Mobile Mapping System for High-Resolution Imaging

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ABSTRACT

Mobile mapping vehicles are rapidly gaining in importance as they accelerate the digitization of road surroundings. This data is indispensable for municipalities as a quantification of the state of the art as well as for planning of infrastructure projects. Fast laser scanners for 3D point cloud generation and high-resolution cameras are becoming more readily available, increasing not only data quality but also the amount of acquired raw data. Thus, taking advantage of modern computing power and developing strategies for data handling is getting crucial. In this paper, a measurement vehicle is presented that handles up to 4 GB/s of raw data. The vehicle is based on a modular system platform from the Fraunhofer Institute for Physical Measurement Techniques IPM. A Clearance Profile Scanner built by Fraunhofer IPM scans a 345° area almost perpendicular to the driving direction and delivers 3D data with 2 MHz sampling rate and millimeter precision. A high-end positioning solution provides the absolute location at any time. Two off-the-shelf panoramic cameras provide images for standard use cases. As a special feature, six 31 megapixels CMOS cameras acquire high-resolution image data from which a panoramic image can also be computed. A special network controller running custom software handles the large amount of network traffic. Additionally, a sophisticated on-board data processing pipeline was developed which performs image compression on a graphic card before the data is stored in permanent memory. Thus, all raw data can be managed and stored for driving speeds up to 144 km/h.

Keywords: mobile mapping, panoramic image, high-resolution images, point cloud, graphic card, GPU

1. INTRODUCTION

The digitalization of the environment is rapidly gaining in importance. Urban areas and infrastructure must be measured and digitized to plan maintenance as well as new projects. High-quality data is required to automate the corresponding processes. Only a digital data basis allows for software to automatically extract relevant parameters or to compare the data over several epochs (e. g. for deformation analysis)[1]. As an example, data from road surroundings can support the planning of infrastructure projects like the roll-out of glass fibres for telecommunication[2]. Also, the state of roads can automatically and quickly be assessed[3,4]. The demand for this data is quickly growing so that the usage of mobile platforms like drones and cars, called mobile mapping, is getting more important. These platforms enable a much faster data acquisition.

Fast laser scanners for 3D point cloud generation and high-resolution cameras are becoming more readily available, increasing not only data quality but also the amount of acquired raw data. A single kilometer of a digitized road can result in many gigabytes of data. The latest computing power and smart data-flow strategies are necessary to handle these large amounts of data. Fraunhofer IPM has established a modular platform to adapt to these needs. Based on this, a new measurement vehicle was developed with two main features: The system is based on a small vehicle to be able to easily map central urban areas. And it features a system of six high-resolution cameras for high-quality visual data. A data processing flow was developed that efficiently handles and compresses up to 4 GB/s of raw data. Standard mobile mapping systems can also be mounted on small vehicles, but they do not achieve the image resolution of the system presented here[5,6].

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2. MEASUREMENT INSTRUMENTATION

2.1 Basic setup

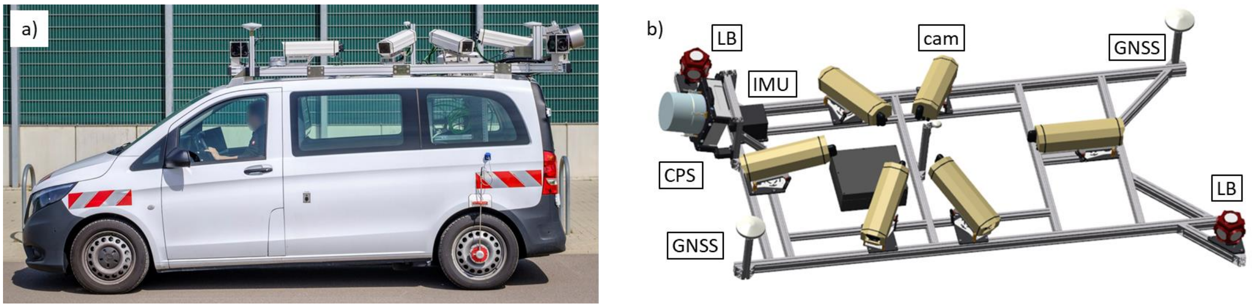

Figure 1. (a) Measurement vehicle with sensors. (b) Schematic drawing of the roof-mounted sensors. Two GNSS antennas and an inertial measurement unit (IMU) are part of the positioning system. Two Flir Ladybug 5+ panoramic cameras (LB) and six high-resolution individual cameras (only one labelled as “cam”) capture images. A laser scanner (CPS) gathers 3D information.

The measurement system is mounted on a vehicle of type Mercedes Vito. Compared to a Mercedes Sprinter, which is often used for these complex setups, this is significantly smaller. Figure 1a shows the measurement vehicle equipped with all sensors. A smaller vehicle is better suitable for navigating in small streets, especially in central urban areas. On the other hand, there are tighter constraints like roof load (max. 150 kg) and available space for racks and general infrastructure in the back of the vehicle.

