Outdoor Augmented Reality using a High-Precision Localization Device

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Abstract

Despite the availability of stable indoor vision-based tracking methods like SLAM, for serious applications outdoors in the BIM or GIS area, an accurate transformation between the local tracking frame (*i.e.,* the camera) and the global environment (*i.e.,* the information from GIS and other sources) has to be established. Unfortunately up to now, this was hardly possible with vision or standard mobile phone grade sensor technology alone.

In this work we present an outdoor AR system leveraging recent developments in the area of location and orientation sensing technology. We developed a device consisting of multiple sensors, which can easily be combined with any mobile phone, tablet or even HMD for accurate visualization of globally registered content. The device can be built out of commercially available components for less than €500, giving up to centimeter-level localization accuracy. We extensively evaluate the device with respect to orientation and localization accuracy, showing different outdoor AR use cases.

Keywords: Augmented Reality, Outdoor, Localization

1 Introduction

Augmented Reality (AR) has become known by almost everyone over the last view years. Especially games like Pokemon GO brought AR to the public. Such games are of course not the only useful applications for AR. Several AR projects exhibit that lots of industrial work cases can profit from additional visualized information. Increasing productivity, involving saving time and money are already well received by industry, especially for indoor AR systems like warehouse management. But AR is also slowly getting its way to customers, considering more and more AR applications in sales, gaming and more. However, whereas indoor AR is already doing its job quite well using vision tracking approaches, outdoor applications did not really establish the up growth from prototypes to actual business use.

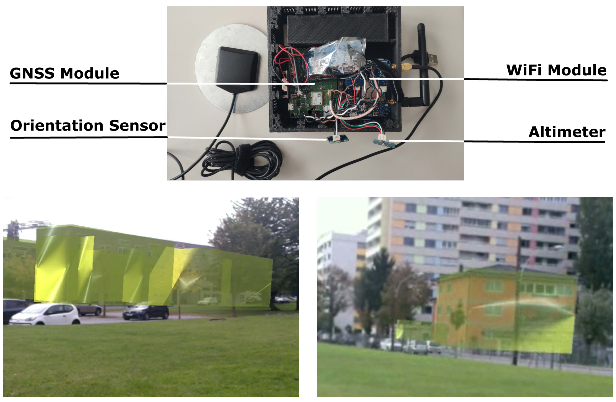

Figure 1: Top: First prototype of the sensor cube labeled with its components. Bottom: GIS data Visualization of building at the university using Unity.

Despite the availability of stable vision tracking methods for urban areas with existing models, other environments additionally require setups with high precise hardware which used to be too expensive for common use. However, nowadays low-cost differential GPS receivers are available for only a fraction of cost to high quality receivers and orientation sensors are also quite cheap. Therefore we designed and assembled a cheap setup for localization in outdoor AR applications. This enables providing low-cost hardware setups, allowing the extension of available mobile hardware for high precise outdoor AR applications. As a result, we created a handy clip-on sensor cube, usable for any mobile hardware, like mobile phones, tablets and head-mounted displays, such as the Microsoft HoloLens for example.

In this paper we present this setup consisting of commercially available components embedded in an 3D printed case: a GPS receiver, an IMU and an altimeter providing localization, combined with an WiFi-module streaming the data to ensure cross-platform usability. In the remainder of this paper, we shortly discuss related work in Sec. 2, followed by the description of the setup in Fig. 3. The hardware setup is evaluated as standalone

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hardware tracking approach and the sensors accuracy is evaluated in detail in Sec. 4. followed by a discussion of the results in Sec. 5.

2 Related Work

Outdoor Augmented reality systems offer lots of use cases. Shin *et al.* [3] break down industrial areas into work flows which can benefit from visualized information and ones which do not benefit. Especially construction engineering processes as Building Information Modeling (BIM), underground structure visualization, outdoor architectural designs, *etc.* seem to have a high chance of profiting from AR applications.

Hardware-based Approaches A great approach for real-time AR access to 4D CAD and BIM information is provided by Hakkarainen *et al.* [14]. The system provides photorealistic augmented visualisations of architectural plans and environment feedback by use of BIM models within a complete mobile setup. This prototype already demonstrated the potential of AR application back in 2008. Schall *et al.* [11] show an approach on visualizing underground structures from geographic information systems (GIS) and evaluated its usability and identified improvements of workflows and better usability with only one-hand-held setups, which could even be improved nowadays by using head-worn devices.

