesthetically pleasing mosaics from collections of orthophotos. Other third-party complements include TerraGo® for publishing results as GeoPDFs and Safe Software FME for advanced format translation.

3.2. SOCET GXP: 3-D modeling

SOCET GXP's strengths in photogrammetric processing of aerial and satellite imagery have been supplemented in the 3-D modeling function area. SOCET GXP's LiDAR capabilities have gradually increased and a host of functions are now available. LiDAR can be viewed and used on its own or with imagery, and there are significant ongoing developments of the combined use of the two data types, for example storing embedded RGB values in a point cloud. SOCET GXP includes sophisticated tools for the measurement and editing of 3-D building models, but at the same time there are simple tools to reduce fatigue and increase productivity. If a bare-earth DEM is available, for example, a building can be measured using only a single-orientated image. The dependency on stereo has been reduced. This is also the case for visualization and SOCET GXP users have been enthusiastic about the new 3D Multiport, where imagery is displayed in a perspective view and measurement data can appear at the cursor's position. Additionally, the 3-D cursor tool allows for point, line, and polygon measurement directly in 3-D. Models created in SOCET GXP can then be automatically textured using the most suitable images. Traditional requirements for stereoscopy have not been ignored, of course, and customers are transitioning to modern, low-cost stereo monitors, now completely commoditized, though more elaborate displays are also compatible, for example zSpace.

3.3. SOCET GXP: A component in an enterprise solution

SOCET GXP is BAE Systems' flagship product, with a comprehensive range of photogrammetric capabilities and a plethora of tools for 3-D data capture, editing and modeling. As customer requirements have evolved; however, it is no longer a product of its own but an element in a broader enterprise solution. Recognizing that customers are often handicapped by spending more time looking for data than analyzing it, BAE Systems developed the GXP Xplorer product, a server-based solution for catalog, search and discovery. The catalog is created in the background as crawlers find data files in holdings specified by the user, locally, on a Wide-Area Network (WAN) or on the Internet. Metadata is extracted and placed in a database, interrogated by GXP Xplorer's powerful search engine. Files can be left in place, without the need to copy them from existing data stores into a single location. Though it is possible to conduct GXP Xplorer searches from a Web browser, it is also possible directly from SOCET GXP. Not all customers, however, require the full functionality of SOCET GXP, so a simpler, browser-based "electronic light table" called GXP WebView was developed, capable of receiving imagery streamed from the server and performing straightforward operations such as measurements, image enhancements, annotations, product generation and format conversions. Computations are performed locally or on the server as appropriate. GXP WebView can run on a range of devices provided a suitable Web browser is available. Also connected to the GXP Xplorer server is a recently introduced range of mobile apps for receiving imagery in the field, or taking photographs and uploading them, with commentary, to the server. The latter app, called GXP Xplorer Snap, runs on Google Glass too.

3.4. New development directions

Customer demand will be at the helm as development directions are determined. These will include the constellations of small satellites as well as larger ones such as WorldView-3. Work is almost complete, for example, on the SkySat sensor model. Processing of WorldView-3 imagery is already possible, but customers will require default processing chains to exploit the SWIR and CAVIS bands as well as the bands already provided on WorldView-2. The use of UASs requires software to process imagery that may have absent or inadequate metadata for traditional triangulation, although the latest GNSS devices for small UAVs will mitigate this challenge substantially. BAE Systems is addressing its own solutions through approaches drawn from computer vision, where the term "structure from motion" is often used. This software has reached the prototype stage and will be integrated into the SOCET GXP product when practical. Accommodating UAS imagery in this way is really the first stage and users will decide whether they are satisfied that a point cloud generated from multiple UAS images is an end in itself, or whether it should be regarded as pre-processing ahead of a conventional triangulation. An important inherent issue here is the treatment of the parameters of interior orientation: whereas block-invariant parameters are the norm for conventional airborne or satellite imagery, the low-cost cameras and rugged operating conditions of the UAS world suggest that some parameters, such as the principal distance and the principal point of autocollimation, may be better treated as image-invariant. SOCET GXP currently includes extensive capabilities for visualizing and manipulating LiDAR data, but multiple enhancements are in work: "triangulation" of LiDAR to ensure optimum fit of LiDAR strips to one another; further work with the ULEM sensor model, not only to facilitate LiDAR processing but to provide rigorous error propagation, whether LiDAR is on its own or, more commonly, fused with imagery; and improved algorithms for certain modes of registration, such as image-to-LiDAR and LiDAR-to-LiDAR, to undergird these new capabilities. Other planned enhancements include a helicopter landing zone tool; terrain analysis in the 3D Multiport; and increased compatibility with Open Geospatial Consortium (OGC®) Web services.

