UAV-BASED AUGMENTED MONITORING – REAL-TIME GEOREFERENCING AND INTEGRATION OF VIDEO IMAGERY WITH VIRTUAL GLOBES

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ABSTRACT:

Over the last few years low-cost micro and mini UAV systems equipped with light-weight geosensors such as video cameras have started to appear on the market. These UAV systems are mostly instrumented with low quality INS/GPS sensors for position and attitude control. Over the same time period web-based interactive 3D geoinformation solutions have evolved into virtual globe technologies which have had a tremendous impact on the geospatial industry within just a few years. Up to now, UAVs and virtual globes have rarely been combined. However, the real-time integration of live or recorded video streams from airborne platforms into virtual globes opens up a wide range of new applications. Real-time infrastructure surveillance, forest fire monitoring, traffic monitoring or rapid to real-time mapping are only a few examples. Today, the use of virtual globes for mission critical applications is frequently hampered by the fact that the underlying base imagery data is often outdated and does no longer reflect the current situation. Hence the real-time integration of image data based on video or still frame cameras into virtual globes bears a great potential for dramatically increasing the benefits of 3D geoinformation solutions. This paper presents an approach to complement virtual globes with up-to-date or even live geospatial content captured from mini- or micro UAV platforms.

1. INTRODUCTION

1.1 Motivation

Today a large number of geosensors and geosensor systems are operational. The available spectrum of geosensors ranges from simple static sensors which capture arbitrary physical phenomena such as temperature or humidity to complex sensors mounted on highly dynamic platforms like satellites or UAV (unmanned aerial vehicle) systems. So far, this real-time sensor data cannot yet be exploited in 3D geoinformation services. However, if the available geosensor data are combined with 3D geoinformation services, new application scenarios can be realized. For such applications, mini- or micro UAV systems are very promising cost-efficient platforms for capturing real-time close-range imagery. Possible application scenarios range from decision support after natural disasters, such as earthquakes, to the virtual piloting of UAV systems.

Our investigations differ from mini and micro UAV based mapping applications in photogrammetry as for example presented in (Eisenbeiss 2006) or (Annen and Nebiker 2007). The focus of our research is placed on real-time data geo-registration and geodata integration into virtual globes. Especially, we have to continuously geo-register and process the available video data streams and low-quality non-metric video cameras use for data capturing.

1.2 Goals and contents of the paper

This paper presents a prototype system solution, which allows for a real-time integration of a video stream captured with a mini or micro UAV system into a virtual globe technology. Two different integration approaches will be presented, one referred to as *augmented monitoring*, the other as *virtual monitoring*. These two approaches will be presented in detail. Additionally, the augmented monitoring approach will enable the real-time mapping of arbitrary geo-objects and sharing this information among numerous virtual globe clients with the use of a collaboration framework. For the realisation of such a solution the video geo-registration process based on low quality and low cost IMU/GPS sensors used in mini or micro UAV systems with an adequate geo-referencing accuracy is a major challenge. Especially the system calibration of the camera misalignment as well as the continuously changing systematic attitude and position error of the MEMS based IMU and navigation grade GPS receivers have a great influence on the achievable geo-registration accuracy.

The paper commences with a technical overview of mini and micro UAV systems, with a focus on their suitability for mapping applications. Additionally, the UAV platform used for these investigations is presented. Next, the state of the art of virtual globe technologies is reviewed and put into perspective with our own virtual globe technology i3D. The paper then describes the entire real time data processing chain and the developed software components. This workflow is subdivided into the following steps. First, the flight data and video stream transmission and synchronisation process is introduced. Subsequently, the geo-referencing approach for geo-registering the captured video streams is discussed. This is followed by a description of the different strategies for integrating video streams into the i3D virtual globe technology. The final section of the paper presents results and experiences from a test case project and provides an overview of new applications. Furthermore, the mapping accuracies obtained from the above mentioned processing chain are recapitulated. The paper concludes with an outlook on ongoing and future development steps.