Due to continuing progress in hard- and software, outdoor AR systems got better and handier year after year. A lot of systems were developed in the last 20 years with several approaches. Bostanci *et al.* [5] reviewed the last 20 years of research in AR and depicted the most important concepts. Most popular approaches for indoor AR systems are SLAM and vision based systems. However, outdoor systems also rely on high precise hardware features like GPS modules, accelerometers and gyroscopes but also vision-based approaches and combinations of both are very common.

An early work on outdoor AR applications is Piekarski *et al.* [15], who developed the wearable computer Tinmith-Metro in 2001, which supports the modeling of buildings and other large physical structures and the positioning and visualization of those objects in AR. The system setup consists of a laptop, an Intersense IS-300 tracker for orientation sensing, Garmin 12XL DGPS receiver, a monocular display, an usb video camera, custom designed pinch gloves for controlling the system, a small lcd display for debugging on the back and a battery for powering the system, mounted on a backpack. The accuracy of positioning is between 1 and 5 meters depending on conditions. King *et al.* [6] achieved even better accuracy with a newer version of the Garmin receiver in their system ARVino.

With improving Hardware Schall *et al.* [12] developed a mobile AR system mostly relying on sensor based localization. Smart vidente achieved the possibility to place virtual objects in the real world with great geospatial accuracy. The system setup consists of a tablet PC, which is equipped with a camera, a 3DoF orientation sensor and a Novatel OEMV-2 L1/L2 Real Time Kinematic receiver for achieving an accuracy in centimeter level. Some years earlier Schall *et al.* [10] developed a similar system, using the Novatel OEMV-1 receiver already showing quite accurate positioning. However, smart vidente also had a laser range finder embedded into to setup to provide a 3D cursor for the system, which allows the user to select and move objects. Differential correction data is supplied by the EPOSA reference system, which enables a position accuracy better than 10cm and the orientation sensor provides an accuracy up to one degree.

Hybrid Approaches Reitmayr *et al.* [7] presented an mainly vision based approach. Since GPS quality was not quite reliable, due to shadowing from buildings and signal reflections in urban areas. So their system used an edge-based tracker for accurate localization. For dealing with motion they used gyroscope, gravity and magnetic field measurements. The setup achieved a really good accuracy in an optimal environment, with a deviation of 0.0979m in easting, 0.1463m in northing and 0.1577m in altitude. However, the problem with this setup is that disturbing objects like moving cars can affect the accuracy and it is computationally very intense (compared to GPS , all work is done by the GNSS). The feature detector yields between 200 and 400 features per frame. For tackling this problem, they later extended this approach by using GPS data for initialization and re-initialization to recover from any failures of the vision-based component [8].

Arth *et al.* [2] realized accurate localization for outdoor AR systems by the approach of SLAM. This system did not need any specific hardware but only an ordinary mobile device (Apple iPad Air in their experiments). Normally SLAM only allows the tracking of relative poses, due to the unknown sale of the local SLAM map. However, initialization of SLAM using the built-in sensors and OpenStreetMap data allows accurate positioning. The only requirement for the algorithm is the visibility two vertical building faade outlines to handle sensor errors up to 45deg rotation offset and 40m position offset.

Many approaches rely on hybrid systems, like Jiang *et al.* [1] that combines mode-based vision tracking in urban areas with an gyroscopes for orientation. Another example is the system of Fong *et al.* [16], which combines GPS , orientation sensors and Computer Vision models. While feature matching based on statistical classification is the main component of their system the hardware components are especially used for initialization and re-initialization. A further hybrid tracking approach of Karlekar *et al.* [13] use 3D models for improving tracking accuracy by edge and corner detection. The sensor provided pose is corrected by matching silhouettes of the 3D models using shape context descriptors. When tracking seems to be ac-

