New automatic method of free stationing by drone

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Key words: GNSS, Free station, Drone, Automation, ICP, GeoCOM

SUMMARY

Setting up a total station can, in some cases, be very time-consuming, for example in a city with too few benchmarks or in a forest. In these situations, surveyors usually measure a few points on the ground with a GNSS rover (in RTK mode) and use these points afterward to set up the total station. However, there are risks of setting up a device on poorly measured points due to multipath (in cities) or poor GNSS coverage (in forests or urban canyons). We propose a new method using a quadcopter drone (UAV) equipped with an RTK-GNSS receiver (10 Hz frequency) and a 360° mini prism that is continuously tracked by the total station, at 10 Hz as well. A Raspberry Pi single-board computer controls the whole system. The software was developed in Python.

The system allows to supervise and visualize the acquisition on a smartphone in real-time. The 3D coordinates of the free station, including precision and reliability information, are automatically calculated and sent to the total station to set the new coordinates and orientation of the instrument. Once this process is completed, the total station is ready to measure with its new stationing. The drone benefits from a better GNSS visibility than a ground user would. To make the system work in real-time, all that is required is a SIM card for mobile internet and an RTK-GNSS service. The system is designed to operate on a Leica Geosystems robotic total station. Time synchronization is properly accounted for and communications between the different parts of the system are implemented in a very robust way.

This prototype has been put to experiment in the Swiss projection system. Within 5 minutes of data acquisition, a centimetric accuracy for the 3D coordinates and near 0.001 gradian ($1.5 \cdot 10^{-5}$ radian) for the orientation of the total station was obtained, without any coordinate reference points on the ground. We believe that our system has a huge potential to enable high precision surveys in difficult environments, such as urban canyons or areas with no or only a few coordinate reference points.

RÉSUMÉ

La mise en station libre d'une station totale robotisée peut dans certains cas être chronophage en raison d'un manque de points connus en coordonnées. Dans ces cas de figure, les géomètres ont souvent recours à un système GNSS-RTK pour la détermination de quelques points utilisés pour le calcul du stationnement de l'instrument. Il existe cependant un risque d'acquérir de mauvaises mesures GNSS en raison des masques d'obstructions importants et du multi-trajet, notamment dans des zones urbaines denses, des forêts, etc. Nous proposons une nouvelle méthode automatique low-cost de mise en station libre par drone quadricoptère qui permet de s'affranchir des éventuelles erreurs citées ci-dessus. Le système est composé d'un récepteur GNSS-RTK (fréquence 10 Hz) et d'un mini-prisme 360° traqué par la station totale robotisée. Afin d'obtenir un prototype fonctionnel en temps réel, il suffit d'une carte SIM et des informations de connexion au réseau de correction RTK. L'ensemble du système est contrôlé automatiquement par un logiciel développé en python, implémenté sur un Raspberry Pi (micro-ordinateur). Le système permet la supervision et la visualisation de l'acquisition en temps-réel via une page web accessible depuis un smartphone. Les coordonnées 3D et l'orientation sont automatiquement calculées et envoyées à l'instrument afin de définir la mise en station. Un fichier rapport et résultats est généré et envoyé au smartphone afin de valider la qualité du stationnement. Ce processus terminé, la station totale est prête à mesurer de façon conventionnelle. L'utilisation d'un drone permet un positionnement dans des régions de mauvaise couverture GNSS au niveau du sol. Le système est développé pour être utilisé avec une station totale robotisée Leica Geosystems. La synchronisation temporelle et la communication entre les différentes parties du système a été implémentée de façon très robuste. Le système a été mis à l'épreuve dans le système de projection Suisse, lors de plusieurs tests en conditions réalistes. Après environ 5 minutes d'acquisition, une précision centimétrique pour les coordonnées 3D et meilleure que 0.001 gons ($1.5 \cdot 10^{-5}$ radians) est obtenue. Ces informations ont été contrôlées sur des points de référence dont la précision est millimétrique. Nous sommes confiants quant au potentiel qu'offre notre système pour des mesures précises dans des conditions difficiles comme des couloirs urbains et des zones à faible densité de points fixes.

