LARGE-SCALE POINT-CLOUD BASED GLOBAL MAPPING FOR ORCHARD OPERATIONS

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ABSTRACT

Robotic motion in orchard fields consists of several components such as mapping, perception, navigation, and route (path-motion) planning. Route planning and navigation are highly contingent on mapping functionality whilst the robotic vehicle operates and adapts itself into a partially known work area providing a safe and accurate routing. Traditional mapping techniques entail an unmanned ground vehicle equipped with laser scan sensors and inertial measurement units resulting to a spatial 3-dimension map, which is a comprehensive guide for the robotic vehicle. The proposed system here takes advantage of the complementary mapping operation of an unmanned aerial vehicle's ample flight height for enhancing its mapping ability. This approach can provide a ground-breaking perception solution especially in agricultural fields, where the targeted area covers extremely wide-open spaces. This combined mapping process reduces the time needed by a ground vehicle for mapping the environment by itself, while it reduces the risk of accidents and operational failures. Furthermore, the ability to implement a camera and a GPS sensor on the vehicle, enables the tree indexing resulting to a significantly more accurate ground vehicle navigation. Additionally, the trees are associated with their geolocation providing future applications with valuable information. The digital map documentation is compliant with a seamless integration with the precision agriculture framework, enhancing field mapping value.

Keywords*:* precision, farming, robotics, UAV, UGV, mapping

1. INTRODUCTION

Mapping is one of the most important fields in robotics, and it is an inseparable piece of the robotic motion and navigation (Bochtis et al., 2007; Hameed et al., 2013). Regardless of the vehicle type, unmanned ground vehicle (UGV) or unmanned aerial vehicle (UAV), mapping is the field in which the robotic vehicle obtains the perception of the area that exists. Combining the sensor data from several sensors like GPS, inertial measurement units (IMUs) and laser range finders (LRFs), the robotic vehicle can estimate its position, localization and velocity. Hsu et al. (2018) proposed an algorithm that combines the advantages of simultaneous localization and mapping (SLAM) using an RGB-D camera and the IMU/laser SLAM.A Microsoft Kinect, a Hokuyo laser scan and an IMU were fused in order to produce the 3D positioning and mapping results. The extended Kalman filter is used for drift correction from the inertial sensor, which is estimated from the Kinect sensor. When the displacement estimated from Kinect sensor is marked as a failure, the vehicle's velocity is estimated from the laser scan. A remarkable research is done by Torres-Sánchez et al. (2018) where he combined the photogrammetric point clouds with an object-based image analysis (OBIA). The research took place on three different almond orchards using a UAV equipped with a visible-RGB sensor while the validation field method consisted of registering the height of a total of 325 trees in two fields. The OBIA algorithm had the high score of $R^2 = 0.94$ while it was used for generating 3D maps for every tree volume and volume growth which would be useful to understand the relations between tree and crop management operations in the context of precision agriculture. An unsupervised detection of vineyards by 3D point-cloud UAV photogrammetry was proposed by Comba et al. (2018) using a UAV. The initial data was created by a multispectral camera which was equipped on the UAV, while the produced 3D point-cloud map was parsed by the proposed innovative unsupervised algorithm. The main results are the automatic vineyard detection while the local evaluation of vine rows orientation is calculated. A research about monitoring 3D areal displacements using a UAV was done by Hastaoğlu et al. (2019) proposing a UAV benchmarking approach. Using a UAV, equipped with GNSS receiver, they produced orthomosaics and digital elevation models (DEM). Based on the coordinates obtained, the velocity values where calculated by the Kalman filtering technique. The velocity values were considered as equal was determined by statistical analyses techniques like t-test, f-test, RMSE and VAF. A really interesting approach was made by Wu et al. (2019) proposing a 2D-to-3D strategy for invasive plants in a mountain area. Invasive plants institute one of the major causes for biodiversity loss. The study took place over mountain region in Shenzhen, China deriving multi view images from an UAV, using a high precision 3D mesh-model and digital orthophoto map. A fine analysis was introduced in order to produce the 3D dimensional distribution by combining the 2D distribution with the 3D respective mesh model. Sünderhauf et al. (2016) suggested an object-oriented semantic mapping using an RGB-D camera sensor. Despite the traditional process of 3D mapping, Sünderhauf implemented an image-based deep-learning object detection and 3D unsupervised segmentation aiming to allow the intelligent robots understand both geometric and semantic properties of the scene surrounding them. Remaining on the semantic mapping approaches, McCormac et al. (2016) introduced an approach that consists of the combination of Convolutional Neural Networks (CNN) and a SLAM system named ElasticFusion. ElasticFusion provides long-term dense correspondences between frames of indoor RGB-D video. Using the CNN, the study targets to predict the multiple view points and be fused into a map. The remarkable point on this apporach is the matter that the frame-rates are approximately 25Hz, providing a real-time interaction. On the terms of localization and mapping, Salas-Moreno et al. (2013) presents the advantages of a new kind of SLAM which involves objects. Despite the traditional SLAM which operates at the level of low-level primitives such as points,line and patches, the object oriented SLAM harnesses 3D object recognition in order to jump over the low level geometry and create an implementation of object detection and six degree of freedom. Additionally, Bosse and Zlot (2009) introduced an algorithmic approach which is based on the well-established Iterative Closest Point (ICP) scan matching algorithm. This approach was executed using a 2D laser scan sensor for 3D mapping. Cole and Newman (2006) equips a UGV with a laser scan in order to produce a point cloud data, used for mapping and navigation of the vehicle. Despite the traditional SLAM techniques, Cole and Newman, supervisingly trained a classifier in order to reject poor scan-matches from the map scanning process. Last but not least, Bosse and Zlot (2008) challenged with the fact that the sensor motion is fast relative to the measurement time is that scans become locally distorted and difficult to align. The proposed solution consists of a 3D scan-matching combing with a continuous 6 degrees of freedom sensor trajectory which is recovered to correct the point cloud alignments. As a result, the product encompasses accurate maps and high vehicle motion reliability.