2. UNMANNED AERIAL VEHICLE SYSTEMS

2.1 Overview

A rapid development of unmanned aerial vehicle systems has taken place in the last few years. Today, a wide variety of different UAV systems exists on the market. The European Association of Unmanned Vehicle Systems (EUROUVS) has drawn up a classification of the different system platforms. In (Bento, M. 2008) the current EUROUVS classification is presented and a good state of the art overview is given.

Category	Max. Take Off Weight	Max. Flight Altitude	Endurance	Data Link Range
Micro	< 5kg	250m	1h	< 10km
Mini	< 30kg	150-300m	< 2h	< 10km

Table 1: Classification of mini and micro UAV systems

This paper is focused on mini and micro UAV systems. Table 1 shortly recapitulates the technical specifications of these two UAV categories, again based on the current classification by UVS International. Most of the mini or micro UAV systems available today integrate a flight control system, which autonomously stabilises these platforms and also enables the remotely controlled navigation. Several systems additionally integrate an autopilot, which allows an autonomous flight based on predefined waypoints. These flight control systems are typically based on MEMS (Micro-Electro-Mechanical System) IMU systems, navigation-grade GPS receivers, barometers, and magnetic compasses. The different sensor observations are usually integrated to an optimal flight state using an EKF (Extended Kalman Filter), which is subsequently used in the flight controller. For mapping applications, it is also possible to use this flight control data to geo-register the captured payload sensor data like still images or video streams. However, as a result of the utilisation of low-weight and low-cost flight control sensors, the achievable geo-referencing accuracy is strongly limited.

2.2 Microdrones md4-200 platform

Figure 1: Quadcopter micro UAV (microdrones md4-200) system (left) with portable ground control station (right)

For the prototype solution presented in this paper we use the micro UAV platform microdrones md4-200 which is illustrated in Figure 1. The following listing contains a short overview of the technical specifications of the platform and of the sensors used for capturing video streams and flight control data.

Platform

UAV category:	micro (quadcopter)
max. take off weight:	0.9 kg
max. payload:	0.3 kg
endurance:	20 min

Sensors

GPS receiver:	u-blox (navigation grade - pseudorange processing)
IMU:	6DOF MEMS based
magnetic compass:	three-axis sensor
barometer	
video camera (payload):	non-metric / PAL output resolution: 640x480 pixels

Flight attitude accuracy (After sensor data fusion)

position:	2.5 m CEP
altitude:	5 m SEP
roll and pitch angle:	1-2°
yaw angle (Heading):	3-5°

Notable is the low attitude accuracy of the integrated flight data, especially the heading accuracy which is approximately three times lower than that in roll and pitch. This has a direct influence on the achievable video geo-referencing accuracy, especially for large image to object distances. Details of the implemented sensor data fusion approach are presented in (Meister et al., 2007). The systems platform includes an analogue data link between platform and ground control station for video- and flight control data transmission. The flight control state consisting of position, velocity and attitude of the platform together with a time stamp in UTC is transmitted with 4-5Hz. Due to the restricted payload of only 300g, it is not possible to use a video camera with high quality optics or a genlock capability.

3. VIRTUAL GLOBES

3.1 State of the art

Different web-based 3D geoinformation services based on virtual globes are available today. Google Earth and Microsoft Virtual Earth are only two prominent examples. Most of the available virtual globe technologies have the possibility to integrate large amounts of geospatial content, like terrain models, orthomosaics, 3D objects, points of interest or multimedia objects. Many solutions have an excellent ability to stream very large volumes of geodata.

Among the shortcomings of virtual globe services are the often outdated geodata contents. However, for many possible application scenarios like real-time surveillance or decision support applications the availability or integration of up-to-date or even live imagery data is crucial. Furthermore, with most virtual globes, it is not known which underlying earth model is implemented. However, for an accurate geospatial content integration the knowledge of the used geodetic global reference system(s) is crucial. Overviews of available virtual globe technologies can be found in (Thalmann, 2007) or (Bleisch and Nebiker, 2006).