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1. INTRODUCTION

The setup of a total station is a routine operation for surveyors. This simple task at a first glance, consisting in determining the position and the orientation of a total station, can become very complicated in areas with no benchmarks or bad GNSS coverage. However, a precise stationing is necessary for any geometric measurements with a total station such as cadastral measurements, topographical surveys, implantation of constructions, monitoring of structures, etc. Nowadays, the common methods of stationing are the following (Möser et al., 2012):

- Set up of the instrument on a station point with known coordinates and one or several orientation points
- Free station based on points with known coordinates
- Free station based on GNSS points

All of these have their strengths and weaknesses but they almost all have in common that they need a sufficient number of benchmarks. The methods that do not use fixed points use a GNSS receiver instead.

This project aims at developing a new way of setting up a total station without the need for benchmarks. GNSS measurements of only a few points are replaced by the continuous tracking of a mobile GNSS receiver mounted on a drone. By doing so, in obstructed environments, GNSS measurements flawed by obstruction masks, multipath, etc. can be avoided.

Figure 1: System during an acquisition

In this paper, a fully automated method of free stationing using a 360° mini-prism and a GNSS receiver mounted on a drone is presented. The performance and automation level were tested and validated in different environments. Comparisons with traditional methods are also presented to quantify the quality of the system in its current state of development.

2. METHOD

This chapter will detail the functioning of the system developed for the free stationing of a robotic total station using a GNSS sensor and tachymetry measurements on a 360° mini prism mounted on a quadcopter drone. Our goal was to develop a low-cost and easy-to-setup system that is reproducible. Hence, the chosen hardware had to be affordable and the software well documented and open source.

The configuration of the system goes as follows: an RTK-GNSS sensor and a mini-prism 360° are mounted on the drone. The RTK-GNSS sensor is composed of a GNSS antenna, a receiver and a 4G cellular chip with a SIM card for the reception of the RTK service. This sensor continuously measures 3D positions and transmits them to a Raspberry Pi single-board computer on the ground via radio communication. The 360° mini prism is measured continuously by the total station. The 3D local coordinates from the tachymetry measurements are sent to the Raspberry Pi via a serial cable. Once the acquisition is finished, the software automatically calculates the position of the total station using a 2D Iterative Closest Point algorithm (ICP) and a 1D ICP between the point clouds of the RTK-GNSS measurements and the total station measurements. The system allows the operator to visualize and to control the acquisition and the calculations in real-time on a smartphone via a web page. Once the 3D coordinates and the orientation of the total station are calculated, a command allows to send these data to the instrument to set a new stationing. A result file is then created and sent to the smartphone to validate the quality of the stationing.

