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Bridge mapping for inspection using an UAV assisted by a total station

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Abstract. In this paper is presented the use of a Total Station as a ground truth to improve the 3D reconstruction of a bridge. The odometry is composed by the XYZ position of the Total Station and the IMU orientation. Under the bridge there is not GPS signal, so that is a reason why use a system like that to estimate position accurately. The camera used to get the map is a Kinect from Microsoft.

Keywords: Total Station, ground truth, UAV, odometry, mapping, bridge

1 Introduction

The UAVs (Unmanned Aerial Vehicle) have become a very useful technology for doing autonomous tasks in a short time. Nowadays, this field continues growing and we can even begin to see the results in areas such as aerial filmography and agriculture.

An interesting area of the use of UAV's is the inspection of places where the access for people is difficult. These can be environmental catastrophe areas or just areas where, due to their orography, access to them is impossible using ground vehicles. UAV's allow to access remotely these areas and, depending on the hardware carried onboard, visualize the place, create a map, analyze the environment and so on.

Positioning UAV's on the space is very important. This will allow them to fly in autonomous mode or even create a map at the same time, also know as Simultaneous Localization and Mapping (SLAM). However, there are still environments where the UAVs can't positionate themselves well with the actual positioning systems. This is for example in situations of low visibility (when using visual systems) or where there is not GPS signal. In these cases, it's dangerous to use the UAV in autonomous mode and it will probably be necessary the intervention of a flight operator. Moreover, if the GPS information is incorrect it can distort the local state estimation. Thus, if it is used in the software to create a 3D model it can produce sifts and missalignments.

Instead of relying the positioning system on the GPS, it can be improved combining several methods. This will help the software to overcome the GPS errors, so improving the positioning system and hence for the performance of UAV's tasks as for example a full 3D model reconstruction.

This paper focus on bridge 3D reconstruction, which is important for inspection tasks where the access to the bridge is difficult. This models generated are typically used to visualize defects on the bridge remotelly.

To do this, we will map a 3D model of the bridge using an onboard camera that will give us a pointcloud. Due to being under the bridge, the system will not have GPS positioning (Global Positioning System). This is by the reinforced concrete that compose the bridge, since it hinders a good GPS signal. To solve this problem, a Leica Total Station will be used which will facilitate a local reference for positioning of the UAV in the space.
In addition to he total station the IMU (Inertial Measurement Unit) information of the autopilot is used too. The combination of both systems remarkably improve the 3D reconstruction.

The remainder of the article is structured as follows:

– Section 2 introduces the state of the art.
– Section 3 explains how to use the Total Station as a ground truth and the basic configuration of the used system.
– Section 4 details how is alignment process solved.
– Section 5 explains the results and the proceduce followed to perfom the experiments.
– Section 6 ends with the conclusions of the article.

2 State of the Art

As mentioned above, accurate positioning with an UAV can become a complex problem. There are currently many additional systems that allow the positioning of an UAV to be relatively accurate. One of the sensors used is the optical flow [1]. This sensor allows, with the help of a camera, to measure the relative movement of environment relative to the UAV. Usually the camera is placed facing down.

Another widely used sensor is ultrasonic [2]. It's less accurate than the optical flow, instead, it cost less money and are easier to implement. The measurement obtained with this system usually has interferences and can depend a lot on the environment. However these ultrasonic sensors are widely extended in commercial UAVs for amateur pilots.

Something less common but also interesting are the systems based on signals and communications, also kowns as Range Only Simultaneous Localization and Mapping (RO-SLAM). An example are the Signals of Oportunity (SOP) that can be emanating from a cellular tower [5]. The authors demonstrate that fusing

SOP pseudoranges in a GNSS-SOP-INS framework produces a better solution than a traditional GNSS-INS framework. Another example are the LTE systems, which uses the cellular LTE signals. This method is based on estimating the channel impulse response from the received LTE signal [9].

There is company called Novadem that uses another different method, the Local Positioning System (LPS) [6]. The LPS technology is close to the GPS technology but instead of using satellites, it uses terrestrial beacons which create a local positioning network. It has approximately an accuracy of 10 centimeters and doesn't need GPS.

