Improved Situational Awareness for the Dismounted Warrior in Urban Terrain

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ABSTRACT

Military operations of the dismounted soldier especially in urban terrain are gaining more and more importance and require a detailed knowledge about the operational area. In the past this has been achieved through 2D products like maps or reconnaissance images. Advanced sensors are able to acquire high resolution images with considerable information content, as 3D information and texture in different spectral bands which are robust against changes of environmental and operational conditions. Passive sensors (VIS, IR) as well as active scanners for 3D imaging in different operating modes (airborne, terrestrial) are employed.

Using these sensors the traditional products can be complemented by 3D models of the urban area as a virtual reality - in fact a modern version of the established sandbox. We want to support the decision makers in operation planning and to improve the common relevant operational picture (CROP). The major challenge is to create such 3D models immediately from acquired reconnaissance data.

We have started with a case study on a small village including extensive data acquisition by tactical sensor systems. The data set contains image sequences of VIS- and IR-Sensors and LIDAR data and has been acquired from airborne (MUAV) and terrestrial sensor platforms. The objectives are to visualize the sensor images for the dismounted soldier fusing it with additional context information e. g. from maps. Additionally we want to create 3D models of the urban environment and also analyzing the suitability of the different data sources for this purpose.

The paper describes our experiments with different sensors and platforms and gives an overview of the image data for the sample scenes. Examples of the different data sets for specific military applications will be presented as well as preliminary results.

1.0 INTRODUCTION

3D geometric and physical modeling of urban terrain represents a strong opportunity to enhance the generation of a common relevant operational picture (CROP). On the one hand such modeling can support visualization, which in turn enhances the user's situational awareness in complex urban scenarios whilst also supporting mission planning and decision processes. Of equal and increasing significance are inputs to such non-visualization tasks as line of sight, mission planning, change detection, sensor network capability assessment, threat analysis and the calculation of acoustic, chemical and EM propagation. Rapid and automatic generation of such 3D models is important.

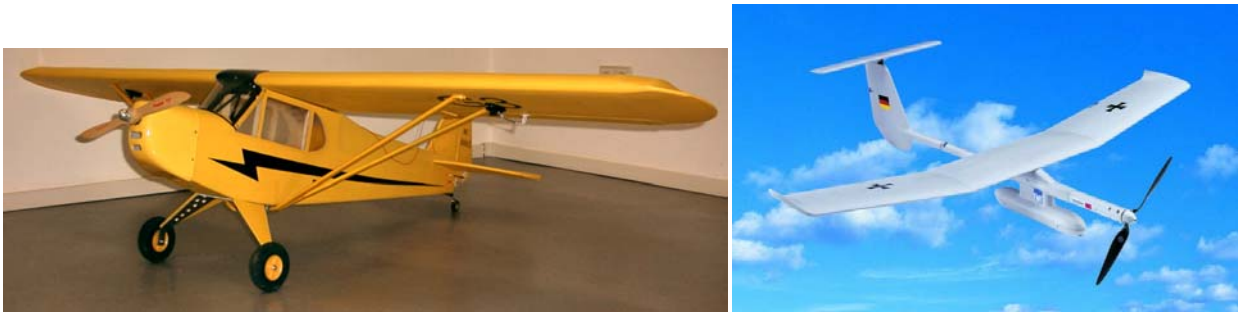
Several types of sensor platforms exist for data acquisition in urban terrain. Typically these are airplanes or unmanned air vehicles (UAV), and terrestrial platforms (UGS) which gather data either at a more or less regular time interval or on demand. In order to acquire suitable input data for basic military research

with respect to future applications, we have investigated different platforms and sensors. Active sensors as well as passive sensors were taken into account. Examples are VIS- and IR-cameras, hand held cameras and LIDAR. During the airborne multi sensor measurements high resolution image sequences, as well as passive IR-sequences in combination with a Laser radar system have been acquired. For the Laser measurements the GPS and INS data were recorded in parallel.

These data sets were the basis to generate up to date 3D object models with a high level of detail for various applications such as planning of military operations or augmented reality systems, but also to deliver real-time information for the task of target detection, tracking and change detection.