3.2 i3D technology

In the virtual globe technology i3D, developed at the University of Applied Sciences Northwestern Switzerland (FHNW), we try to address the above-mentioned shortcomings by supporting and integrating imagery data and arbitrary geosensor data in real- or near real-time. In the development we aim at integrating geosensor data at a sub-meter accuracy level. In Figure 2 a screenshot of the i3D virtual globe is presented.

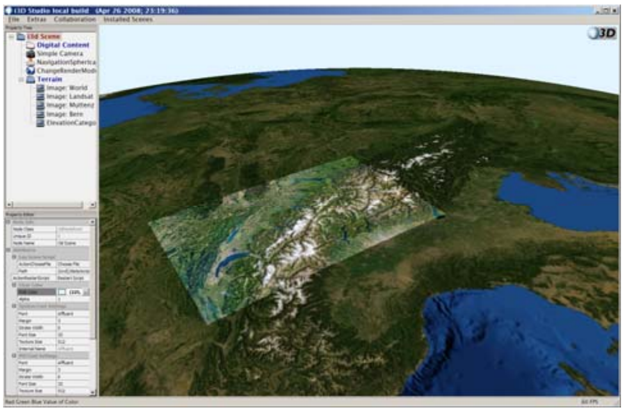

Figure 2: Print screen showing the virtual globe editor and viewer i3D Studio with a scene of Europe

Subsequently, the i3D technology and its main components are introduced. Thereafter, the i3D video data integration module is presented in detail in the main part of this paper. All components are part of the i3D Studio software system.

3.2.1 i3D core

i3D is a 3D geovisualisation engine which is optimised for real time spherical rendering of the entire globe. Like other virtual globes i3D can also stream extremely large volumes of geodata over networks or from local drives. Supported geospatial content types are digital terrain models, orthomosaics, points of interest, and 3D objects. i3D uses an extensible scene graph concept to define a virtual world scene. This scene graph can be custom-built for arbitrary application scenarios. For application development and customisation a scripting API is available based on the high performance *lua* scripting language (Ierusalimschy, 2006).

The i3D virtual globe is based on an ellipsoidal earth model. As position reference the ECEF WGS84 reference system is used and the geoid is defined as height reference surface. This definition is important when a GPS-based geosensor 3D position has to be integrated into the virtual globe. In case of a geoidal reference surface as in i3D, this GPS height has to be corrected with the corresponding geoid separation.

3.2.2 i3D collaboration framework

The i3D collaboration framework enables the creation of a collaborative virtual world (Nebiker et al., 2007). In this environment, it is possible to visualise and exchange information between different collaboration clients. In i3D, this information could consist of the position and attitude of an actor (virtual camera) located in the virtual globe or of an arbitrary geoobject such as a point of interest. Furthermore, this framework allows the integration and utilisation of distributed geosensor data in real-time.

4. VIDEO DATA INTEGRATION

In the following the developed video imagery integration processing chain and software components are described, which enable the realisation of real-time and offline *augmented monitoring* and *virtual monitoring* solutions based on mini and micro UAV systems on the one hand and the i3D virtual globe technology on the other. In this context the term *augmented monitoring* refers to the superimposition of the geo-registered video stream with objects of the virtual globe. In contrast to this, the *virtual monitoring* approach refers to the synchronised rendering of the video stream in parallel to the virtual scene containing the UAV system and the geo-registered view frustum of the video camera. Figure 3 shows an example of the augmented monitoring scenario with an overlay of the semi-transparent video in the centre of the screen with the 3D scenery of the virtual globe. Figure 4 depicts the virtual monitoring video imagery integration approach presented, with the video view of the real world on the left hand side and the synchronised virtual view on the right.