The accuracy obtained with these systems is sufficient for navigation, but not to improve the map of the environment by converging a series of pointclouds on a complete map. To improve that it has been used a better system based on very accuracy sensors. This is the case of an automatic theodolite also known as Total Station (TS) from Leica Geosystems. This will be the system that will aid the positioning which aim is to improve the convergence of differents pointclouds.

3 Total Station as a ground truth

Without the possibility of use GPS, it is needed a positioning method for improve the 3D reconstruction of the bridge. Here is when is interesting the use of a Total Station. This is a very precise laser positioning machine from Leica Geosystems, one of the most important companies in spatial measurement and tophograpy.

It measure the position pointing to a 360^o prism with a laser. The light is reflected and then we obtain polar coordinates of the prism, which can be transformed into X, Y and Z axis. Later, the information is sent to the onboard PC which collects all the data and make the 3D model. It can measure to a maximum distance of 3km with a accuracy of 1mm.

Fig. 1. Leica mini prism 360^o.

The Total Station is connected to a computer that will communicate with the UAV onboard system. It sends the position and the UAV computer save that info in a ROS bag, including the orientation (using mavros) and the pointcloud info from a Kinect camera. Then we'll use all that topics information to compose a complete pointcloud.

Fig. 2. Leica Total Station MS50.

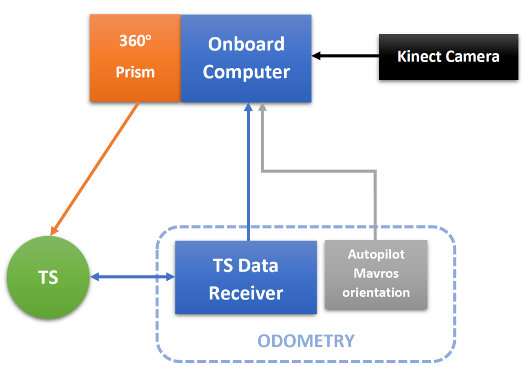

Fig. 3. System diagram.

The Total Station can create also a pointcloud without the help of an UAV. It take a long time (about 15 minutes) to measure a simple pointcloud from one side. This means that if we want to create a pointcloud of the whole bridge it will take approximately 1 hour. With the use of an UAV it can be performed in real time and furthermore reach not visible areas from the perspective of the Total Station.

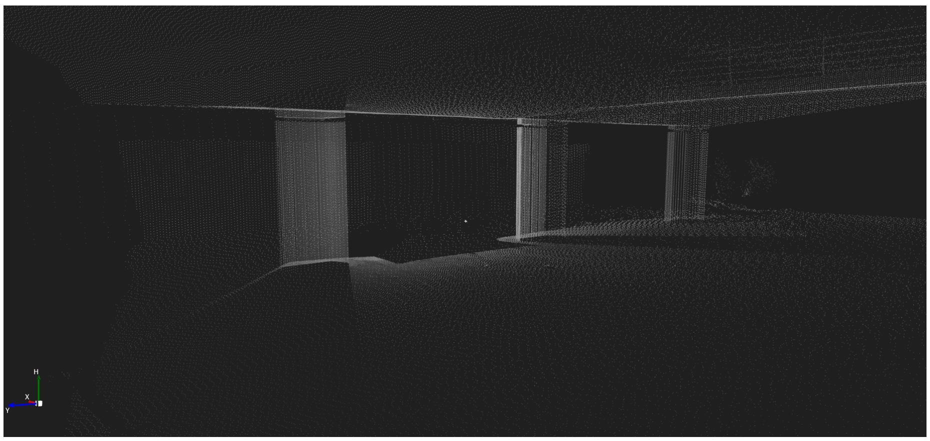

Fig. 4. Pointcloud map taken by the Total Station.

4 Alignment process

The aim of this paper is to get bridge's map from several pointclouds. To do this, we will have odometry and visual information from different sensors:

– **Kinect camera:** it will get the images and pointclouds needed to create the map.

Fig. 5. Kinect camera.

- **Pixhawk autopilot [7]:** using mavros [4] node from ROS (Robot Operating System) to get the orientation of the UAV. That will allow to have the rotation matrix and perfom the position transformation of one pointcloud and the previous one.