In this paper, a 3D mapping approach is presented. The process contains a UAV photogrammetry technique using an RGB camera, a laser sensor and a Real Time Kinematic (RTK) GPS receiver in order to obtain the data from the field. After that, the process is being processed via a proprietary software while the point-cloud of the field is constructed. Although, the produced point-cloud is not reliable enough in order to be a working mapping base for the UGV. Consequently, a preprocess action took place in order to create a solid mesh model using a triangulation technique. In the end, the mesh model was transformed to a map file which is recognizable from the UGV. Since this step was successed the navigation of the robot was a straightforward process.

2. IMPLEMENTATION

A mapping process requires both software and hardware integration, both consisted in a vehicle. The hardware implementation contains the necessary sensors and materials while the software implementation contains the external software used for data manipulation and product result. Vehicle's software is also considered as hardware implementation and it will be detailed below.

2.1 Hardware integration

This subsection briefly describes each hardware component used in the mapping approach while the need of environment recognition is tightly connected with the sensors. The fixed-wing drone constitutes the main core of the mapping process. Possessing a high flight time duration, senseFly's eBee is able to imprint large scale areas in order to produce orthomosaics and point-clouds. It is equipped with an RGB camera called SODA which is a proprietary RGB camera for the eBee and it is connected via the integrated USB port. The drone is also equipped with an RTK GPS in order to optimize the aerial navigation and precision while a vertically mounted laser scan is constantly measuring the flight height of the drone. Despite the aerial vehicle, the described approach contains a laptop computer, which is responsible for drone's control and command. The antenna of eBee's controller is communicating with the proprietary USB antenna which is connected to the laptop. This ground station contains the necessary software, aiming to provide the most reliable result regarding the drone and the computer communication (Figure 1).

Figure 1. SenseFly's eBee, the RGB camera and the antenna

2.2 Software implementation

Software constitutes the core of the drone and the process itself. The embed proprietary eBee software is reliably connected with the software running to the ground station while providing any real time useful information about the UAV. The proprietary software, eMotion, comes packed with all necessary drivers and communication protocols in order to achieve a successful connection with the aerial vehicle. On the other hand, the final product of 3D mapping is being produced by the Pix4DMapper Pro software while it manipulates the recorded data from eBee.

2.3 Process

The proposed process consists of multi-level subprocesses since the final product is complicated to be produced. From ground station preparation to UGV navigation, the mapping process of a large-scale area is structured by different type of implementations while the whole process is a sequentially executed series of actions (Figure 2).

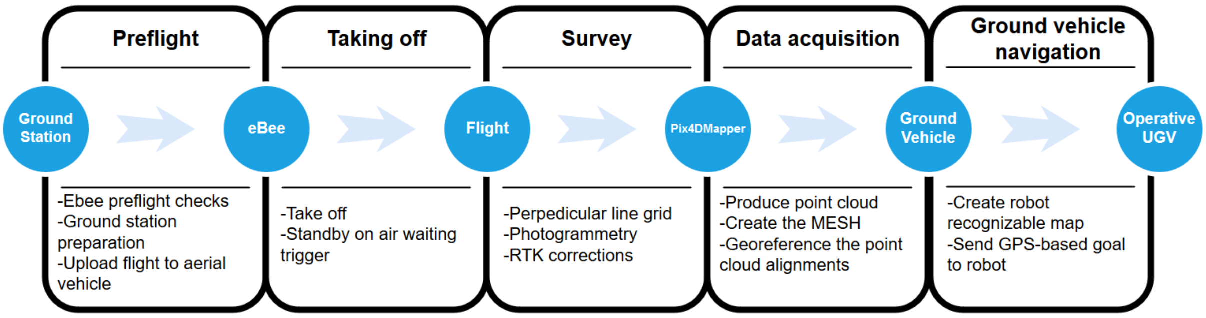

Figure 2. Required actions until mapping result

Once the mapping procedure is completed, the result is being edited and imported to a ground vehicle in order to benchmark the integrity of produced map.

3. Results

The mapping process provides a collection of georeferenced images of the field, where the Pix4DMapper Pro software is responsible for point-cloud construction. Since the produced point cloud is not reliable enough to be imported to the ground vehicle, a mesh model was created using a triangulation method applied on the point cloud file in order to cover up the hardly accessible spots that drone missed due to canopy size (Figure *3*).