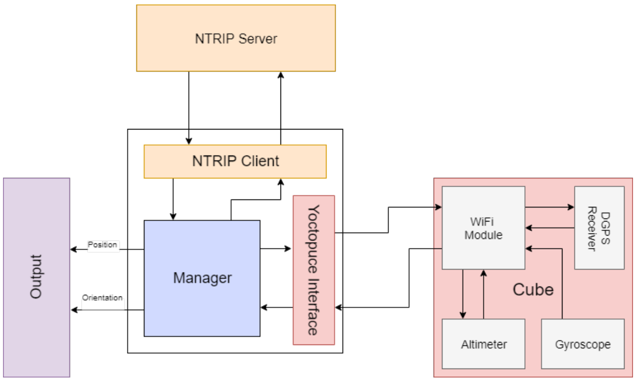

Figure 2: The general architecture of the system, showing its components and the communication of all parts.

curate, the system fully switches to vision tracking using an extended Kalman filter. To counter drifts of edge and corner detections over time due to occlusions in urban areas, an additional Keyframe based tracking approach is used and combined with the model based tacking, managing robust tracking. Also Artemciukas *et al.* [4] describe the combination of orientation senors and kalmar filter to a very robust and accurate approach in orientation estimation, which is a very common solution for improving power of those sensors.

Since pretty good localization can be achieved with low-cost DGPS modules and orientation sensors are getting better and better, a setup for useful outdoor AR applications could be built with cheap solutions. However, these different approaches illustrate pros and cons of vision based and hardware tracking. Furthermore hybrid approaches seem to be most effective and robust way, since hardware tracking is necessary in environments without good features/models to for accurate registrations and is also feasible for initialization for vision approaches in environments with existing models for tracking, where hardware alone is not accurate enough due to noise in urban areas of GPS and IMU .

3 Outdoor Localization Prototype

For developing a low budget outdoor tracking system, the first step was to find cheap sensors, which still fulfills our need of accurate localization. Comparing different hardware with smart phones built-in sensors got us to a first choice of sensors. After selecting individual hardware components, a first prototype was built to be attached to mobile devices and used in outdoor AR applications.

3.1 Hardware

The first setup consists of a common setup for outdoor 6 dimensions of freedom (6DoF) tracking systems. Most important in the setup is the differential GPS receiver, needed for precise positioning in real world, since vision approaches alone are only able to track local positioning and even with available 3D models, real world positioning is needed for initialization. Furthermore, localization in open space environment needs to rely on high precise positioning. Second sensor of the setup is an inertial measurement unit (IMU), providing high accurate real world orientation. Selected was an IMU consisting of a magnetometer, an accelerometer and a gyroscope correcting each other for robust and accurate orientation estimation. The advantage of an external orientation sensor over the mobile device built-in is a more robust and also more accurate tracking, especially for yaw, since built-in magnetometer (compass) are more prone to metallic/magnetic noise. Additionally, an Altimeter was integrated to compensate the GPS 's least accurate positioning in height. These sensors are joined with an WiFi module to provide hardware independent streaming of positioning data, so that it can be combined with all kind of mobile devices such as head-mounted and hand-held devices but it can also be used for tracking any objects like cars and stuff.

Component	Name	Price
GPS Module	uBlox M8P-C94[1]	€150
IMU	Yocto 3d[2]	€50
Altimeter	Yocto Altimeter[3]	€30
WiFi Module	YoctoHub-Wireless-g[4]	€100

Table 1: The Hardware components used for the first prototype and their price.

On the top of Fig. 1, the prototype and labels all installed sensors is shown. Tab. 3.1 exhibits the technical details of the setup. To get an idea of the costs, our cube including all sensors and the 3D print was for less than €500, while in relation a highly precise DGPS receiver, like the Novatel OEMv2 used in the smart vidente setup [12][5], alone is more than €10000.

3.2 Software

The goal was to provide an C++ Library with an easy drag and drop extension for Unity to ensure usability and cross-platform support. A general flow chart of the proposed system is depicted in Fig. 2. The individual components are described in the following.

NTRIP Client: The NTRIP Client is responsible for communication with the NTRIP Server. Requests with the current position are sent to the server and responses with correction data are obtained.

Yoctopuce Interface: The Interface is used for communication with the Sensor cube via WiFi. Callbacks are

[5]Novatel OEMv2 Receiver: `https://www.novatel.com/products/gnss-receivers/oem-receiver-boards/oemv-receivers/oemv-2`

Figure 3: GPS track of a walk through the park, comparing mobile built-in GPS to the uBlox receiver. Green: uBlox Red: LG G5

fired by the WiFi module when sensor data changes. Furthermore correction data and initializations are sent to the cube.