Fig. 6. Pixhawk autopilot.

- **Total Station and 360^o prism:** it will get the position (X, Y and Z) of the UAV. This information is necessary for the transformation matrix.

The more accurate the information will be, the easier will be to get the map and better quality it will have. That is the reason we use a Total Station to get a stable local position of the UAV.

For the alignment process we will use a ros package called *rtabmap* [8] [3]. This ros package doesn't use external odometry by default. But the problem of not using external odometry is that if you visualize a white wall, where there aren't similar features between a pointcloud and the next one, the software will not correctly simulate the visual odometry and will not fit well a pointcloud with the previous one. To solve this, external odometry is proposed.

5 Experimental testing

To prove what is proposed above, we will perfom a set of experiments on non transit bridges. These bridges are in the *Escuela Técnica Superior de Ingeniera* in the University of Seville.

One of the bridges is more exposed to sunlight and this is an inconvenient for the Kinect when taking the pointclouds (see figure 7). The reason why it is an inconvenient is because the Kinect camera projects a set of infrared dots and then visualize them with an infrared camera. But the sunlight has a component of infrared light in his spectrum, so the information is mixed and the experiment is not valid at all.

5.1 Experiment with Total Station

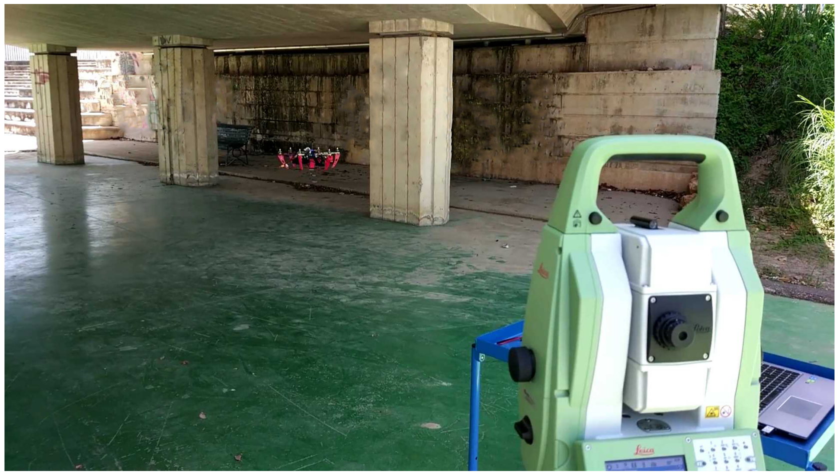

Fig. 7. Total Station taking measurements for odometry position under one of the bridges.

The other bridge is less exposed to the sunlight (see figure 8), so that is the one in which we are going to work. The aim is demostrate that using external odometry with a Total Station is easier and more accurate than just with visual odometry by software (matching features between pointclouds).

Fig. 8. Photo under the bridge used for mapping.

We have focused on analyzing three columns of the bridge. If the odometry is fine, it should be able to fix the deviation between pointclouds and the backgroud should be perfectly straight, as well as the trayectory. As we can see in Fig 9, there are three vertical flights corresponding to each of the columns.

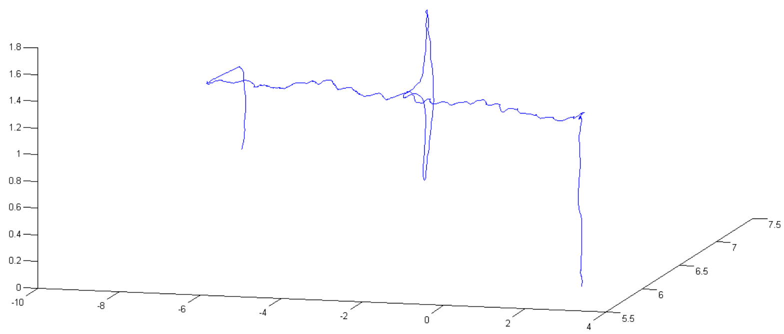

Fig. 9. UAV Trajectory under the bridge.