1.1 UAV for Real-time Data Acquisition

In order to acquire suitable input data for data analysis and image processing, we have selected a small remotly controlled model aircraft. Since these aircrafts are not built to carry any significant payload, only small and lightweight devices can be used as sensor testbed (Figure 1).



a) Model of *Piper J-3* b) ALADIN system

Figure 1: UAV Testbed

The focus for our first model has been based on two major points, payload capacity and size. Rough calculations yielded an anticipated payload of not more than 500g. The smallest model aircraft that could carry this payload according to its technical specifications was a Styrofoam aircraft with two electric engines, an open loading bay for the camera and other equipment and a wingspan of 1.3m.

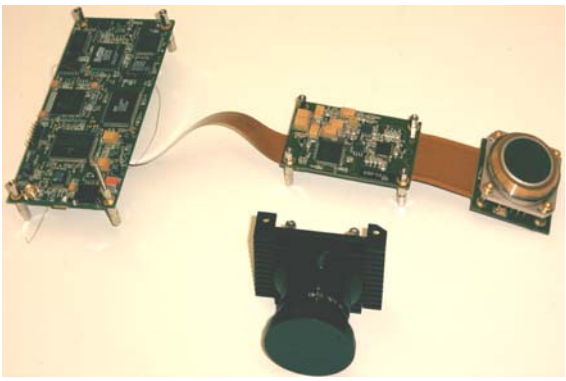


Figure 2: Small IR-Camera with sensor head

Imaging sensor	a-Si Focal Plane
Pixels	320×240
Pitch	45 µm
Thermal resolution NETD	< 120 mK @ 300 K
Spectral range	8–14 µm
FOV	41°×31°
Weight	250 g

AIM IR sensor characteristics

Another system is a larger but more robust model aircraft. The platform is the model of a *Piper J-3* made of wood and textile covering and with a wingspan of 2m (Figure 1a). The sensor equipment can be

mounted inside the hull and therefore is less vulnerable to damage in the case of a crash. We anticipate this model to be strong enough for a payload of 1kg. The sensor equipment chosen [10] is optimized for video data acquisition and storage. In all cases, the power supply for each device will be separated from that of the model aircraft in order to avoid interference with the high frequencies from the remote control.

- The first camera module is a mini **colour CCD camera.** It has an analogue video composite signal as output, so that either a digital recorder or a frame grabber must be used as interface to the computer. The main purpose of this camera is to provide the pilot's sight during the flight to adjust altitude or course while a camcorder records the main data for evaluation. But as the image quality is surprisingly good, it might as well serve as a sensor for data gathering.
- The second option is a small **thermal imager**. Since the thermal imager does not come with onboard recording capabilities, it must be used with a video downlink. One of the most important features of this particular uncooled IR camera is the very low integration time of only 4 ms. When used along with the CCD camera, the fields of view should match for data fusion.

However it has not yet been realized to fit both cameras into the small aircraft at the same time. Further components of the system are a tiny camcorder for onboard recording, video downlink for external recording, GPS receiver, pan and tilt head (foreseen). Another opportunity to take video sequences under operational conditions was the deployment of the military used ALADIN UAV (Figure 1b).

1.2 Airborne Platforms with Laserscanner

The employed Laser Scanner system uses a pulsed laser beam and measures the time between emitting a laser pulse and the detection of the reflected echo. The elevation is derived by converting this time to a distance. The scanner system consists of four major elements which are the pulsed laser, the detection device, the receiver and the time measurement unit. The laser operates at a repetition time of about 83kHz and at an eye safe wavelength of 1.56 µm. The fiber scanner system has a viewing angle of ~14^0 and a resolution of 0.114^0. The diameter of the footprint of the pulse on the ground is for example 30cm at 300m altitude. The position accuracy is <0.25m and the elevation accuracy <±0.15m absolute and <±0.1m relative.