Manager: The manager is used for passing data between the NTRIP Client and the Yoctopuce Interface, preparation of the NMEA position to another output format and providing the current device orientation. It could also be responsible for preprocessing the correction data or postprocessing the NMEA Data or any additional computations.

Cube: The WiFi module is configured to manage communication on sensor cube side. Communication with the uBlox receiver is implemented via an yoctopuce serial hub and the WiFi module is already parsing the NMEA output of the receiver and forwarding all sensor value changes via Callbacks.

The communication with the NTRIP server will be via TCP. After sending an HTTP Request for correction data the server starts streaming this data as RTCM Messages. The correction data are also passed as RTCM messages to the receiver, that decodes those messages on his own, via the WiFi Module using http. Positioning data is provided as NMEA strings from the receiver. The WiFi module decodes these NMEA strings , orientation changes of the IMU and altitude changes of the altimeter and forward data if any changes occur.

3.3 Vision tracking extension

Since Hardware tracking only is still not robust and consistent accurate enough for high precise localization, combining vision tracking approaches with sensor tracking to an hybrid setup would lead to best results. Lots of hybrid systems are described in Reference Sec. 2 and could also be an approach for our current setup. For the first vision extension we stuck on the SLAM approach of Arth *et al.* [2] for the implementation, but while their approach is using OpenStreetMap, we are using specific GIS data.

Algorithm: First of all feature points of buildings are extracted by filtering feature points of the frame image using depth masks of the buildings. Next depth information of feature points can be estimated by back-projecting these onto the building models. Points with abnormal depths are filtered out. Then 3D map points are created and projected smoothly to the next frames to complete the initialization step. Only map points are optimized over the first 50 frames, afterwards the optimizer begins to optimize both three-dimensional points and camera poses. At the moment we have following two error functions for optimization:
One error function is using the building map

$$min \sum P_{vslam} - P_{2.5Dmap}$$

$$min||Ax + By + Cz - (Ax_0 + By_0 + Cz_0)$$

where $Ax + By + Cz + D = 0$ represents a 3D building facade function, $P_{vslam}(x, y, z)$ a reconstructed mappoint from SLAM and $P_{2.5Dmap}$ represents a 3D mappoint on 2.5D building, which is usually a corner of the building.

An additional Error function using the sensor data is:

$$min \sum T_{vslam} - T_s$$

where T_{vslam} is the reconstructed pose from SLAM and T_s the obtained pose of the sensors.

4 Experiments

To show how accurate such a low-cost setup really is, all sensors were evaluated individually in several scenarios to from perfect conditions to the worst conditions. Since its enough evaluations for a whole paper, the most important tests are stated in the following Sections. Furthermore, the standalone sensor tracking was used in a simple GIS visualization application.

4.1 GPS Tests

Starting with an comparison to arbitrary mobile GPS receiver, the first test was tracking a walk through the park using once the uBlox receiver and an LG G5. As shown in Figure 3 mobile built-in hardware drifting very much and most of the time more than 5 meters off, pointing out that mobile built-in GPS are not very accurate by now.

To test the accuracy of the uBlox receiver it is compared with a high precise DGPS receiver, the Novatel OEMv2. For representing the results, received GPS coordinates were converted into UTM. For the respective graphs in the Figures throughout the rest of the document, X refers to *east* and Y refers to *north*. Both receivers were placed side by side with an approximate distance of the antennas of about 2 cm. The reference GPS position was taken from the Novatel receiver. All accuracy measurements are

Figure 4: Environment setup for the compass validation. Left: Map of all reference Points. Middle: Reflective prism on a tripod. Right: Laser Range Finder mounted on the sensor cube.

(a) Deviation Map (b) Error X (c) Error Y

Figure 5: Positioning comparison of uBlox and Novatel receiver for the ideal operation test. First row: Minute 0-5, Second row: Minute 5-10, Third row: Minute 10-15.

calculated with respect to the final measurement of the Novatel receiver (the last measurement in the record).

