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Visual Odometry For Industrial Cable Laying

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Abstract. *In order to support broadband network expansion in rural areas, the LAYJET Micro-Rohr Verlegegesellschaft has developed a highly automated cable laying technology based on a Fendt 936 tractor as the carrier vehicle and a milling machine with an integrated cable laying unit [3]. Operating at a speed of approximately 1kph, LAYJET is able to lay cables of several kilometres of length per day along of existing roads. The position of the cable needs to be precisely surveyed for documentation purposes, which is a time consuming and costly process. LAYJET is therefore equipped with a high-end GNSS RTK positioning system (TRIMBLE NetR9). In areas with bad GNSS signal reception or even complete GNSS outage (e.g., roads through a forest) an alternative positioning method is needed. JOANNEUM RESEARCH and the surveying office Höppl / Graz have therefore developed a calibrated stereo camera setup triggered by an odometer which allows reconstructing the trajectory of the GNSS antenna using visual odometry (VO).*

1. Introduction

VO is perfectly suited to reconstruct the trajectory of (very) slow moving vehicles as the LAYJET tractor as the drift error is dependent only on distance but not on time (as it is the case for Inertial Measurement Units (IMU)). Using a calibrated stereo camera system also allows determining the scale correctly without additional measurements [4]. In the following we describe the camera system and the implemented VO workflow and show first results from a LAYJET production run.

Figure 1. Example for a left and right camera view of the LAYJET camera system during operation.

2. Method

The stereo camera rig consists of a very stable steel bar carrying two camera housings separated by a baseline of 1.7m. The camera rig is mounted on top of the tractor at 3m height looking backward and tilted down by approximately 20 degrees. SONY Alpha 7 consumer 24 MPixel cameras equipped with 20mm lenses have been selected having a stable inner orientation in mind (auto focus can be switched off, no image stabilization). Calibration is done at the measurement lab of the Institute of Engineering Geodesy and Measurement Systems (IGMS) at TU Graz using the Remote Sensing Graz (RSG) software of JOANNEUM RESEARCH [2].

During field operation of the LAYJET system the stereo cameras are triggered at a fixed spacing of 2m $\pm$ 2cm by using the integrated odometer of the Fendt tractor (see Figure 1). This allows stable image trigger also in absence of a reliable GNSS solution. Images and GNSS positions (if available) are stored onboard and are transferred each day to a cloud storage from where they can be accessed in the surveying office for further processing.

Another software tool developed by JOANNEUM RESEARCH scans the data of each mission and decides for which sections the trajectory has to be im-

Figure 2. Template of the GNSS antenna (left) and best position found in the right image.

proved due to bad GNSS quality or if there are antenna positions missing due to GNSS outages and need to be derived from VO solely. It is important that there are GNSS positions available before and after an outage has occurred to ensure that the VO trajectory is correctly oriented and placed w.r.t. the defined coordinate system (UTM). One issue that had to be solved is to mask out all areas in the stereo images covered by the tractor or milling machine itself as this would deteriorate the VO process significantly and often caused complete fail of the VO solution.

The GNSS antenna is mounted straight above the position where the cable is laid at a known height offset. It is therefore necessary to determine the exact 3D position of the GNSS antenna which can move relatively to the camera system. This is solved by automated detection and measurement of the GNSS antenna in both stereo images using an advanced template matching process (see Figure 2). GNSS positions of good quality are introduced as ground control points (GCP) in the adjustment process. If the GNSS position is inaccurate or even unknown the 3D position of the antenna is reconstructed by using the stereo image measurements of that event.

The VO workflow has been implemented by using the Agisoft Metashape v1.5.4 software [1] and its Python scripting capabilities. Importing of the images, correcting image distortions, applying image masks, feature point extraction, image matching and photogrammetric triangulation are fully automated by the script. The reconstructed camera positions and derived GNSS antenna positions can be inspected using the Metashape GUI and QC reporting tools. If the expected accuracy level has been reached the GNSS antenna position are exported to an ASCII coordinate file.

3. Results and Conclusion

The VO workflow has been tested with data from a LAYJET production run collected in Germany. The road passes through a forest which causes bad GNSS signal quality and a low number of visible satellites (in addition the RTK correction signal has been lost). The estimated position accuracy is therefore strongly reduced to about $\pm$ 2m. The photogrammetric bundle adjustment uses the GNSS solution as approximate positions and the well-defined relative geometry of the stereo pairs and consecutive stereo models to improve the accuracy at least by a factor of 10-20.

Figure 3 shows the reconstructed trajectory of the stereo rig and the derived GNSS antenna positions for 50 trigger events (section of 100m length). The sparse 3D point cloud generated during the VO process can be easily improved by an additional dense matching step which allows to inspect the environment and cable routing more closely.

First test evaluations have shown a throughput of about 10 stereo models per minute (50min per km) on an Intel workstation equipped with 16GB RAM and a NVIDIA GeForce GTX 1660 Ti GPU which should allow for overnight processing of the data collected on one day.

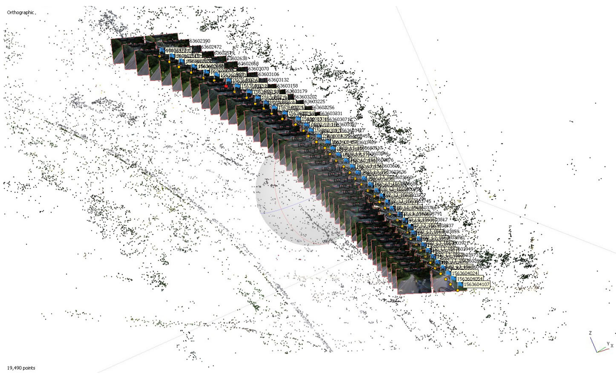

Figure 3. Path of the LAYJET tractor reconstructed using a VO workflow implemented in Metashape.

The VO system described in this paper derives absolute orientation angles solely from GNSS positions, which is straightforward for the heading angle but also works for roll and pitch as long as there are turns included in the trajectory. In case of exactly straight road sections the pitch angle is not defined and has to be set to zero. As the road cross profile inclination can be assumed to be in the range of $\pm$ 3deg this causes a lateral position error of up to 15cm (GNSS antenna height $\sim$ 2.5m).

For longer GNSS outages the estimation of the roll angle degrades with distance which can lead to significant height errors in case of steep descents. It is therefore recommended to integrate an additional inclinometer to measure roll and pitch angles at a precision of about $\pm$ 1deg in a next version of the LAYJET VO system.

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