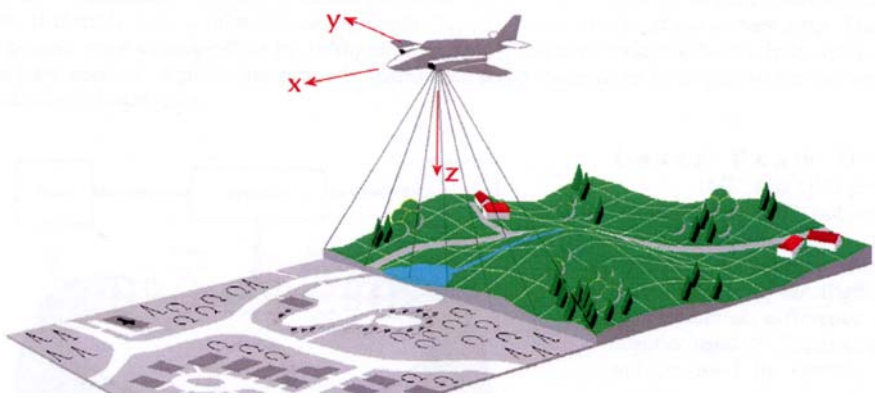


Figure 3: TopoSys Laser system and principle of data gathering [12]

For reconnaissance the sensor was set up as multisensor suite delivering IR, RGB and LIDAR in a coregistered mode. An example of a combined data set gathered in this mode (together with the 3D registration) is shown in Figure 7.

Figure 4: Color-coded Laser line scanner data and 3D registration

1.3 Terrestrial Platforms with Laserscanner

Airborne systems are widely used but also terrestrial laser scanners are increasingly available. They provide a much higher geometrical resolution and accuracy (mm vs. dm) and they are able to acquire a building facade details which is a requirement for realistic virtual worlds. The investigated data has been acquired by the terrestrial laser scanner Z+F Imager 5003 [11].

For the imaging measurement system a laser beam is deflected in two dimensions: vertically by the rotating deflection mirror and horizontally by the rotating movement of the entire measuring device. Within a very short space of time, the Z+F IMAGER 5003 supplies high-resolution results with a maximum range of 360° horizontally and 310° vertically (approximately 50° are hidden by the superstructure and tripod). At a maximum data sampling rate of 625,000 pixels per second the amount of data collected totals up to 200 million picture points per scan which can subsequently be further edited or processed and reduced. The resolution (amount of data) can be determined via the software, depending on the application. The scan range is up to 53.5 m (radius). The typical surveying times from 30 seconds up to 2 minutes for 360° scans, depending on the selected level of detail.

The acquired range images represent the geometric conditions of the objects in the environment. The reflectance images are used for identification and extraction of objects or visual inspection, as well as for classification of the object surfaces. Reflectance images are similar to video images, the only difference is that they are independent of external lighting and represent surface reflection in a very narrow band

The chosen scene (Fig. 5) contains several buildings along a street at various distances. The reflected light

from the laser beam is recorded as a greyvalue and is used for texturing. Because no light is returned from the open sky, it appears black.