For this test a wooden platform with open sky view was chosen as location. Due to the absence of any obstacles and full view onto the hemisphere, the GPS positioning is tested under best conditions. The first row in Fig.5 shows the first 5 minutes of the position estimation procedure, the second and third row represent time intervals from 5-10 and 10-15 minutes respectively. The Novatel receiver already starts with an error smaller than one meter and achieves cm level accuracy after about 15 seconds. While the uBlox receiver is starting with quite a large error of more then 2 meters overall, and is reaching cm level accuracy within the first minute. The deviation map of the first 5 minutes shows the position approximation of both devices. Both receivers are performing reasonably well. The maximum error of the uBlox receiver is about 5 cm, with a slightly greater error in Y dimension and a maximum error of 2 cm by the Novatel receiver. Also uBlox s maximum resolution of 2cm can be obtained in figures 5 (a), while the Novatel receiver has a resolution in cm accuracy. However, the uBlox receiver can keep up with the Novatel receiver, as long as a constant accuracy of less than 2 cm is sufficient for a particular use case. This test exhibits the accurate positioning in best conditions, which more than only suffices initial positioning for hybrid approaches, as also accurate enough for high precise positioning in open space environments for hardware standalone setup.

4.2 Gyro especially Magnetometer

Back in 2010 Schall *et al.* [9] point out that orientation sensors often suffer from jitter and external disturbances. Especially the magnetic compass is vulnerable for noise, which is a big problem for accurate orientation estimation. Therefore compass accuracy was tested. To provide an exact ground truth of the bearing values for the compass validation, the setup makes use of UTM (Universal Transverse Mercator) coordinate system and its north directed y axis. Using precise measured reference points (error $<$ 2 cm), shown on the left of Fig. 4 and a setup to provide an exact alignment from one to another point, the validation can be done by easy trigonometric functions as exhibit in Fig. 6. The alignment system consists of two tripods, one with a prism and one the other one the sensor cube combined with an laser range finder to align to the prism. This setup is shown on the right of Fig. 4.

The compass bearing was tracked once per second to check how accurate and how consistent the compass is. The first measurements were made from Point IF-15. The calculated ground truth angle and the compass measurements are shown in Tab. 2. The obtained error seems to be consistent and decreasing on higher distance between the reference points. So it can be assumed that the error contains of a real error summed with an setup error. Since the setup error decreases on higher distance, we can assume that setup errors like not hitting the prism in directly in

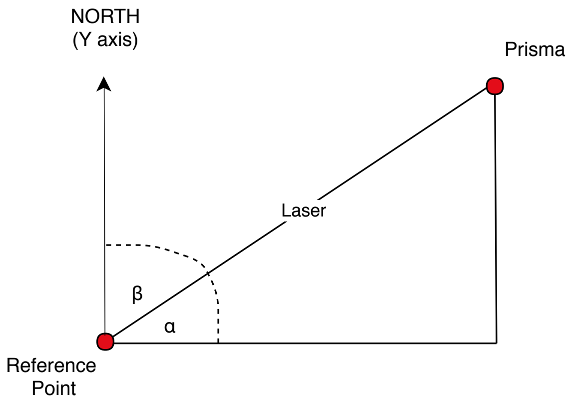

Figure 6: Illustration of north angle calculation making use of the UTM coordinate system, where β corresponds to the north angle.

15 to	ground truth	compass
03	344.7685	343.437
04	280.8829	280.312
14	186.2871	185.812
16	96.085371	96.437
17	85.162329	85.562
18	66.898923	67.312

Table 2: The Obtained compass values of the Yoctopuce 3d and the ground truth northening angle calculated using UTM coordinate system.

the middle are contained in the measured values.However, comparing the obtained errors, a compass error smaller than 0.5 was measured over all, which is quite accurate and robust enough to feed our needs. Moreover, this test was taken without any direct noise by metallic objects, what still leads to outliers especially when walking by cars, so vision extensions would still be needed for urban environments.

4.3 First visualizations

For an first application GIS data are used to visualize buildings within the hardware tracking setup. The sensor cube was mounted onto a Microsoft Surface Pro 3. On the bottom of Fig. 1, some visualizations with high precise localization are depicted. However, hardware standalone tracking is prone to noise and especially compass outliers induce greater errors for visualizations more away, as shown on the left of Fig. 7. Most of the time tracking seem to be quite accurate in such half urban areas, meaning in such cases simple vision tracking approaches, like Key frame based tracking, would suffice a robust hybrid tracking system.