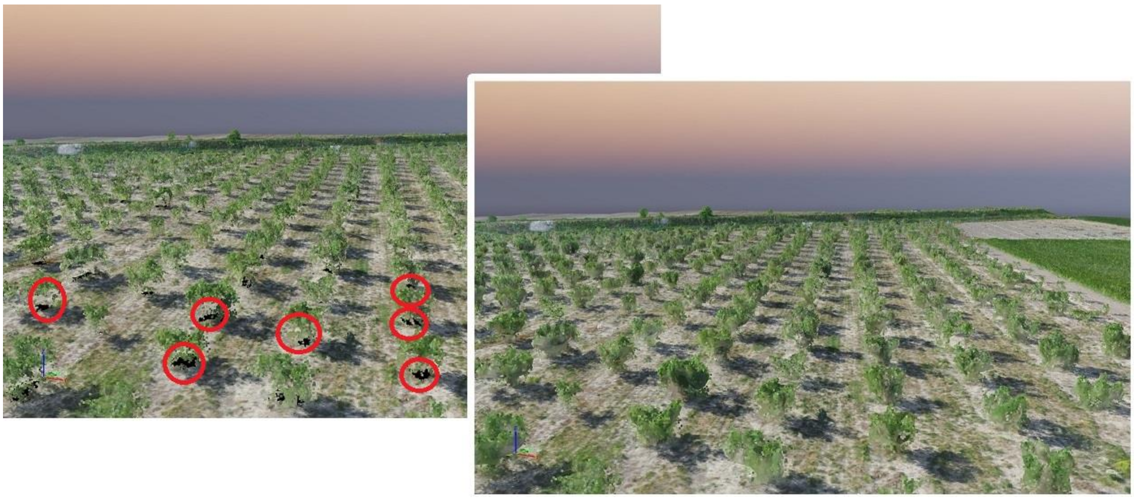

Figure 3. From point-cloud to mesh model

Covering up the spots allows the robotic software to create a robot-friendly map. The ground vehicle that was used is operating based on the ROS framework (Quigley et al., 2009) (Figure 4) which

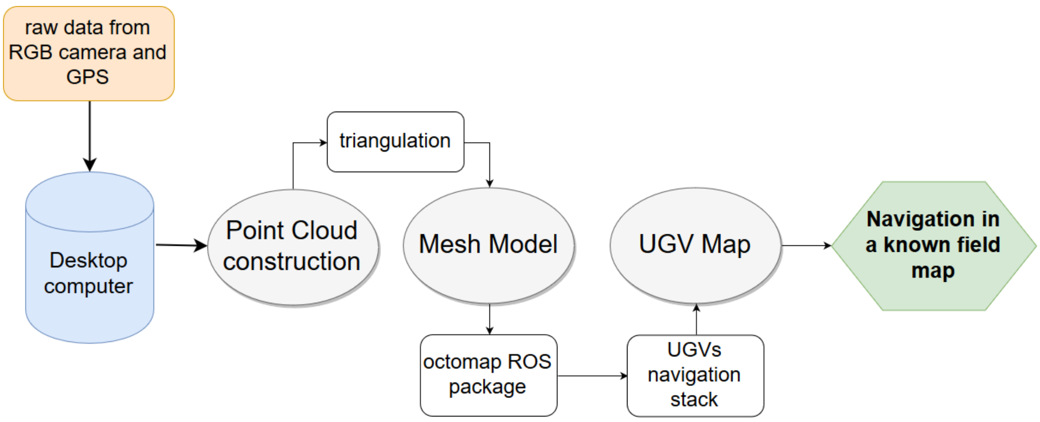

Figure 4. From raw data to useful product

combines both the core and the visualization software for the robotic operations (Figure 5), providing a complete solution on robotics navigation and manipulation. From the ROS framework side, the octomap package was used in order to convert the mesh model to a UGV map.

Figure 5. Benchmarking the mapping product with real robot

The benchmarking result was satisfying while the robotic vehicle was navigated safely among the orchard trees, reaching the desired goal that users targeted with the assistant of the robot's algorithmic planner. Despite the fact that some expected errors existed such as inaccuracy of mapping product GPS coordinates and actual coordinates measured by the vehicle's GPS, the approach is nearly matched with the desired result.

4. FUTURE WORK AND CONCLUSION

In this paper, a large-scale point-cloud based mapping using an unmanned aerial vehicle was presented. Aerial vehicles are commonly used in precision agriculture exploiting their ability of high observation of a large area and their energy cost awareness. Fetching the data from the UAV, manipulating the resources and importing the product into a real robotic vehicle, the mapping process is completed in a reduced duration, comparing with the mapping time that would cost to a UGV on the same field area. The bleeding edge feature of this work, consists of high-speed mapping process with an aerial vehicle, avoiding using the traditional time consuming UGV mapping.

The proposed process can be used by many applications such as virtual interactions and robot navigation. In the future, the interest is focused on the GPS matching improvement, a real-time mesh model and map creation while the cooperation of UGV and UAV on mapping, is marked as the main goal.

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