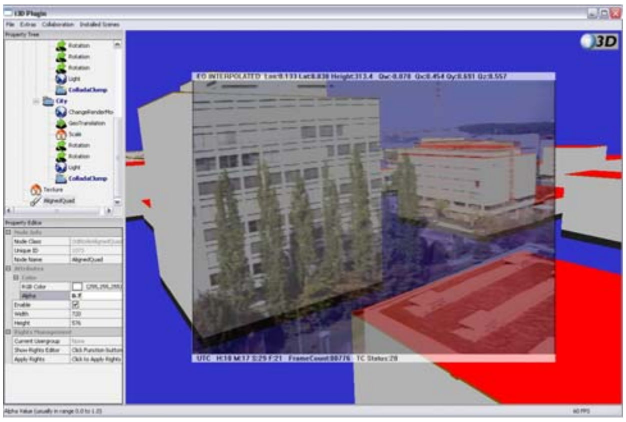

Figure 3: Example of the augmented monitoring scenario

Figure 4: Example of the virtual monitoring scenario

4.1 Systems architecture and data flow

Figure 5 shows all involved hardware components and the entire data processing chain of the developed prototype solution. At the beginning of the chain is the mini- or micro UAV platform consisting of a flight controller, a video camera and a data link transmitter. This video camera captures the imagery stream that will be integrated into the virtual world. With the deployed 'microdrones md4-200' platform an analogue data link is available. Over this data link the analogue video signal as well as the flight control data consisting of platform attitude, position, velocity, and time stamp data can be transmitted. The analogue transmission of the video stream has the advantage that the time delay of the actual data transmission can be neglected, in contrast to the delay in digital transmissions which is introduced by the data encoding and decoding processes and which varies depending on the contents of the video imagery to be encoded. The portable ground control station of the md4-200 platform provides a data link receiver, which continuously writes the flight control data stream to a serial RS-232 interface and the video stream to a composite video signal output.

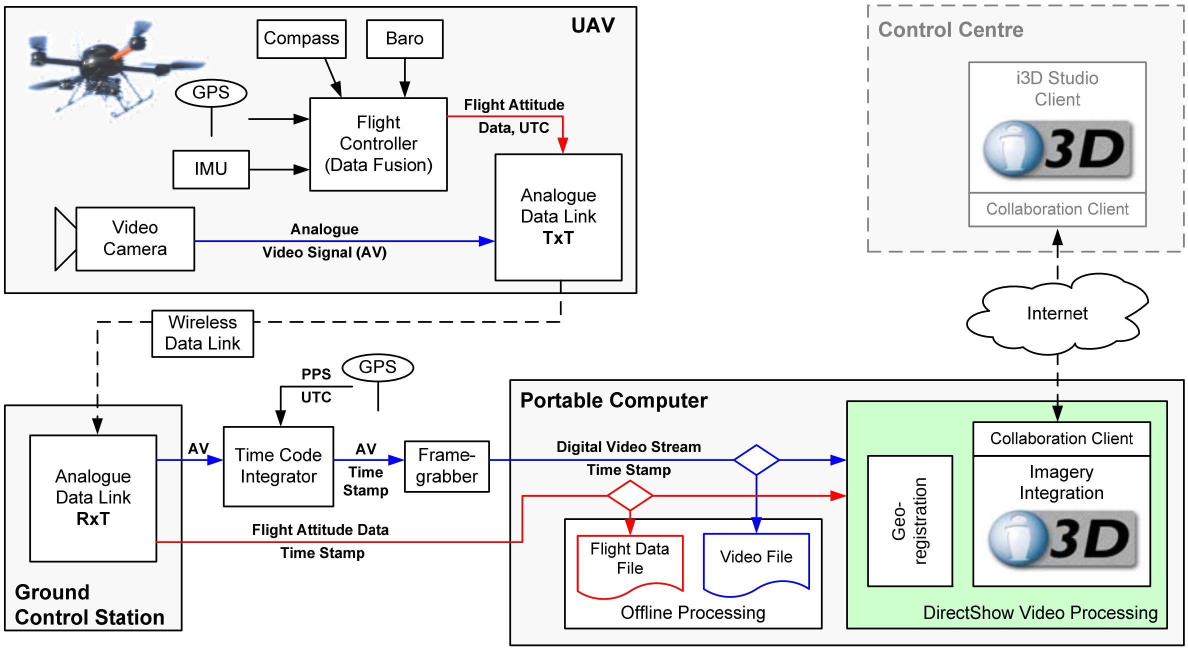

Figure 5: System architecture and data processing chain of the video imagery integration