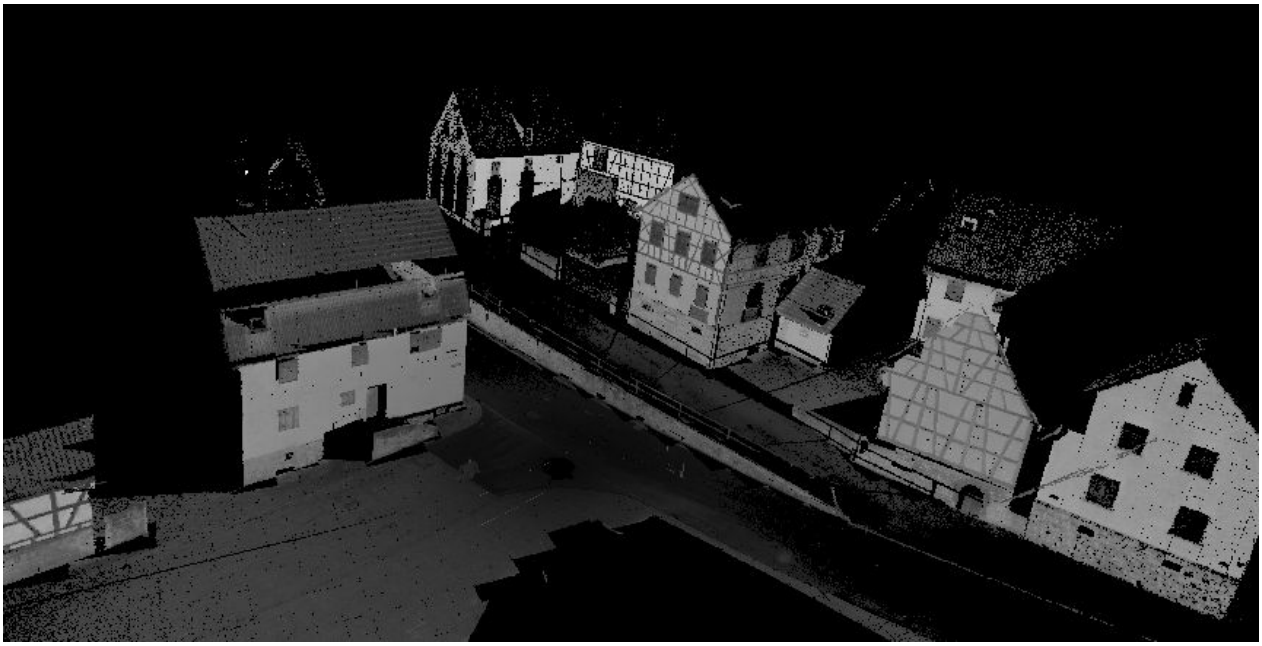


Figure 5: Visualization of Laser Scanning data (Z+F 5003)

1.4 Modular Mini Missile Demonstrator M3D

The basic idea for a modular built up Mini Missile arose with the EADS-LFK -the missile system house in Germany - in the context of considerations in particular to future threat scenarios in so-called ‘asymmetrical conflicts’ Thereby primarily missions are addressed in crisis areas, in the surrounding field of terrorism and in so-called ‘Amok-Scenarios’ with police applications/missions.

With the ‘Mini Missile’ a flexibly applicable, system is to be put to the soldier or the police officer for reconnaissance and identification of targets in urban and/or badly observable areas. In a second step it will also be possible to transport and insert effect means like small blend/shining means etc. into target areas. The “Mini Missile” possesses a total weight of less than a kilogram and can be very easily equipped and exploited in the application of one man.

The Mini Missile mission concept comprises controlling various flight states for the fulfilment of reconnaissance tasks, a fast cruising flight to the observation place with a following autonomously controlled hovering flight. In addition the Mini Missile is equipped with a complex miniaturised autopilot (IMU), which is supported by additional sensors such as GPS, earth magnetic field sensor and ultrasonic – and barometric altimeter.

The reconnaissance results from one or more mini cameras will be transmitted by a broadband downlink to a screen of the control unit of the operator. In combination with optical reconnaissance equipments the Mini Missile flight vehicle can be equipped also with microphones, detectors among other things. For stationary real time observations, e.g. over several hours, the Mini Missile can be put down on roofs or other open spaces by a automatic landing procedure, and can be commanded back afterwards again to the operator. The M3D Mini Missile can thanks to its high degree of automation for each user be controlled

already within a few minutes, without expensive flight training.

A prototype of the M3D was already delivered for internal testing to the Federal Office for Military Technology and Procurement (BWB).

Figure 6: Mini Missile Demonstrator M3D® (l) Visualization of Video Sequence (r)

2.0 DATA ANALYSIS AND PROCESSING

In the preceding sections platforms as well as sensor equipment have been presented. In this chapter we discuss the image processing algorithms for reconnaissance, modelling of urban structures, and the classification and localisation of targets by our ATR system. These tasks require the knowledge about the pose of the cameras as well as their calibration parameters.

