Leica RTC360: SLAM in Terrestrial Laser Scanning

White Paper

3D Reality Capture

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Simultaneous Localization and Mapping (SLAM) in Terrestrial Laser Scanning

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1. Summary

Terrestrial Laser Scanning (TLS) is now an established technology that is used in a variety of applications. The technological development over the past few years has made laser scanners faster, more accurate and easier to use, making scanning data acquisition in the field more efficient than ever before. An issue that still presents itself as a hurdle for many potential users, is the registration of the scan data. In addition to the increasingly efficient data acquisition in the field, this typically represents a complex second work step in the office. The Leica RTC360 3D Reality Capture solution addresses this problem by fully automating the registration process and delivering actionable results directly in the field. The core technology that is used is based on the Simultaneous Localization and Mapping (SLAM) method, which is integrated in the "Visual Inertial System (VIS)" of the RTC360 laser scanner.

This white paper provides a brief overview of the RTC360 solution and goes into more detail on how the VIS sensor works.

2. Leica RTC360 3D Reality Capture Solution

Leica Geosystems introduced the "Leica RTC360 3D Reality Capture Solution" in June 2018.

This highly automated, intuitive laser scanning solution designed for maximum productivity consists of:

- The RTC360 3D laser scanner
- The Leica Cyclone FIELD 360 mobile-device app for automatic scan registration in real time and quality control in the field
- The Leica Cyclone REGISTER 360 post-processing office software to seamlessly integrate the resulting 3D model into the subsequent work processes and evaluations
(Fig. 1).

The special features of the solution include:

- Capture high resolution scans including spherical High-Dynamic Range (HDR) images in less than two minutes
- Complement the recorded scan data in the field with additional information (photos, videos, text, etc.)
- Automatic recording of station-to-station movements to pre-register scans without manual intervention in the field
- Automatic post-processing of data in the office in Cyclone REGISTER 360

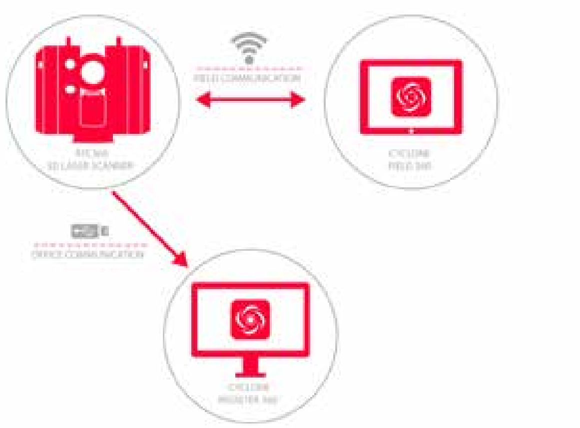

Fig. 1: Leica RTC360 3D Reality Capture Solution.

2.1. Leica RTC360 "Smart Registration (SmartReg) Workflow"

A key feature of the RTC360 solution is the ability to automatically pre-register scans directly in the field and visualise the results using the Cyclone FIELD 360 mobile-device app before the final registration takes place in Cyclone REGISTER 360 office software. Unlike most scanning systems, in which two successive scans are recorded in more or less random local coordinate systems and then have to be transformed into a common coordinate system using complex registration procedures, this step happens automatically with the RTC360. The result is shown symbolically in Fig. 2. The typical result of two successive scans with traditional scanning systems is shown on the left, while the right side shows the result with the RTC360 solution, in which the two scans are automatically available in their correct relative position and orientation after data acquisition.

This "Smart Registration Workflow" (also known as SmartReg) is largely based on the ability of the RTC360 laser scanner to independently and automatically determine its current position and orientation relative to the last setup. This is done with a multi-sensor system; the "Visual Inertial System (VIS)" which is described in more detail below.