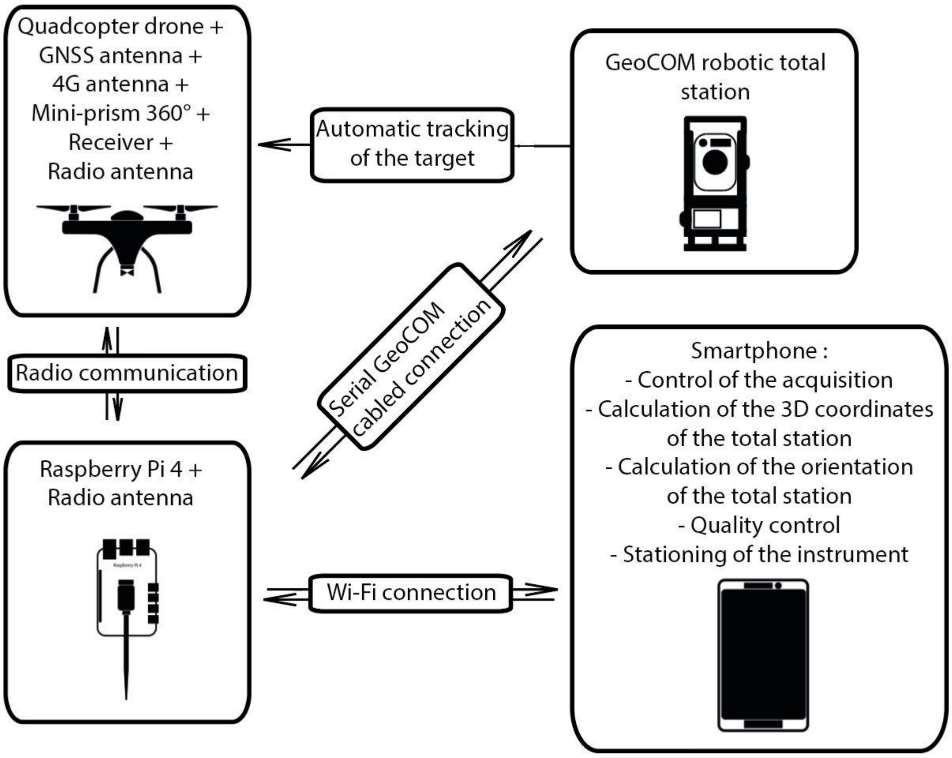

Figure 2: Prototype composants and communication

Synchronisation issues are avoided by using an ICP algorithm. Leica Geosystems AG robotic total stations have the possibility to be controlled remotely using the GeoCOM client-based application (Leica Geosystems AG, 2006). The GeoCOM serial port protocol does not provide time stamps for the measurements. Hence, an unknown delay can occur between the measurement epoch and the reception of the message. The chosen solution, a 2D ICP for the planimetric coordinates and the orientation of the instrument, and a 1D ICP for the altimetry, does only rely on the geometry of the measurements but not on their epochs.

2.1 Hardware

2.1.1 Installation on the drone

The drone provides the total station on the ground with continuous GNSS measurements. It also serves as target for the total station. The drone carries the GNSS receiver, the GNSS antenna, a radio module, a mobile data module and the 360° mini prism.

2.1.2 GNSS system

The quality of the stationing depends directly on the precision of the positioning system. The chosen GNSS antenna is a ublox ANN-MB1 and the receiver a ublox ZED-F9R module for high precision positioning. A standalone board from Ardusimple with integrated ublox receiver with an additional cellular module and a radio module was used (Hamza et al., 2020). This set-up allows to acquire and to transmit GNSS-RTK positions at 10 Hz data rate.

2.1.3 Radio communication

The communication between the control module installed on the Raspberry Pi 4 and the GNSS sensor is made possible by a radio communication between two XBee SX868 RF modules.

2.1.4 Control system

The control system refers to the hardware hosting the processing software. We have chosen a Raspberry Pi 4 for this task. The radio communication module and the RS232 cable for the communication with the total station are connected to it (Kälin et al., 2022). The Raspberry Pi is configured to start the software as soon as the system is powered on. All the files written during the process are saved on its internal memory.

2.2 Software

The software is developed in Python 3.7 a free license programming language. The web server, that can be accessed by smartphone, is based on the open-source library Flask (Grinberg, 2018). The calculation of the 3D coordinates and the orientation with a 2D ICP and a 1D ICP are based on the library Open3D (Méndez et al., 2020). Further libraries are used for minor tasks.

2.2.1 Automated acquisition

Once the total station is aimed roughly towards the prism, the system is ready for the data acquisition. When the operator chooses to start the measurements using the corresponding button on the interface on his smartphone, an acquisition thread is started. This process starts by connecting the radio module connected to the GNSS and by opening the serial port connected to the total station. After an inspection of the data transmitted by both sensors, the acquisition starts.

The data originating from both sensors are transmitted at a frequency of 10 Hz or less (our prototype uses a Leica MS60 which can measure at 10 Hz) and stored in an ASCII file that is created at the beginning of every acquisition. During this process, various data integrity checks are carried out:

- Radio connection to the GNSS and data transmission;
- Serial port connection to the total station and data transmission;
- Proper transmission of GNSS-RTK corrections;
- Lock of the reflector (360° mini-prism) by the total station;
- Correct data saving;
- Successful computation of the scaling factor.

If one of these controls is not validated at a certain point during the acquisition, the saving of the data is interrupted until the problem is resolved manually or automatically. For example, if the total station loses the reflector, the operator can roughly aim the scope towards the drone and the total station automatically finds the reflector. Following this, an integrity check is carried out until everything runs correctly, and data can be written again.

Once the acquisition is satisfying, the operator can stop the acquisition which disconnects the communication and starts the calculation of the 3D coordinates and orientation of the total station.

2.2.2 Calculation of the 3D coordinates and orientation

The computation of the 3D position and the orientation is based on a 2D ICP for the planimetric position and the orientation and a 1D IPC for the height component. Some other processing strategies were considered (for instance a classical least-squares adjustment combined to an outlier detection with RANSAC) but did not lead to satisfactory results.

Two acquisition methods are available. The first is the stop-and-go method. It filters the point according to the velocity of the GNSS sensor. Only points with a velocity below 0.2 m/s are considered. It is therefore important to stop the drone in flight for approximately 10 seconds to have enough data for each group of points.