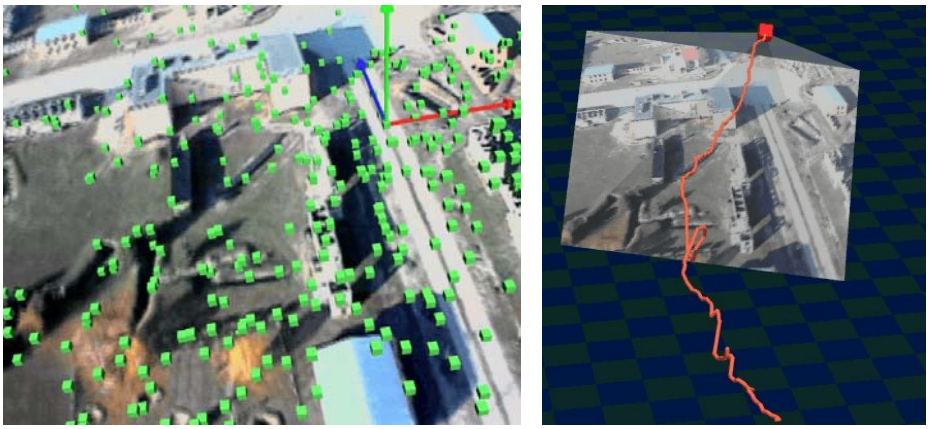
When IR- and VIS image sequences are recorded and the platform flight data (INS, GPS) respective the sensor extrinsic parameters are not available or not precise enough for image analysis and geo-registration, the first task is to reconstruct the sensor/platform trajectory.

2.1 Sensor Trajectory from Image Sequences

Such a task – simultaneous computation of intrinsic and extrinsic camera parameters when no initial values are known – is commonly referred to as sensor auto- or self-calibration [1][5][8]. Current research is focussing on the computation of sensor trajectories from video sequences in real time [6]. This will lead to fast “structure from motion” and finally to the fully automatic generation of city models. Several images taken from different viewpoints or from the video stream of a moving camera provide enough information to reconstruct both the sensor pose and trajectory along with calibration parameters for the camera. In [1] many aspects are covered in detail so that only a brief overview will be given here.

Suppose an object point is imaged by one camera so that the coordinates of its image are known. If a second camera takes an image of the same scene, what is known about the location of that particular object point in this image? It turns out that its position is restricted to lie on a straight line – namely the image of the viewing ray of the first camera to the object point. This line is called the epipolar line and its parameters for any point are defined by the relative pose of the two cameras and their inner parameters (e.g. the focal length) which describe the image formation inside the camera. Every known pair of corresponding points thus yields one constraint. A total of at least seven corresponding points between

both images are exploited to compute the fundamental matrix which expresses their mathematical relation. To generate the full sensor trajectory for an image sequence the processing chain can be divided into following parts: Point tracking, initial projective reconstruction and complete reconstruction.



a) 3D reference points b) Reconstructed sensor trajectory

Figure 9: Reconstructed trajectory of test flight

Figure 10: Mosaic created by projection of image sequence onto the ground.

Figure 9a shows one frame of such a sequence with marked interest points. The reconstructed sensor trajectory is shown in Figure 9b along with a projection of the frame onto the ground.

If all frames of the whole flight path are mapped onto a surface, an image mosaic can be produced, to give

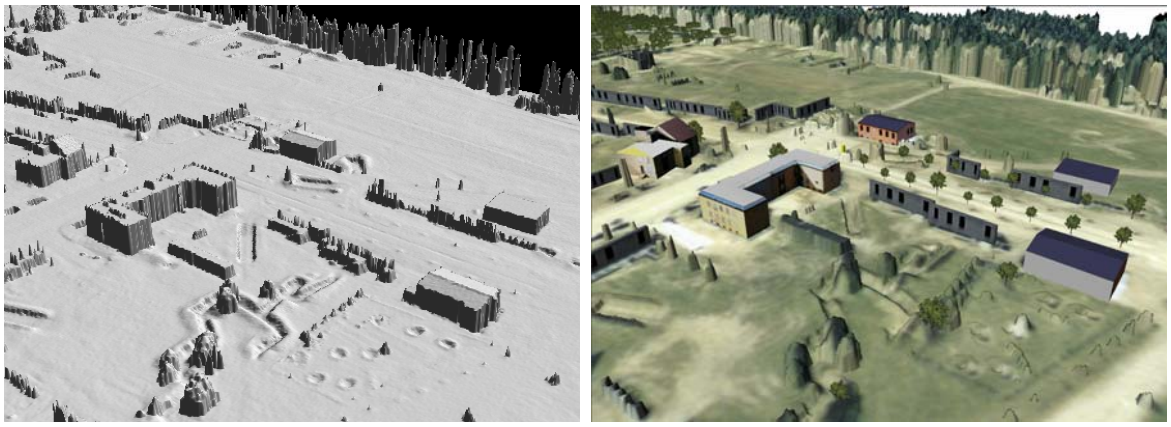
the operator stabilized information on his screen. An application could be rapid terrain mapping, e. g. for updating a ROI in an older aerial photo by actual UAV sensor data.