Figure 1b provides a schematic overview of all sensors mounted on the roof of the vehicle. A position and orientation system is installed which is used to capture the precise trajectory (Applanix POS LV 420). It consists of two GNSS antennas mounted at maximal distance, an inertial measurement unit (IMU), and an odometer mounted at the left back-wheel. The trajectory is recorded with 200 Hz.

A LiDAR (light detection and ranging) scanner, the clearance profile scanner (CPS) built by Fraunhofer IPM, is mounted at the back of the vehicle. This sensor is used to capture a 3D representation of the streets and their surroundings[3,4,7]. It is a profile scanner with a deflection mirror rotating at 200 Hz and covering about 345° scanning angle. It is mounted with its scanning plane almost perpendicular to the direction of travel to better capture structures like traffic signs and building corners. The CPS has a sample rate of 2 MHz and millimeter precision.

Several camera systems are mounted to visually capture the surrounding. Two 360° panoramic cameras (Flir Ladybug 5+) with a resolution of 30 megapixels (MP) and a large viewing angle are installed to always get an overview of the full scenery. The cameras are mounted at the front-right and back-left positions of the mounting frame. This way, a vehicle-free panoramic image can always be constructed. Additionally, six high-resolution cameras with 31 MP each are mounted. This system in described in detail in the next section (2.2). Image acquisition of all cameras is triggered after a fix (but adjustable) distance, typically 5 m.

2.2 High-resolution imaging system

For a detailed visual representation of the street scenery, six high-resolution RGB cameras are installed on the roof (Flir ORX-10G-310S9). Each camera has a 31 MP image sensor and is connected to the computing infrastructure via a 10Gig Ethernet connection. High-quality objective lenses (Zeiss Interlock 2,8/15 ZF-1) with a viewing angle of 85.8° (sensor diagonal) and high optical transmission (more than 85 % for the largest part of the visible spectrum) are used.

All cameras are shielded by a protective housing. As shown in Figure 1b, they are mounted symmetrically with an angle of 60° between each camera and slightly facing downwards. The front camera is mounted flat and moved forward to not see the nose of the vehicle. The camera positions guarantee that within 3 m distance from the vehicle an overlap between neighbouring cameras is given. Given the external calibration, a highly resolved panoramic image can be computed.

3. DATA ACQUISITION AND PROCESSING

3.1 Data acquisition and processing of the basic setup

The CPS continuously acquires 40 MB/s of raw data, independent of the driving velocity. The two panoramic cameras are typically triggered every 5 m, which results in a data rate of approximately 170 MB/s at a velocity of 50 km/h. The handling of the extremely large amounts of data from the individual cameras is described in the next section (3.2). All data is precisely time-stamped using network time protocol (NTP), precision time protocol (PTP) and pulse per second (PPS). All data is locally stored on SSDs in the vehicle.

Given the trajectory from the positioning system a georeferenced point cloud can be calculated. All sensors have a full inner and outer calibration so that camera images and point clouds can be overlayed. Semantic information can be extracted from the individual images using a trained neural network and projected into the point cloud. A more detailed information of this process can be found in earlier publications[2,3].

3.2 Data acquisition and processing of high-resolution images

At each image trigger approximately 180 MB of raw data (or approximately 540 MB of RGB data after debayering) are generated from all six high-resolution cameras. To handle these large amounts of data a multi-stage data-processing concept has been developed. The concept was designed so that a maximum frame rate of 8 Hz, which corresponds to a driving velocity of 144 km/h, is supported.

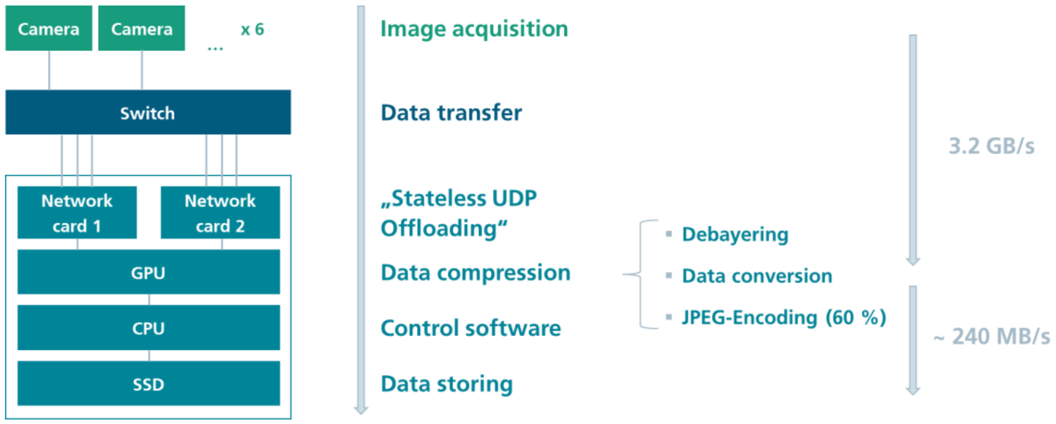

Figure 2. Data flow and data sizes of the high-resolution images. The given data rates are calculated for the max. supported frame rate of 8 Hz.