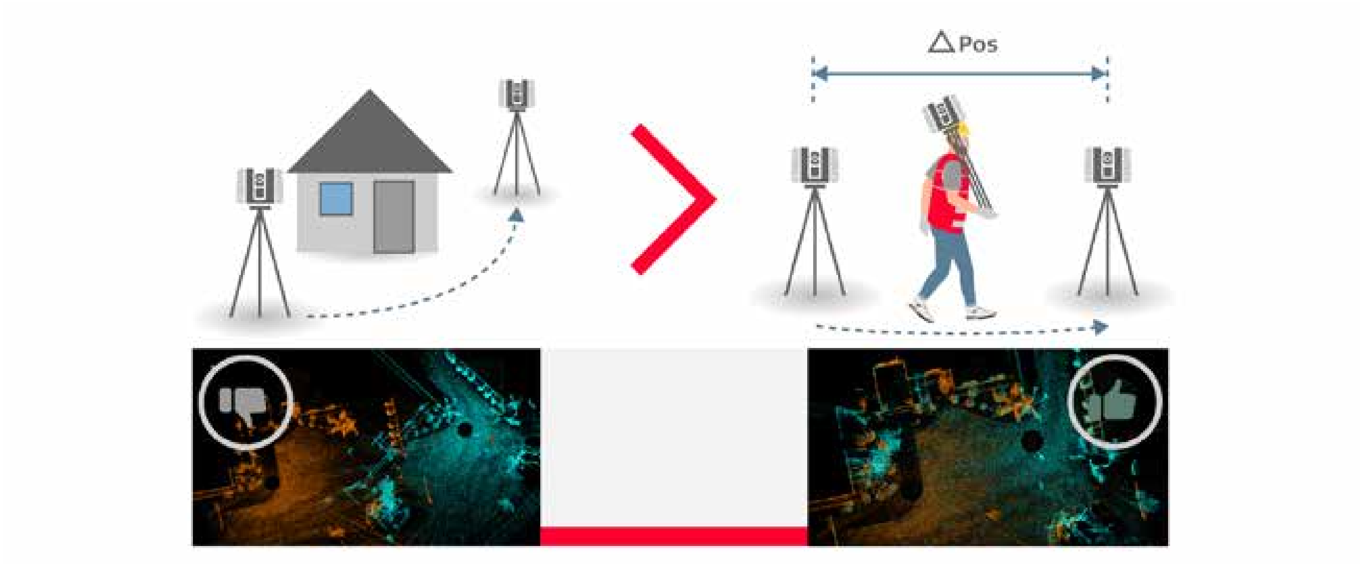

Fig. 2: Automatic pre-registration with the RTC360 solution.

3. Visual Inertial System (VIS)

3.1. Objective

The task of the Visual Inertial System (VIS) is to determine the relative position and orientation in space between two successive positions of the laser scanner. Based on this information, the point cloud recorded at the second setup position can be rotated and shifted to match the first and hence an automatic pre-registration, i.e. a geometrically correct combination of the two point clouds can be achieved. In addition to a representation of the combined point cloud and thus the situation already recorded in the field, the pre-registration also serves as a starting value for high-precision registration later in the office.

3.2. Measuring Principle - Visual SLAM

The functionality of VIS is based on the principle of Simultaneous Localization and Mapping (SLAM).

SLAM is generally based on a fusion of different sensor data in a Kalman filter, whereby the type and number of sensors used can differ depending on the method. VIS falls into the category of "Visual SLAM" methods, so it is primarily based on image processing methods and the detection and tracking of natural features in camera images.

3.3. Sensors

VIS consists of five cameras and an Inertial Measurement Unit (IMU). The distribution of the cameras is chosen so that the entire visible part of the sphere around the laser scanner is covered. Four of the five cameras are located in the corners of the laser scanner, the fifth camera is attached to the top of the scanner and points to the zenith. The IMU is located directly inside the laser scanner housing (Fig. 3).

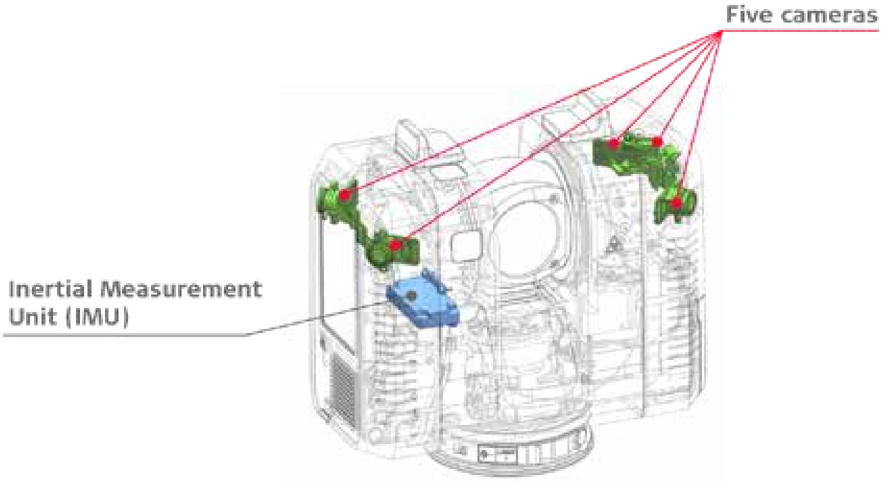

Fig. 3: Visual Inertial System (VIS) sensors.