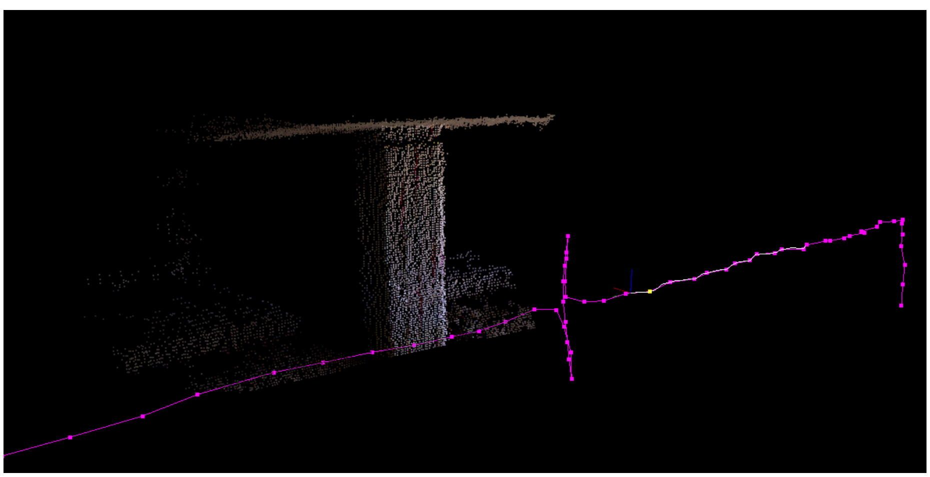

Fig. 10. Single pointcloud of a column and UAV trajectory (color pink).

The next figure is an image of the experiment zone whole map. In just one pass we have mapped three columns with a good quality.

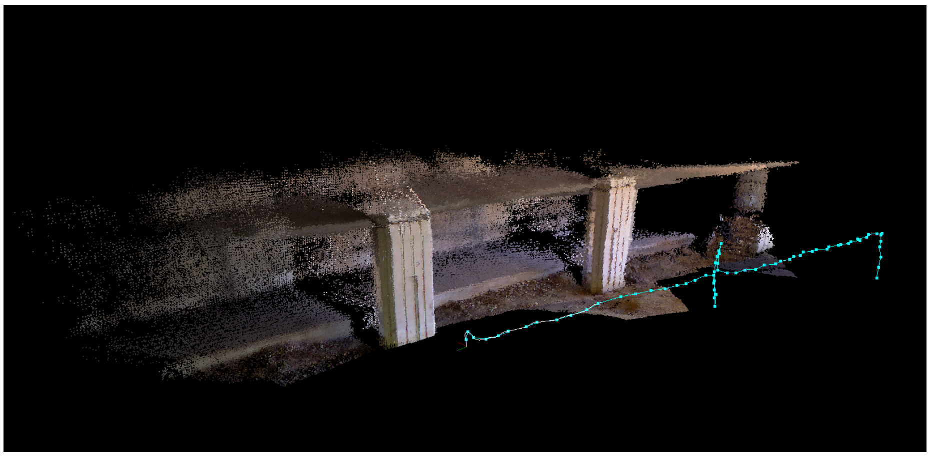

Fig. 11. Pointcloud map and UAV trajectory (blue color).

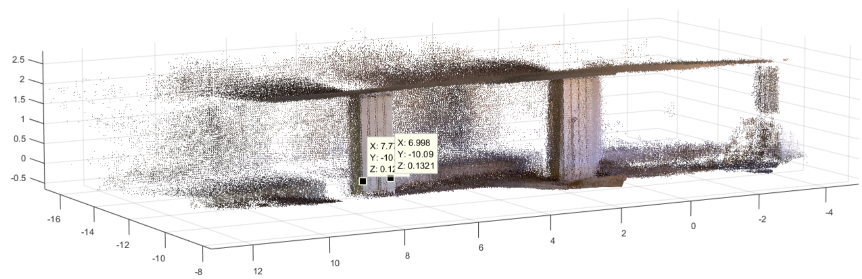

Fig. 12. Pointcloud map represented in Matlab with datatips.

We have taken several measurements to compare the real dimensions of the bridge and the model 3D. On average, the error is about 3 cm.