Figure 2 shows a schematic representation of the data flow. Acquisition of the raw image data takes place at the sensor level. From there, the data is transferred via a 10Gig Ethernet switch to a high-power computer. Two special network cards (Myricom MVA network adapter) handle the UDP network stack. This concept is called “stateless UDP offloading” and assures the required network performance while reducing the load on the CPU/GPU at the same time. Images are then transferred to the GPU using direct memory access (DMA). Custom Cuda code is running on a Nvidia RTX3090 graphics card performs mainly three processing steps: (i) Debayering of the images; (ii) Data conversion from YUV to BGR; (iii) JPEG-encoding of the images to 60 % quality. Additionally, a downsampled version of each image is calculated which can be live displayed in the data acquisition software of the vehicle. Finally, the data is stored on solid state drives (SSD). This approach reduces the data rate from a maximum of 3.2 GB/s (RGB images at 8 Hz) to a manageable rate of about 240 MB/s.

3.3 Quality of resulting high-resolution images

To assess the quality of the resulting images a comparison was performed. A target chart with Aruco samples of two different sizes were built and positioned on the ground at a fixed distance of approximately 10 m in front of the vehicle. First, an image was acquired using a reference system with a standard camera (AVT Prosilica GT2460C with 5 MP and objective lens Kowa LM5JC10M). Then an image of the same target from the same distance was acquired using the high-resolution camera. The resulting images are shown in Figure 3. The increased image quality of the high-resolution image can clearly be seen as edges appear sharper and smaller details can be resolved.

Figure 4 shows a sample image from the front-right camera from a test drive. It shows a house front with entry at a distance typical for urban areas (street – green stripe – sidewalk – house). In the inset a zoomed-in view on the entry of the house is shown. The house number is well resolved and even the number of doorbells can still be counted. Also, there are no distortion artefacts or color aberrations visible in the image.

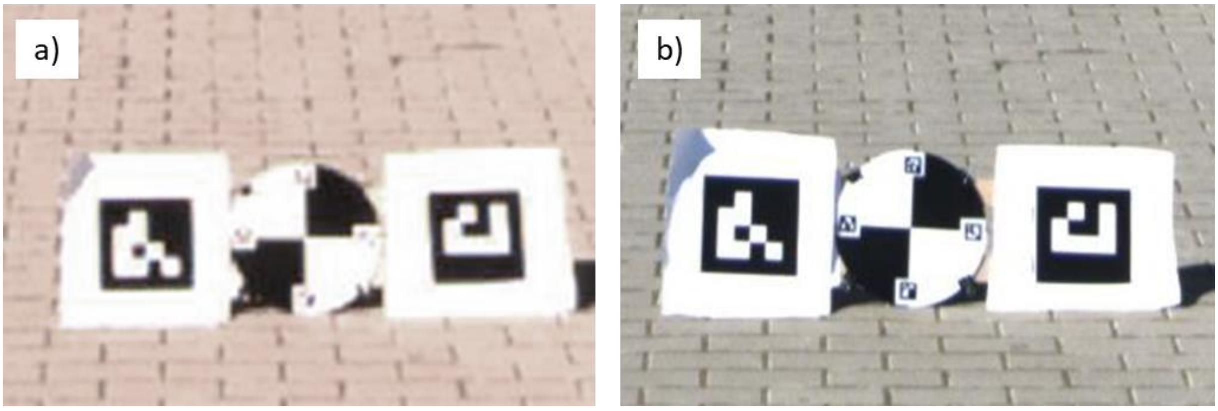

Figure 3. Comparison of the optical resolution using an Aruco sample target at a distance of about 10 m: (a) Standard camera and objective lens (AVT Prosilica GT2460C with 5 MP and objective lens Kowa LM5JC10M); (b) Camera and objective lens used in this system (Flir ORX-10G-310S9 with 31 MP and objective lens Zeiss Interlock 2,8/15 ZF-1).

Figure 4. Sample image of the front-right camera of an arbitrary house front. The inset shows that the house number is well visible and even the number of doorbells is countable in this case.

4. CONCLUSIONS

A novel mobile mapping vehicle for the surveying of road and their surroundings was presented which is optimized in size for small and narrow urban areas. It features a precise positioning system, a LiDAR sensor (CPS) for 3D information, two panoramic cameras for visual overview, and a system of six high-resolution cameras for high-quality visual information. All data is time-stamped, synchronized, and georeferenced and can thus be overlayed in any post-processing step. A concept for handling the large amounts of data from the high-resolution cameras was developed, which allows the acquisition of 180 MP of image data with up to 8 Hz. The increased resolution of these images guarantees high quality when digitizing street infrastructure.

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