4.4 ORB SLAM

We are currently working on an hybrid tracking extension built on ORB SLAM, as described in Sec. 3. For testing,

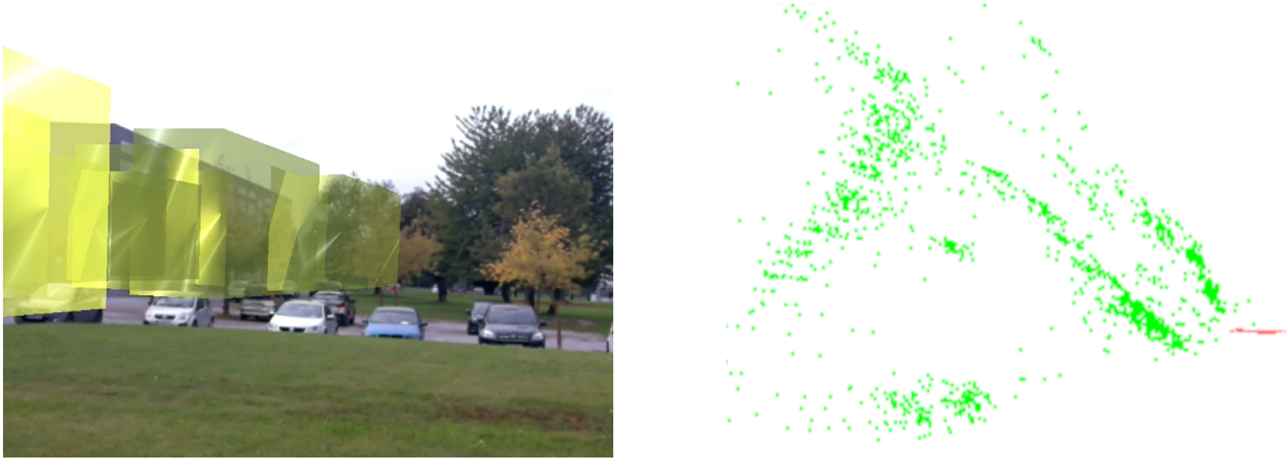

Figure 7: Visualization results. Left: GIS data Visualization of building at the university using Unity, when a compass error occurs. Right: Point cloud of key features (green) and the optimized poses (red) of the test track between reference points IF-07 to IF-08.