The second, the dynamic method, is continuous. The drone does not need to have stationary moments during the flight. This algorithm processes all the data.

As mentioned above, an Iterative Closest Point (ICP) algorithm is used to fit the point cloud from the RTK-GNSS to the points acquired with the total station. A point-to-plane ICP registration is performed for the planimetric component and the orientation (Chen & Medioni, 1992) which constructs a rigid transformation matrix by searching the point-to-plane correspondence between two datasets and aligns them accurately through iteration (Li et al., 2020). The algorithm takes the point set in the target point cloud and searches for the corresponding point in the source dataset using the normals of the target points. The function to minimize is the following (Chen & Medioni, 1992) :

$$E(\mathbf{T}) = \sum_{(\mathbf{p},\mathbf{q})\in\mathcal{K}} \left((\mathbf{p} - \mathbf{T}\mathbf{q}) \cdot \mathbf{n}_{\mathbf{p}}\right)^2$$

Equation 1: ICP point-to-plane equation
http://www.open3d.org/docs/release/tutorial/pipelines/icp_registration.html

Where :

- $E(\mathbf{T})$: Function to minimize
- **p** : Point from the target point cloud (total station acquisition)
- **q** : Point from the source point cloud (GNSS acquisition)
- $\mathbf{T}_{3x3}$: Transformation matrix (in 2D : 2 translations and 1 rotation)
- K : Correspondence set between the target point cloud **P** and the source point cloud **Q**
- $\mathbf{n}_{\mathbf{p}}$ The normal of point **p**

The result of this optimization procedure is a transformation matrix between the source point cloud and the target point cloud. Finally, a root mean square (RMSE) is calculated and if the result is greater than a fixed threshold, another iteration is performed.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(q_i - p_i)^2}{n}}$$

Equation 2 : RMSE function

The point-to-plane ICP registration has been shown to have a faster convergence speed than the point-to-point ICP algorithm (Rusinkiewicz & Levoy, 2001). The 2 translations extracted from the **T** matrix are used to compute the new coordinates of the total station and the rotation for its orientation.