3.4. Measuring Procedure

SLAM continuously and alternatingly determines:

- A new pose, i.e. the six degrees of freedom of the laser scanner determined by a spatial resection based on 3D points from the map (localization)
- Including the new pose, determining further 3D points through a forward intersection and expanding the map accordingly (map creation)

At the beginning, the map is initialised by selected 3D points from the first scan. For these points, optically significant features with high contrast in the image such as corners and edges are selected. Their change in position in the camera images during the movement of the scanner can be determined robustly using a feature tracking method. Fig. 4 shows an example of detected features in the five VIS cameras (the picture below on the right shows a reference picture with a colour camera).

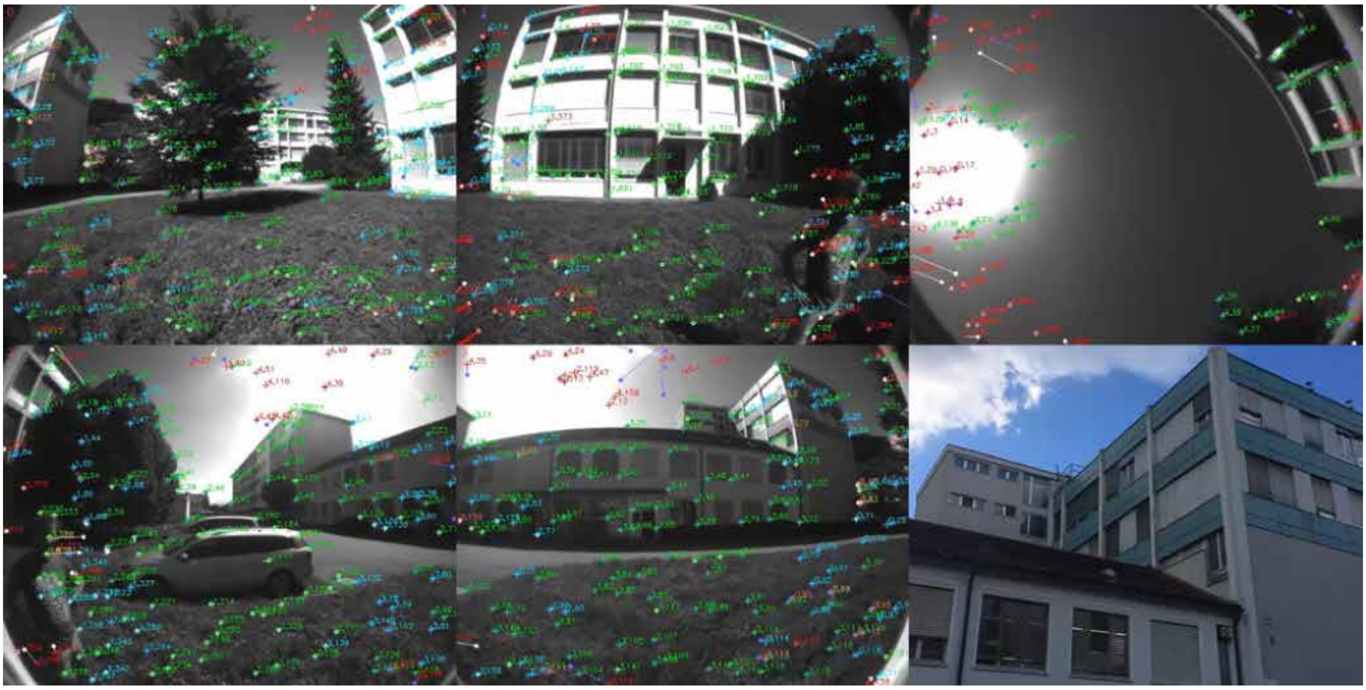

Fig. 4: Feature extraction in VIS camera images.

After initialisation, there are a number of 3D points with their corresponding feature points in the initial images, for which their position can be determined in the following images using feature tracking.

If the scanner is moved, the new pose of the scanner can be calculated based on the 3D points and the corresponding feature points using a spatial resection known from photogrammetry.