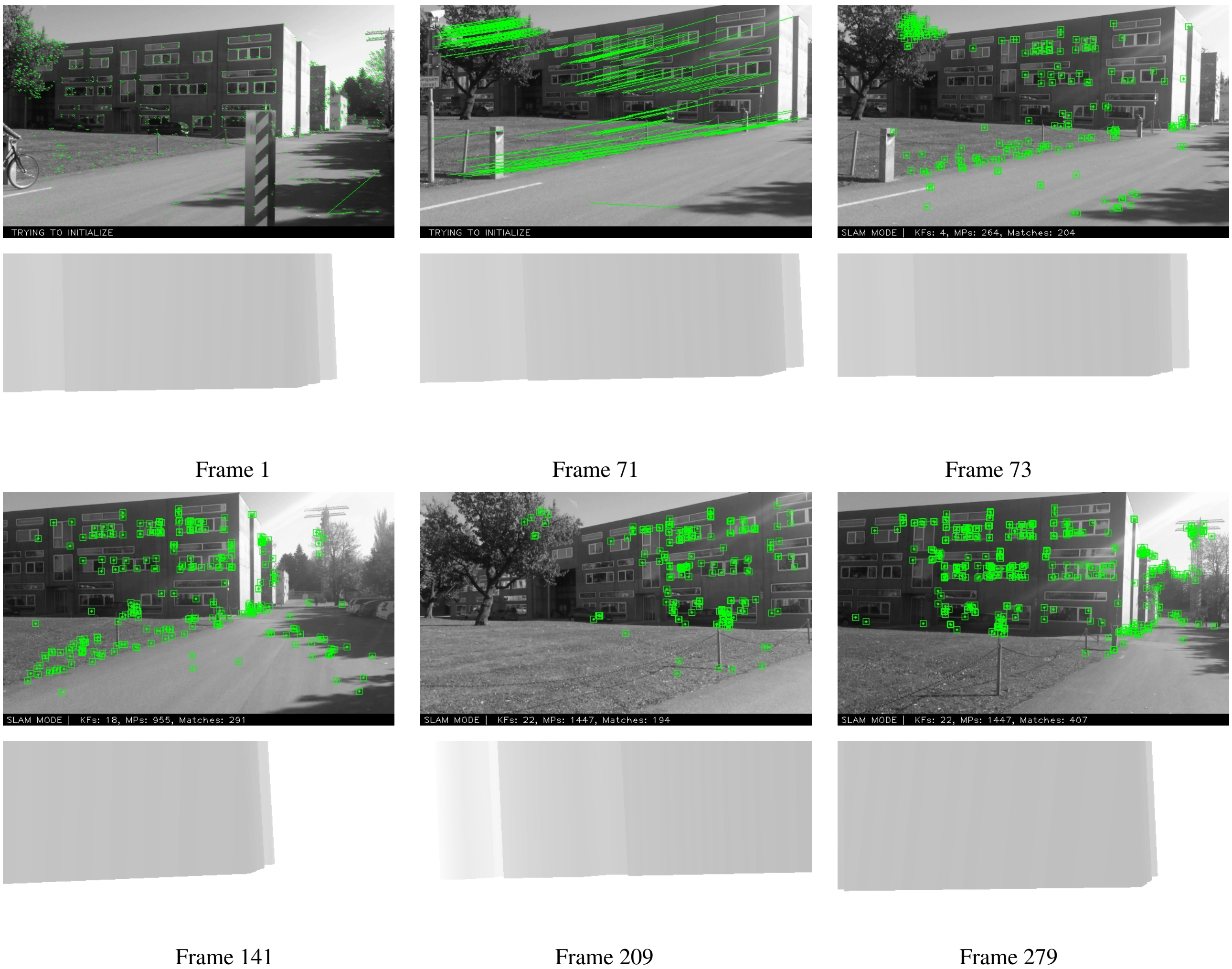

Figure 8: Test run of the ORB SLAM system between reference points IF-07 to IF-08 with visualized key features and the corresponding depth images over several frames. Initialization steps from frame 1 to 71 and applied tracking in further frames.

several tracks between two reference points, as seen in Fig. 4, were recorded with an frequency of five images per second. The frame interval of Fig. 8 exhibit key frames and the corresponding depth images between reference points IF-07 to IF-08. From frame 1 to 72 the initialization step is performed. It takes quite some time, till the system succeed linking from 2.5D map to the real world buildings and initialization is finished. Afterwards tracking is carried out, in Frame 73 to end the tracked key features are visualized and mapped to the corresponding depth images. In this example the building map error function is used for optimization. The right of Fig. 7 shows the point cloud of key features (green) and the optimized poses (red) of the test track. However, initialization still takes some time and the system is not running in real-time by now. Furthermore, the unknown height of the buildings providing a noisy 2.5D map is a cause of errors in the current optimization. This problem is already notable in Fig. 8, where depth images of GIS models do not perfectly fit the real world buildings due to unknown height information.

5 Conclusion

The sensor cube provides accurate and rather robust 6DoF localization. Nowadays cheap hardware can keep up with the high precise setups from former approaches. However, hardware tracking alone can still not guarantee robustness at all time. Especially in urban areas, satellite shadowing and reflection by buildings and other objects can effect GPS accuracy. Similarly, the magnetometer is very likely affected by close metallic objects such as cars. For these reasons, a hybrid tracking approach was chosen to eliminate disadvantages of both vision based and sensor based tracking. We already started with a first concept to extend the setup with a SLAM tracking approach as described in Sec. 3. The hybrid approach already provides reasonable optimization to the sensor setup. Nevertheless, the current SLAM setup is not working in real-time on mobile devices yet and is still in construction. Future steps include the investigation of suitable vision tracking extensions, whether using the current SLAM approach or a different one, *e.g.,* the use of edge fitting. The goal is to create a system which is not only temporarily accurate, but which provides highly precise and robust measurements constantly. Reducing the sensor cube size by designing a board containing all necessary sensors is desirable. Finally, a calibration routine for the cube to the actual camera would be a great extension to decrease possible error sources. To summarize, nowadays cheaper hardware can bring outdoor AR to public use by decreasing costs of such setups. Nevertheless, sensor tracking alone is still not reliable enough for standalone use in scenarios requiring high precision. Therefore hybrid approaches are needed, which rise research costs on implementing real-time tracking on limited computation power mobile devices.