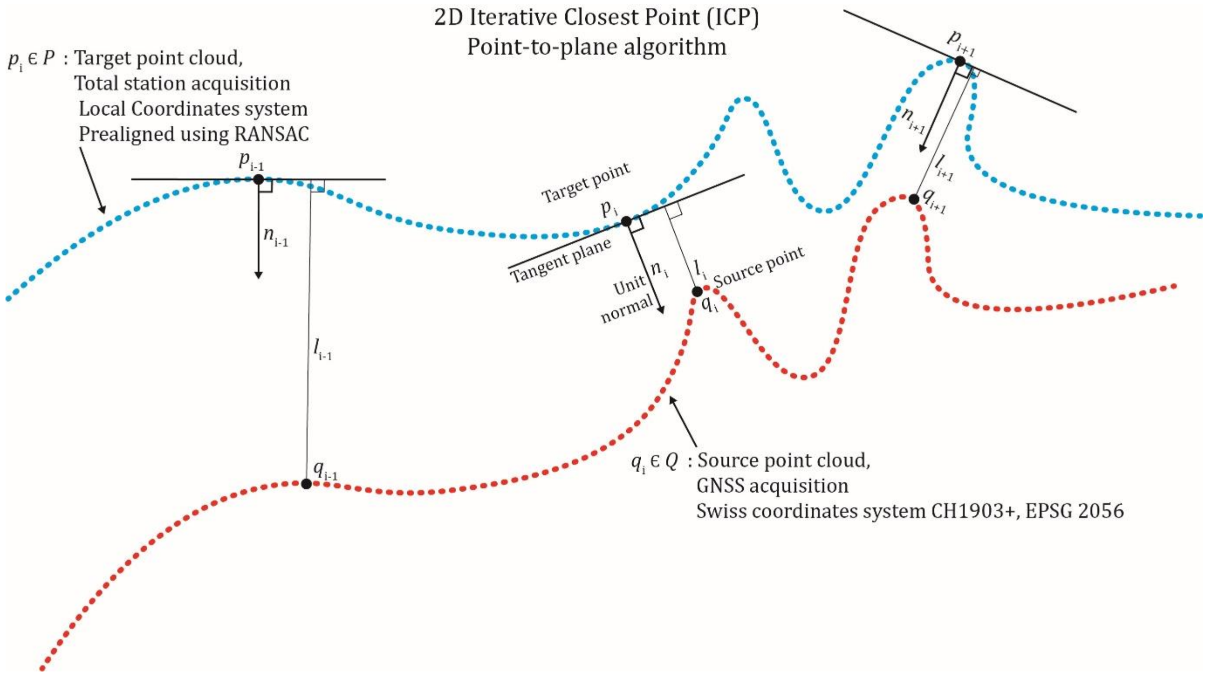

Figure 3: Principle of the ICP point-to-plane algorithm

In this case, the source point cloud are the total station points in their local coordinate system and the target point cloud is obtained from GNSS. The GNSS positions are transformed into the Swiss reference system (CH1903+ / RAN95, EPSG2056) beforehand, in order to obtain a stationing in this system as well. Additional coordinate systems could easily be supported by adding the corresponding coordinate transformation.

The prealignment, which is necessary for the ICP, is obtained by the means of a RANSAC (random sample consensus) algorithm (Fischler & Bolles, 1981).

For the altimetric component, the process is the same except that the algorithm is a point-to-point ICP that searches point-to-point correspondence instead of point-to-plane. Whereas the 2D ICP for the planimetric coordinates and the orientation takes only into account 2D positions, the 1D ICP builds upon the results from the 2D ICP and solely estimates a vertical translation.

2.2.3 Web server

The user interface is realised through a web server running on the Raspberry Pi. This web server is based on the Flask open-source Python library. Essential information, such as quality indicators and calculated parameters, are displayed on the page. Once the calculation is finished, a PDF result file is generated.

3. RESULTS AND DISCUSSION

To test sites were selected for the validation. The first one has an existing network of benchmarks referenced in the Swiss projection system with millimetric accuracy. The second one was used to validate the proper functioning of the system in difficult environments. We thus chose a site with thick vegetation and no benchmarks. A traditional stationing is therefore difficult, as no GNSS can be used at ground level and no orientation point is available.

2.3 Validation of the accuracy

To properly validate the accuracy of the system, we did two free stations using our system, One with the static method and the other with the dynamic. We then measured a known point and compared the results obtained with the reference. After that, we carried a free station out of the benchmarks of the network and another free station out of GNSS measured points. The reference point has been measured as well and the results obtained were the following :

	Drone RTK static stationing	Drone RTK dynamic stationing	Free station on Benchmarks	Free station based on GNSS points
σ 2D [m]	--	--	0.003	0.008
σ H [m]	--	--	0.004	0.013
RMSE ICP 2D [m]	0.006	0.029	--	--
RMSE ICP 1D [m]	0.019	0.004	--	--
σ ω [rad]	0.00004	0.00006	0.00003	0.00004
Δ 2D Station [m]	0.006	0.011	0.002	0.007
Δ 3D Station [m]	0.013	0.018	0.010	0.015
Δ 2D Control [m]	0.006	0.010	0.003	0.018
Δ 3D Control [m]	0.018	0.013	0.012	0.031

Figure 4: Results of the stationing using different methods

The table presented above shows the results using four different methods of stationing. The first two are made with our solution, one in static mode and the second in dynamic. The others methods are free stations, one that uses benchmarks and the other GNSS measured points. The values calculated are the following :

- σ 2D, σ H : The planimetric and altimetric standard deviations issued from the calculation of the free station;
- RMSE ICP 2D, 1D : The root mean square issued from the calculation of the ICP;
- σ ω : The standard deviation of the orientation of the station;
- Δ 2D Station, Control : The planimetric difference between the reference of the network and the coordinates calculated;
- Δ 3D Station, Control : The 3D difference between the reference of the network and the coordinates calculated;

The sigma's and RMSE's issued from this tables come from the acquisitions done to setup the instrument. The delta's are the difference between the reference known and the acquisition made after the setup was made. The atmospheric conditions during the measurements were stable, cold, and cloudy. We can see that the quality of the stationing using our method is similar to the traditional methods of free stationing. Furthermore, we see that using our system, the altimetry shows differences under 3 cm and the planimetry under 2 cm. We can also note that the two methods (static and dynamic) show similar results.