In order to perform an accurate video geo-registration later in the processing chain, we require a time-coded video stream based on the same time reference as that of the available flight attitude data. In the prototype system this task is performed by a time code integration component, composed of a GPS receiver and a VITC (Vertical Interval Time Code) time code integrator. This time code integrator is synchronised based on the available PPS (pulse per second) signal of the GPS receiver. For each frame the absolute GPS time or rather the derived UTC is integrated. Because of the limited payload weight on the UAV platform we are forced to outsource this process to the ground control station. Subsequently, the analogue video signal is converted from analogue to digital and further processed with the developed video processing software components on the portable computer, which complements the ground control infrastructure. These software components enabling the video imagery integration are described in detail in section 4.2.

In order to realise a real time processing solution, the available flight control data stream has to be connected to this computer. For subsequent offline video imagery integration, the time-coded video stream as well as the flight control data stream can be stored on a local drive (see Figure 5).

4.2 Video processing

The subsequent processing of the time-coded video stream and of the available flight attitude data happens with software based video processing filters. These software components have been implemented based on the Microsoft DirectShow framework. This framework provides the basic functionality for designing a customised video processing application on Microsoft platforms. Different filters which implement functionality such as the reading and writing of streams, video conversion, video rendering or video multi- and de-multiplexing are available. For more details on DirectShow interested readers are referred to (Pesce, 2003). To realise a custom-built video processing application these filters can be freely combined to a filter graph. When this filter graph is executed, each frame of the video stream is processed serially by each filter defined in the graph. For the video geo-registration and the integration into virtual globes different new filters have been implemented, which are described in the following two sections. Figure 6 presents the simplified filter graph with the newly developed filters.

4.2.1 Video imagery geo-registration

As depicted in Figure 6 the geo-registration process consists of the *VITC time code reader* and the *flight data integrator* filters. The first filter extracts the integrated time code and makes the time stamp of each frame available to the following filters. The second filter implements the actual geo-referencing process. In this process the unknown sensor model, which consists of the exterior and interior orientation of each frame is estimated. For this estimation the direct geo-referencing approach is implemented. The direct georeferencing approach is introduced, for example, in (Mostafa and Hutton, 2005), (Cramer, 2001) or in (Skaloud, 1999), who give a good overview of characteristics and problems. In contrast to direct geo-referencing applications in airborne photogrammetry (cp. Cramer et al., 2000), we have to rely on flight attitude states from low quality INS/GPS sensors only. With the aid of the time stamp of each video frame, the synchronisation between the current video frame and the flight attitude data can be established. As shown in Figure 6 the flight integration filter reads the flight attitude data either directly from the specified RS-232 interface in the real-time case or from a file in the offline case. With the aid of the flight attitude state it is possible to compute the relation between WGS84 object coordinate system and camera coordinate system for each frame. For this task, additional information such as the interior orientation of the used video camera as well as a system calibration is required. This system calibration describes the misalignment angles between INS reference frame and camera coordinate system. Details of the two required calibration processes and the implemented direct geo-referencing algorithm can be found in (Eugster and Nebiker, 2007). Because of the lower frequency of the flight data stream the required sensor model has either to be interpolated in the offline case or predicted in the real-time case. The entire filter can be parameterised by the user via a XML instance. In this XML file the current interior orientation parameters and misalignment angles can also be defined. So the output of this filter is the time stamp and the sensor model for each frame.