These are principle results, but they already show the capabilities of a rather inexpensive airborne platform coupled with automatic image processing techniques. For basic tests, we have used the commercial program *MatchMover*. In most cases the program came to plausible results, but some instability could be noted. If the constraints on the intrinsic camera parameters were too loose, the solution would not converge. This is due to the restricted movement of the sensor platform which leaves some of the camera parameters correlated [3]. Therefore new *sensor auto-calibration* methods are under development [7].

2.2 Reconnaissance and 3D Modeling

3D modeling of urban areas and an appropriate visualization is one opportunity to enhance the situation awareness essentially. It can increase the understanding and explanation of complex scenario, supports the decision process and gives the opportunity of a common situational awareness. Additionally, an enhanced mission planning is one of the most effective methods to compensate the lack of local knowledge.

A composite 3D model of urban environment gives the possibility for rehearsal, to "fly through" the local urban structures with multiple perspective viewing, and to visualize a military order. To generate the necessary models of the urban scenario different approaches are discussed in the literature. For large urban scenarios LIDAR data can be utilized [9]. M. Pollefeys uses projective geometry for a 3D reconstruction [1] from image sequences. C. S. Fraser et al. use stereo approaches for 3D building reconstruction [2]. We propose a combination of the different approaches mentioned before. In LIDAR data 3D information is directly available. Due to the vertical view of the sensor to the nadir during data acquisition, the building structures are bounded by the ground projection of the roof surfaces (Figure 10). Algorithms were developed for the segmentation of roof surface areas and the generation of CAD-models of gabled roofed buildings [4]. These common CAD-models represent the geometrical properties of the main structures of the objects.



a) Laser elevation Data b) Laser DTM and 3D models textured

Figure 10: Multi sensor modeling

By texturing the models important additional information of an object can be provided. The images providing the textures can be captured by a UAV or by local ground based sensor systems. This requires a determination of the camera parameters to project the model surfaces onto the images as described before. An example with data of the TopoSys Laser line scanner (Figure 10a) together with the textured 3D objects is shown in Figure 10b. The cameras mounted in UAVs often have a low geometric quality compared to true photogrammetric devices because of weight restrictions or the expendability of the

complete system. Nevertheless, it is anticipated that in combination with real time processing 3D models suitable for tactical purposes can be produced from such systems. Due to the fact that UAVs can be use only for data acquisition in small local areas, large areas still have to be covered with LIDAR or similar sensors.

2.3 Exploitation of Terrestrial Laserscanning data

In contrast to airborne LIDAR data, where only one dataset covering the complete scene is delivered, terrestrial LIDAR data typically consists of several datasets taken from different positions. The first step in the processing chain therefore is the fusion of all datasets into a single geometric reference frame. This task can be split up into two subtasks – a coarse and a fine registration. The coarse registration consists of the global transformation from one dataset into the other and typically is the difficult part, since a matching of either 3D points or features recovered from the point clouds is required. Often this step is carried out through manual interaction from the operator. The focus is on robustness so that the resulting transformation parameters are only an approximate solution which will then be improved by the fine registration. The results of the coarse registration are taken as initial values for an iterative least squares adjustment combined with a possible reassignment of the matching. We have developed and implemented a method for the completely automatic registration of two LIDAR datasets.