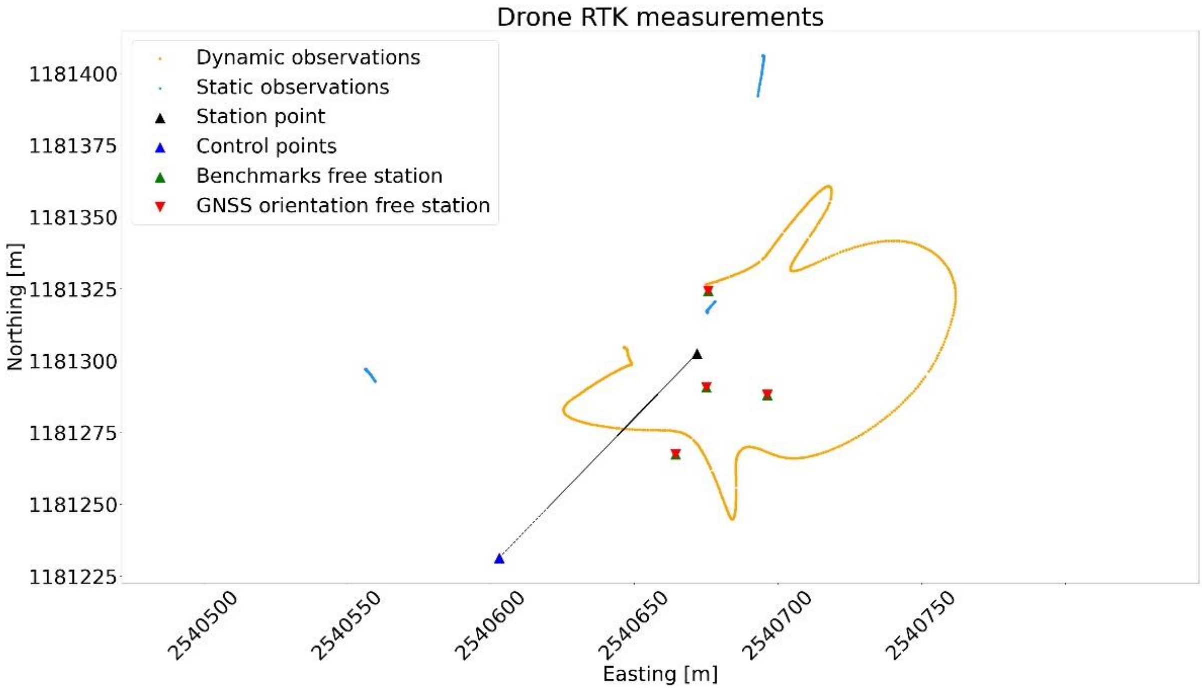

Figure 5: Disposition of the measurements

2.4 Reliability in difficult environments

The main goal of this system is to get rid of benchmarks and discrete GNSS measurements to allow stationing in difficult environments. We consider a difficult environment a place where no known coordinate points are available and where a GNSS cannot be used at ground level. We, therefore, tested our system in a forest with thick vegetation and chose a station location where only some portions of the sky could be seen. An acquisition was performed in these adverse conditions. A benchmark with known coordinates could then successfully be measured, reaching a coordinate difference of below 2 cm in planimetry and below 3 cm in 3D.

Figure 6: Free station using the stop and go method

4. CONCLUSION AND PERSPECTIVES

This project investigates a new possible way of stationing a robotic total station. In the first part, we presented the required hardware. The system relies only on few low-cost components. We then presented the acquisition procedure and the computation strategy. The system showed to be functional in difficult environments and to give satisfying results within a centimetric precision as soon as only a portion of the sky is visible.

The strength of the system is the availability of the position and the orientation in real time. If no RTK-service is available, the solution could also be postprocessed.

The following improvements will further increase the potential of the system:

1. Implementation of other reference systems to allow the system to be functional in other countries;
2. Miniaturization of the prototype to allow the system to be mounted on smaller drones (DJI Phantom 4 for example);
3. Publication of the source code under open source licence;
4. Implementation of a function for the determination of the orientation of a station with known coordinates (for instance a benchmark).

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BIOGRAPHICAL NOTES

Fabien Délèze is currently a part-time Master student in the University of applied sciences and arts Western Switzerland in the field of geomatics engineering and part-time research and development collaborator in the HEIG-VD Yverdon-les-Bains. His projects are related to the development of multi-sensors systems, the monitoring networks, and the development of virtual reality in the field of geomatic.

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