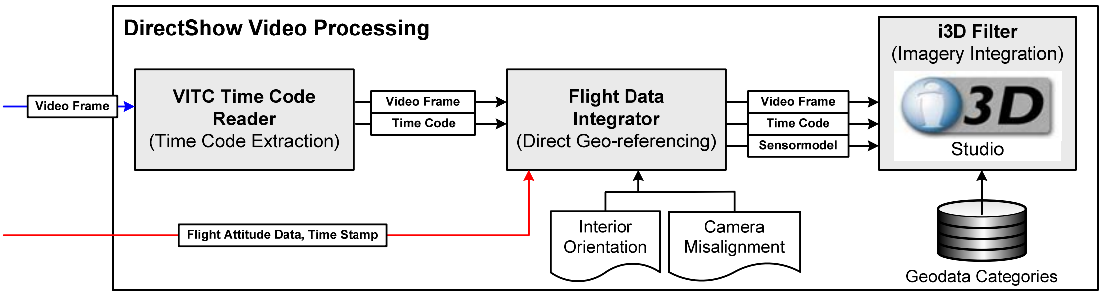

Figure 6: Filter graph for video processing

4.2.2 Video imagery integration

The last step in the video processing chain is the integration of the geo-registered video stream into the virtual globe technology i3D. This integration process has been implemented by means of the *i3D Filter* depicted in Figure 6. This filter encapsulates a fully operational i3D Studio software system. In order to realise the augmented or virtual monitoring video imagery integration, the filter reads each frame's sensor model which is delivered by the *flight data integrator* filter. In case of the augmented monitoring integration, the virtual camera of the virtual world, i.e. the observer's view, is controlled by the sensor model which has been encoded in the video stream. Thus, the video frame can be superimposed with the graphics output of the i3D terrain engine. The achievable overlay quality depends on the geo-referencing accuracy and the accuracy of the rendered virtual world objects. This integration approach allows for the real-time mapping of arbitrary geo-objects. With the aid of the available terrain model underlying the virtual globe, an object identified in the video can be manually picked. Based on the available image coordinates and the known sensor model, the unknown 3D object coordinates can be determined by intersecting the object ray with the currently loaded terrain model or with 3D objects present in the 3D scenery. In the virtual monitoring integration, the UAV platform, the video camera and the current view frustum are drawn in the virtual world. These objects and especially the view frustum are controlled by the available sensor model for each frame. Parallel to this graphical output the video stream can be rendered in a separate window. The result of the two video imagery integration approaches is visualised in Figure 3 and 4.
In the offline mode, the video imagery processing solution additionally supports features such as play, stop, pause, skip forward and backward. Finally, the implemented i3D collaboration framework allows for the real-time synchronisation and sharing of the mapped geo-objects or the UAV position and attitude information, for example, with operations control centres or to other clients in the virtual world (cp. Figure 5).

5. APPLICATIONS AND RESULTS

5.1 Application scenarios

The presented prototype solution consisting of a) a mini or micro UAV system, b) the proposed video processing chain and c) a virtual globe technology such as i3D offers a great potential to realise new applications in various application areas. The foundation for all applications is the i3D virtual globe technology. The proposed video imagery integration processing chain allows for the real-time or near real-time video integration into the 3D virtual world. With the aid of the two presented integration strategies arbitrary geodata content can be extracted from the video stream. The integrated collaboration framework additionally allows for the exchange of extracted geodata content with other involved clients of the 3D geoinformation solution. With this architecture it is possible to immediately capture and process geo-referenced video imagery at the ground control station of the UAV system. If required, the extracted geospatial data can be distributed in real-time, for example, to control rooms where this information can be visualised, further processed and/or stored.

Typical application areas are in the domains of safety and security. Border patrol, forest fire monitoring, pipeline inspection or traffic surveillance are a few promising examples. Also search and rescue applications which support the decision making in cases of natural disasters like earthquakes, forest fires or floods are promising candidates. Additionally, the augmented monitoring video imagery integration is well suitable to realise a virtual piloting solution for controlling and piloting unmanned aerial platforms. In this scenario, the pilot view based on the transmitted video stream can be superimposed, for example, with flight obstacles.