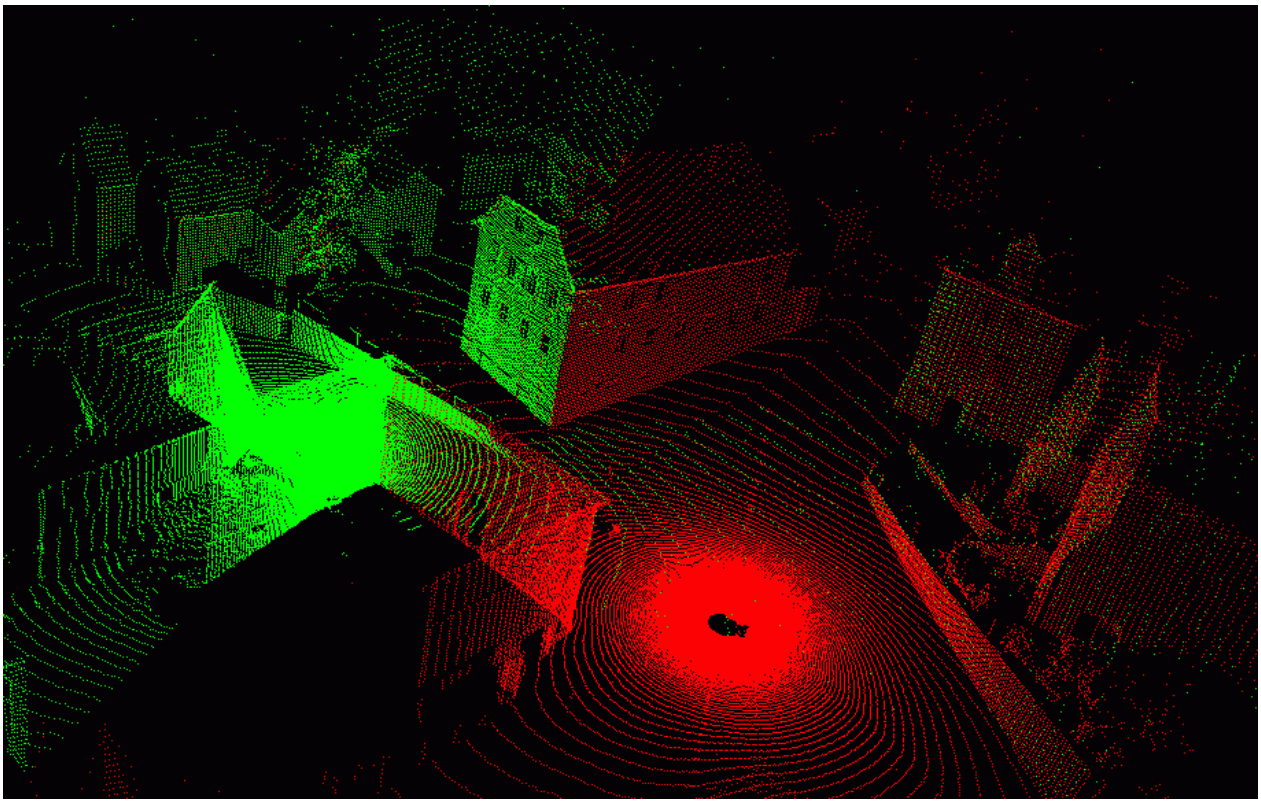


Figure 11: Fusion of two terrestrial Laserscanner data sets (green, red)

3.0 CONCLUSION

For planning and visualization of military operations, e.g. "fly through" visualization and detail analysis - especially at missions in urban terrain -, the fusion of Laser data and images of other sensors is the appropriate method. In addition to elevation data the texturing of the different 3D object models gives a more realistic impression and decreases the interactive modeling effort. Especially for the texturing process image sequences from UAVs can be used. Presented results demonstrate the perspective and the

challenge for a combined or distributed sensor system for remote sensing, which gives considerable advantage together with a high precision in object location and pose estimation for airborne applications.

The next generation of 3D imaging Laser sensors will be provided with lightweight miniaturized components like micro-scanner and intelligent software to help solving challenging tasks like surveillance tasks during long endurance missions.

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