The movement changes the immediate surroundings and some of the feature points will no longer be visible in the camera images, as they e.g. can be covered by other objects. Therefore, the image data is continuously analysed for new, significant features, which are then included in the set of feature points. As soon as a new feature point can be observed from at least two poses, the corresponding 3D point is determined via a forward intersection and added to the 3D point map. This constant expansion is intended to ensure that there are always sufficient 3D points available to determine a new pose.

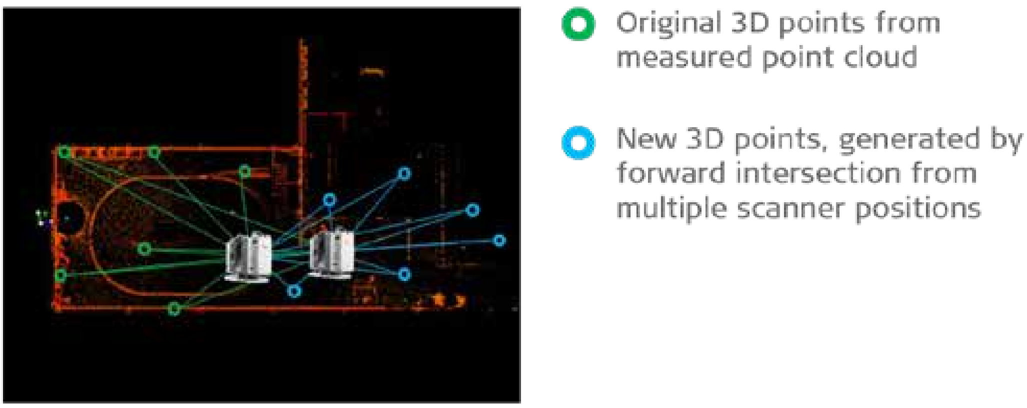

Fig. 5: Visually inertial navigation.

In parallel to the evaluation of the camera data, the accelerations and rotation rates are recorded using the IMU. These measurements are fused with the poses from the image evaluation in a Kalman filter. Specifically, the prediction is carried out with the data of the IMU and the correction with the poses resulting from the image processing.

As already mentioned, the poses of the SLAM are determined one after the other and thus the movement of the scanner (localisation) and at the same time the map on which the pose determination is based on is expanded (map creation). At the end of the movement, i.e. if the second setup position is reached, all poses, including all feature observations, are subjected to a global optimisation process by means of a bundle block adjustment, thus increasing the accuracy.

A further improvement in accuracy is achieved by performing a cloud-to-cloud registration of the two point clouds after the scan at the second setup position. With this optimisation, the end pose is corrected again by minimising the distances between the two point clouds in the overlap area.

3.5. Accuracy & Robustness

The design of VIS is intended so that the deviation of the estimated position amounts to a maximum of 5% of the path length between the two viewpoints. This accuracy requirement is selected in such a way that, with sufficient scan overlap, it allows a sufficiently accurate starting value for an automatic cloud-to-cloud registration.

In internal tests, this accuracy was reliably met in various application scenarios and under a wide variety of conditions. The most challenging conditions during these tests included quick scene and light / shadow changes, e.g. when passing through doors from the inside to the outside, jerky movements when carrying the scanner and environments with little lighting or few natural features.

Although VIS proves to be extremely robust even under such conditions, there are natural limits for every image-based system because it relies on the detection of reliable features in its environment. Where this is not possible, e.g. in complete darkness, no pose can be calculated. In our extensive tests, this only happened in absolute edge cases. In the rare case that VIS cannot deliver a reliable position, the Cyclone FIELD 360 mobile-device app provides a simple, visual method in which the last point cloud created can be moved to its desired position and rotated with simple touch-screen gestures.

4. Conclusion

Although modern laser scanners are becoming more and more powerful and easier to use, scan registration still represents a major obstacle in the processing of scan data, especially for new users. The RTC360 3D Reality Capture Solution automates the registration process using a combination of coordinated components, the RTC360 laser scanner, the Cyclone FIELD 360 mobile-device app and the Cyclone REGISTER 360 post-processing office software. At the heart of the RTC360 "Smart Registration Workflow" (SmartReg) is the ability of the scanner to determine its relative positioning and orientation in space using a Visual Inertial System (VIS). This is done fully automatically without the user having to trigger certain processes or having to follow special rules of conduct when using the scanner. The measuring principle of VIS is based on the Visual SLAM method, in which after an initialisation step, natural features of the environment are continuously detected and tracked using cameras and image processing algorithms, and relative poses are estimated from them. Tests during the development of the system have shown that the system delivers results with high robustness that are accurate enough to fully automate the registration process.

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