5.2 Experiment without Total Station

In this case the same bag file of the previous experiment has been used. The different is that now we have run the *rtabmap* package but without the Total Station and IMU odometry. The package looks for matching features between pointclouds and estimates the position of the UAV with that visual information.

Using the same file, the software can't create the map and loses the previous pointcloud, due to the big discrepancy between the first pointclouds (it starts on a bright zone and there is not much information). From one pointcloud to the next one there is such a few coincident points and the software is not be able to follow the movement of the UAV (see figure 13). That is the reason why external odometry is usefull.

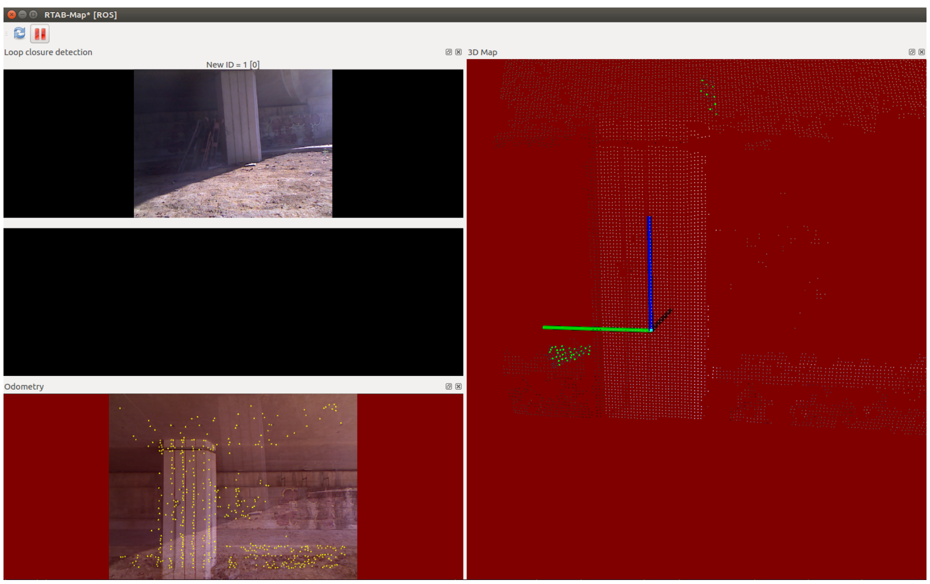

Fig. 13. *Rtabmap* package cant estimate the position with visual odometry.

6 Discussion

It has been proven that the use of a total station is useful when there is not much information in the cloud of points. If the ros package is not able to generate an odometry from the point clouds, it will not be able to generate a bridge map. Thus, the use of a total station is important to generate a reliable odometry that can be used to reconstruct the map.

References

1. Aasish, C., Ranjitha, E., Ridhwan, R., et al. Navigation of uav without gps. In *Robotics, Automation, Control and Embedded Systems (RACE), 2015 International Conference on* (2015), IEEE, pp. 1–3.
2. Gupta, N., Makkar, J. S., and Pandey, P. Obstacle detection and collision avoidance using ultrasonic sensors for rc multirotors. In *Signal Processing and Communication (ICSC), 2015 International Conference on* (2015), IEEE, pp. 419–423.
3. Labbe, M., and Michaud, F. Online Global Loop Closure Detection for Large-Scale Multi-Session Graph-Based SLAM. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems* (Sept 2014), pp. 2661–2666.
4. Mavros node from ROS. `http://wiki.ros.org/mavros`.
5. Morales, J., Roysdon, P., and Kassas, Z. Signals of opportunity aided inertial navigation. In *Proceedings of ION GNSS Conference* (2016), pp. 1492–1501.
6. Novadem Beacons. `https://www.suasnews.com/2014/12/novadem-unveils-a-new-positioning-technology-for-uav-allowing-automatic-inspection-of-structures-without-gps-coverage/`, 2014.
7. Pixhawk web. `https://pixhawk.org/`.
8. rtabmap node from ROS. `http://wiki.ros.org/mavros`.
9. Shamaei, K., Khalife, J., and Kassas, Z. Performance characterization of positioning in lte systems. In *Proceedings of ION GNSS Conference* (2016), pp. 2262–2270.