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Outdoor Navigation under Tree Canopy for Unmanned Ground Vehicle (UGV)

Muhammad Annas Shah Manan[1], **Mohamad Fauzi Zakaria**[1]*

[1]Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: This paper is focusing on implementing the Global Localization System (GPS)-an independent localizing method using a single sensor so that the UGV can drive autonomously in the GPS-denied environment. This paper aims to measure the performance of the localization between using GPS navigation and Visual Odometry (VO) navigation. The UGV platform is built with Intel Realsense T265 as VO camera for visual navigation, Ublox M8N as GPS receiver for navigation evaluation purposes, Pixhawk as the autopilot, and Raspberry Pi 4 as the companion computer for the autopilot. To perform this paper, the Mission Planner will be used as Ground Control Station to set the parameters and settings for the autopilot and compose the missions to the UGV to be executed in form of waypoints. From the results, this paper has achieved its objective where the error when using VO navigation compared to GPS navigation is 0.21 meters. Hence, using the VO camera itself can provide comparatively the best option to replace the GPS receiver for navigation by using the same settings set in this paper where the PID gains of the steering are P=0.00528620, I=0.14430414055, D=0.019767, IMAX=79, FF=0.811, and the setting for the throttle are P=0.9681, I=0.9966, D=0.0484, IMAX=140. Different values of PID gains, data filters, or more recent camera technologies can improve the results of the VO navigation.

Keywords: GPS-Denied Environment, Vision-Based Localization And Navigation, Wheeled Mobile Robot, Unmanned Ground Vehicle

1. Introduction

The food crisis happened over the last few decades and becomes worse after the pandemic Covid-19 spread to all parts of the world where 2.3 billion people faced the issue of insufficient food in 2020 [1]. The food supply chain is strongly dependent on the agricultural sector to ensure the sustainability of the national food security and economy [2],[3]. The key thing about the issues that arose in the agricultural sector is because of the lack of labor to produce the agricultural outputs [4]. Hence, for the long-term sustainability to substitute the labor shortage issue in the agricultural sector, the autonomous vehicle or agricultural robot is seeming as one of the solutions as the automated machine or vehicle has fewer limitations compared to humans [5].

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*Corresponding author: mfauzi@uthm.edu.my

The navigation system for autonomous vehicles particularly UGV is mostly using satellite navigation or GPS. However, the GPS signal will be attenuated when the GPS sensor is used in the GPS-denied environment particularly in the area of palm oil estate, for example, as there are physical obstructions such as an array of leaves that may block the signal from propagating directly from the transmitter (satellite) to the receiver (GPS sensor) due to multipath errors [6].

Some other approaches had been established by several researchers to substitute satellite navigation such as using multi-sensor localization [7], visual-based standalone localization [8], LiDAR-based standalone localization [9], and laser scanning-based standalone localization [10]. However, in this paper, the visual-based standalone localization approach will be used as the baseline to perform navigation in a GPS-denied environment.

1.1 Problem Statements

The first problem that leads this paper to be conducted is that navigation using GPS-based is not efficient in the tree-canopy area. Since satellite navigation requires a geolocation signal from the satellite (transmitter) to the GPS sensor (receiver), any physical obstructions such as an array of leaves or even in an indoor environment may block the signal from propagating directly from the transmitter to the receiver. Not only that, satellite navigation always requires the user to re-calibrate each time it is wanted to be used. Hence, it is very time-consuming and it is such a tedious situation for the new or inexperienced user to use it as *plug-and-play*.

The second problem is the recent GPS-independent navigations are using multi-sensors which results in higher financial costing. It is true that the multi-sensors approach does provide a significant result for the vehicle to drive autonomously, but in terms of implementation in the real world, it might not gain interest for any companies or consumers to utilize the technology. Hence, the development of an autonomous vehicle that uses the multi-sensors approach might be a waste.

The first objective of this paper is to set-up the UGV where GPS localisation by using a GPS sensor (UBlox M8N) and VO localisation by using a tracking camera (Intel Realsense T265). Then, the performance of the localization between using GPS navigation and VO navigation will be measured by comparing the error rate between them.

2. Materials and Methods

The UGV platform is based on the Wheeled Mobile Robot (WMR) concept [11] and it is designed with a three-wheel configuration (a wheel at the center of the front section and two wheels at the side of the rear section) [12]. For the electronic parts, the devices that will be used are Pixhawk, Raspberry Pi 4, Arduino Mega 2560, Intel Realsense T265, and Ublox M8N. For the steering system and the drive system, the components that will be used are the linear actuator and Brushless Direct Current (BLDC) motor, respectively. On the other hand, the software used in this project is Mission Planner and APSync.

2.1 Materials

Each device has its own unique functionality and they are exclusive from each other. Hence, these functionalities are only limited in a certain scope, particularly in this project.

- Pixhawk is used as the autopilot’s firmware to obtain the vehicle’s parameters.
- Raspberry Pi 4 with pre-installed APSync is used to provide the access point to inter-communicate between the user PC and Pixhawk as well as providing a web interface to display the telemetry data from the Pixhawk wirelessly.
- Arduino Mega 2560 is used as the motor, actuator, and servo controller.
- Intel Realsense Tracking Camera T265 is used as the VO camera to localize the vehicle without using satellite navigation.