References

[1] B. Jiang, U. Neumann and S. You. A robust hybrid tracking system for outdoor augmented reality. *Int. Symp. on Virtual Reality*, pages 266–275, 2004.

[2] C. Arth, C. Pirchheim, J. Ventura, D. Schmalstieg and V. Lepetit. Instant Outdoor Localization and SLAM Initialization from 2.5D Maps. *IEEE Transactions on Visualization and Computer Graphics*, pages 1309–1318, 2015.

[3] D. H. Shin and P. S. Dunston. Identification of application areas for Augmented Reality in industrial construction based on technology suitability. *Automation in Construction*, 17(7):882–894, 2008.

[4] E. Artemciukas, L. Sakalauskas and E. Zulkas. Kalman Filter for Hybrid Tracking Technique in Augmented Reality. *Elektronika ir elektrotechnika*, 22:1392–1215, 2016.

[5] E. Bostanci, N. Kanwal, S. Ehsan and A. F. Clark. User Tracking Methods for Augmented Reality. *Int. Journal of Computer Theory and Engineering*, 5:93–98, 2013.

[6] G. King, W. Piekarski, and B. Thomas. ARVino - Outdoor Augmented Reality Visualisation of Viticulture GIS Data. *Int. Symp. on Mixed and Augmented Reality*, 2005.

[7] G. Reitmayr and T. W. Drummond. Going out: Robust Model-based Tracking for Outdoor AR. *Int. Symp. on Mixed and Augmented Reality*, pages 109–118, 2006.

[8] G. Reitmayr and T. W. Drummond. Initialisation for Visual Tracking in Urban Environments. *Int. Symp. on Mixed and Augmented Reality*, pages 161–172, 2007.

[9] G. Schall, A. Mulloni and G. Reitmayr. North-centred orientation tracking on mobile phones. *Int. Symp. on Mixed and Augmented Reality*, 9:267–268, 2010.

[10] G. Schall, D. Wagner, G. Reitmayr, E. Taichmann, M. Wieser, D. Schmalstieg and B. Hofmann-Wellenhof. Global Pose Estimation using Multi-Sensor Fusion for Outdoor Augmented Reality. *Int. Symp. on Mixed and Augmented Reality*, pages 153–162, 2009.

[11] G. Schall, E. Mendez, E. Kruijff, E. Veas, S. Junghanns, B. Reitinger, D. Schmalstieg. Handheld Augmented Reality for Underground Infrastructure Visualization. *Personal and Ubiquitous Computing*, 4(13):281–291, 2009.

[12] G. Schall, S. Zollmann and G. Reitmayr. Smart vidente: advances in mobile augmented reality for interactive visualization of underground infrastructure. *Personal and Ubiquitous Computing*, page 15331549, 2012.

[13] J. Karlekar, S. Z. Zhou, W. Lu, Z. C. Loh, Y. Nakayama, and D. Hii. Positioning, tracking and mapping for outdoor augmentation. *Int. Symp. on Mixed and Augmented Reality*, page 175184, 2010.

[14] M. Hakkarainen, C. Woodward and K. Rainio. Software Architecture for Mobile Mixed Reality and 4D BIM Interaction. *25th CIB W78 Conference*, pages 1–8, 2009.

[15] W, Piekarski and B. H. Thomas. Tinmith-Metro: New Outdoor Techniques for Creating City Models with an Augmented Reality Wearable Computer. *Int. Symp. on Wearable Computing*, page 3135, 2001.

[16] W. T. Fong, S. K. Ong and A. Y. C. Nee. Computer Vision Centric Hybrid Tracking for Augmented Reality in Outdoor Urban Environments. *Int. Conf. on Virtual Reality Continuum and its App. in Industry*, pages 185–190, 2009.