The above notes on future directions have been focused on the SOCET GXP product, but must be considered in a wider context. The concept of the enterprise product range will be facilitated by separating out functionalities used in multiple places in the product line. These will then be invoked as required, rather like Web services, thus not only improving the performance of existing products but accelerating the development of new products. At the same time, the software is being run on devices such as the Microsoft Surface™ tablet, not a challenge in itself, but it may lead to issues related to the optimum handling of disconnected operations when remote workers are without Internet connections: data has to be downloaded in anticipation of disconnection, then, when connection is re-established, a smooth synchronization operation has to be conducted. These directions, however, are but threads of a more ambitious strategy – to develop a "platform," a group of technologies used as a base upon which other applications, processes, technologies or services are developed or from which their benefits are provided. It includes a server framework; data services; desktop, Web and mobile client framework; data sources (BAE Systems will make it easy for users of its software to access third-party data); APIs and SDK. Work on this has already begun.

4. Summary

3-D modeling from remote measurement is the heart of modern photogrammetry. Today's users are able to select from a wealth of imagery and data that has burgeoned incredibly in recent years. The performance of airborne digital sensors has comfortably surpassed the aerial film camera, though many customers continue to enjoy decades of use from the latter. Medium-format, multiple-camera configurations and oblique image capture provide the user with top-quality imagery rich with information and ideal for incorporation in 3-D models. LiDAR sensors continue to improve and the growing range of LiDAR-based terrestrial and indoor systems has to be considered an equally important source of 3-D modeling data. All these data sources are supplemented by the fantastic development of satellite imaging systems and UASs. The range and economy of data exceeds anything that has gone before.

As data sources provide a seemingly endless choice, software must keep pace, so that the full value of the data is exploited. BAE Systems has invested heavily since the beginning of this century, developing SOCET GXP initially as a tool for defense image analysts to generate rapid, informative products, then as a digital photogrammetric workstation replacement for SOCET SET. These developments have included extensive functionality for 3-D modeling and texturing. More recently, the product line has grown in the direction of the enterprise, centered on a server product for catalog, search and discovery, GXP Xplorer. The next step is the development of a platform to enable not only BAE Systems, but also system integrators and end users, to build their own custom applications, including 3-D modeling and a wide variety of analytics. It is difficult not to be excited by data acquisition developments such as small satellites and UASs, but the software challenge is no less compelling.

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Zdalne metody pomiarowe dla potrzeb modelowania 3D przy użyciu oprogramowania BAE Systems

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Streszczenie

Efektywne i precyzyjne pozyskiwanie danych na podstawie różnego rodzaju zobrazowań, jest kluczem do ekonomicznego wytwarzania użytecznych produktów geprzestrzennych. Ciągły rozwój technik pozyskiwania danych geoprzestrzennych oraz pojawianie sie nowych źródeł danych obrazowych przyczyniają się do tworzenia nowych jak i dostosowywania już istniejących pakietów oprogramowania służących do przetwarzania danych. W przeszłości, cyfrowa stacja fotogrametryczna BAE Systems – SOCET SET zaspokajała ówczesne oczekiwania związane z przetwarzaniem danych i pozyskiwaniem danych wektorowych. Obecnie jej następca – SOCET GXP wychodzi naprzeciw dzisiejszym wymaganiom związanym z przetwarzaniem fotogrametrycznym i nowymi źródłami danych. SOCET GXP jest zaawansowaną stacją fotogrametryczną i kartograficzną, umożliwiającą zautomatyzowane wykonywanie triangulacji, tworzenie modeli terenu, przeprowadzanie ortorektyfikacji i mozaikowania, pozyskiwanie danych wektorowych oraz tworzenie modeli 3D z teksturowaniem. W odpowiedzi na potrzeby klientów, BAE Systems kontynuuje dodawanie modeli sensorów w celu dostosowania SOCET GXP do nowych źródeł danych obrazowych. Jednocześnie funkcjonalności dodane do najnowszej wersji SOCET GXP ułatwiają modelowanie, wizualizowanie i analizowanie obiektów 3D.