5.2 Achievable geo-registration accuracy

Figure 7 shows the estimated a priori geo-registration accuracy of a low-cost solution in relation to the image-to-object distance. It can be seen that the presented direct video geo-referencing approach using a combination of micro UAVs, consumer grade video cameras and virtual globes offers a point localisation or digitising accuracy in real-time between 6 and 15 meters. It should be further noted that these results are independent of any control points and that these accuracy figures apply on a global scale.

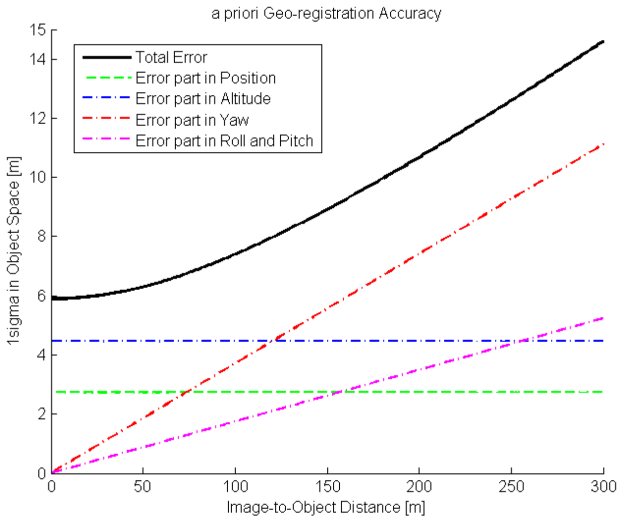

Figure 7: A priori estimate for the achievable direct geo-registration accuracy with the micro UAV 'microdrones md4-200'

The direct geo-registration accuracy achievable with low cost UAV platforms, video sensors and virtual globe technologies is more than adequate for many real-world applications.

However, for certain application scenarios the above-mentioned geo-referencing accuracy of the direct geo-referencing approach is not yet sufficient. In such situations it is conceivable to use the available geospatial contents of the virtual globe to improve the geo-registration accuracy. This approach further denoted as *integrated geo-referencing* tries to continuously estimate and correct the systematic error part of the direct geo-referencing solution with image-based resection updates resulting from an image-to-model matching. First investigations of this geo-referencing approach show an accuracy improvement by a factor of four. A detailed accuracy investigation of the introduced direct geo-referencing and first investigations of the mentioned integrated geo-referencing approach performed with a similarly INS/GPS sensor configuration are presented in (Eugster and Nebiker, 2007).

6. CONCLUSIONS AND OUTLOOK

This paper presented a prototype solution for the integration of video imagery captured with mini or micro UAV systems into virtual globes – both in real-time and offline. Two different integration scenarios – the *augmented monitoring* scenario and the *virtual monitoring* scenario – were introduced. The augmented monitoring approach, for example, allows for the real-time 3D localisation or mapping of arbitrary geo-objects based on the video imagery content. A key element in the realisation of the video imagery integration is the video stream geo-registration process. This current video integration process is based on the direct geo-referencing approach, in which the achievable geo-referencing accuracy depends on the quality of the available flight attitude data and the synchronisation accuracy between video and flight data stream. A priori estimates and first field tests show that the presented solution offers a point localisation accuracy between 6 and 15 meters – anywhere on the globe and in real-time. This accuracy level is more than sufficient for numerous applications – especially when put into relation with the low costs and simple operation of our solution and with the fact that the system not only yields position information but also valuable context information in the form of real-time video views of the observed area and of a collaborative virtual environment.

However, quite naturally the quality of the available flight attitude data of mini or micro UAV systems is much lower than that of the position and attitude data provided by the high-end GPS/INS systems used for direct geo-referencing in conventional airborne photogrammetry applications. In order to overcome these problems and to further increase the achievable mapping accuracy of mini or micro UAV systems, a new integrated geo-referencing approach has to be implemented. For such a solution an adaptive and robust image-to-model algorithm will be crucial. First investigations have shown that real-time image-to-model matching is a promising but very challenging task. Further, the matching process requires a robust video feature extraction which is delicate in outdoor environments due to changing weather conditions and variable lighting.

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