- U-Blox M8N is used as the GPS receiver to localize the vehicle by using satellite navigation.
- Linear actuator (powered by 24V DC power source) is used as the steering motor.
- BLDC motor (powered by 48V DC power source) is used as the drive motor.
- Mission Planner (ArduRover) software is used as the platform for autopilot's navigations and settings.

2.2 Methods

The overall integration of the electronic parts, steering system, drive system, and the software that results in the motion of the UGV are shown in Figure 1 and the flowchart in Figure 2 elaborates the navigation process execution. From Figure 1, the step-by-step procedures for giving output to the steering system (linear actuator) and drive system (BLDC motor) are as follows:

1. The LiPo battery will power up the motor driver, motor controller, and Raspberry Pi 4 at the initial startup.
2. Then, the motor controller will give input power to the hall effect sensor, the motor driver will give input power to the linear actuator, and Raspberry Pi 4 will input power to Pixhawk, Intel T265, and Arduino Mega 2560.
3. The User PC that has Mission Planner will be connected to Pixhawk wirelessly through APSync's access point (Raspberry Pi 4) by using User Datagram Protocol (UDP) communication with a baud rate of 916000 and port 14550.
4. The flight modes that are selected in Mission Planner will initiate the Pixhawk to send output signals to the Arduino Mega 2560. Then, the Arduino Mega 2560 will translate the output signals from the Pixhawk to give controlling signals to the servo and linear actuator.
5. If the Auto Mode is used, the Pixhawk will send automatic controlling signals for the vehicle to follow the mission. If the Manual Mode is used, the Pixhawk will send controlling signals for the vehicle according to the signals that were obtained from the RC transmitter.
6. The linear actuator moves accordingly to the given input controlling signals.
7. The servo moves accordingly by the given input controlling signals. Then, the servo that is attached to the permanent magnet will touch the hall effect sensor. After that, the BLDC motor will rotate with the speed accordingly to the distance between the permanent magnet and the hall effect sensor.

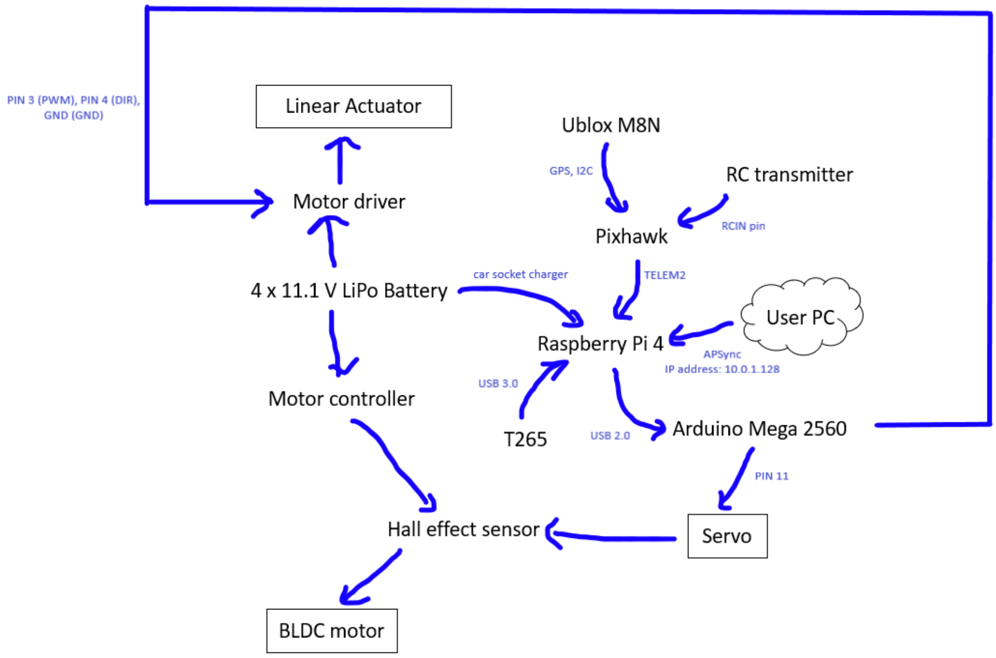

Figure 1: The logical interconnection between all of the materials used

From Figure 2, the navigation process happened is controlled and monitored by using Mission Planner software from the User PC. The step-by-step of these processes are as follows:

1. The user has to set whether to use GPS navigation or VO navigation. If using GPS navigation, the EKF3 source's parameter will be set to 3 and if using VO navigation, the EKF3 source's parameter will be set to 6.
2. To set the Home, for GPS navigation, the Home has can be set by selecting "Set EKF Home here" while for VO navigation, the Home can be set automatically by the GPS location.
3. Set the waypoint by adding between two points or more.
4. Select whether to Arm / Disarm. If Arm, the UGV will stop and recheck the condition. If Disarm, the robot will move from the current point to the next point.
5. The UGV will check the condition if the vehicle has arrived at the next (target) point. If the UGV has arrived at the target point, the UGV will check whether it is a Return To Launch (RTL) point or the mission point. If the UGV still has not arrived at the target point, the UGV will continue to move.
6. If the UGV detects that the vehicle has arrived at RTL, the UGV will stop. If the UGV is still not arrived at the RTL, the UGV will detect that it has arrived at the target point and it will change the direction to move to the next point.

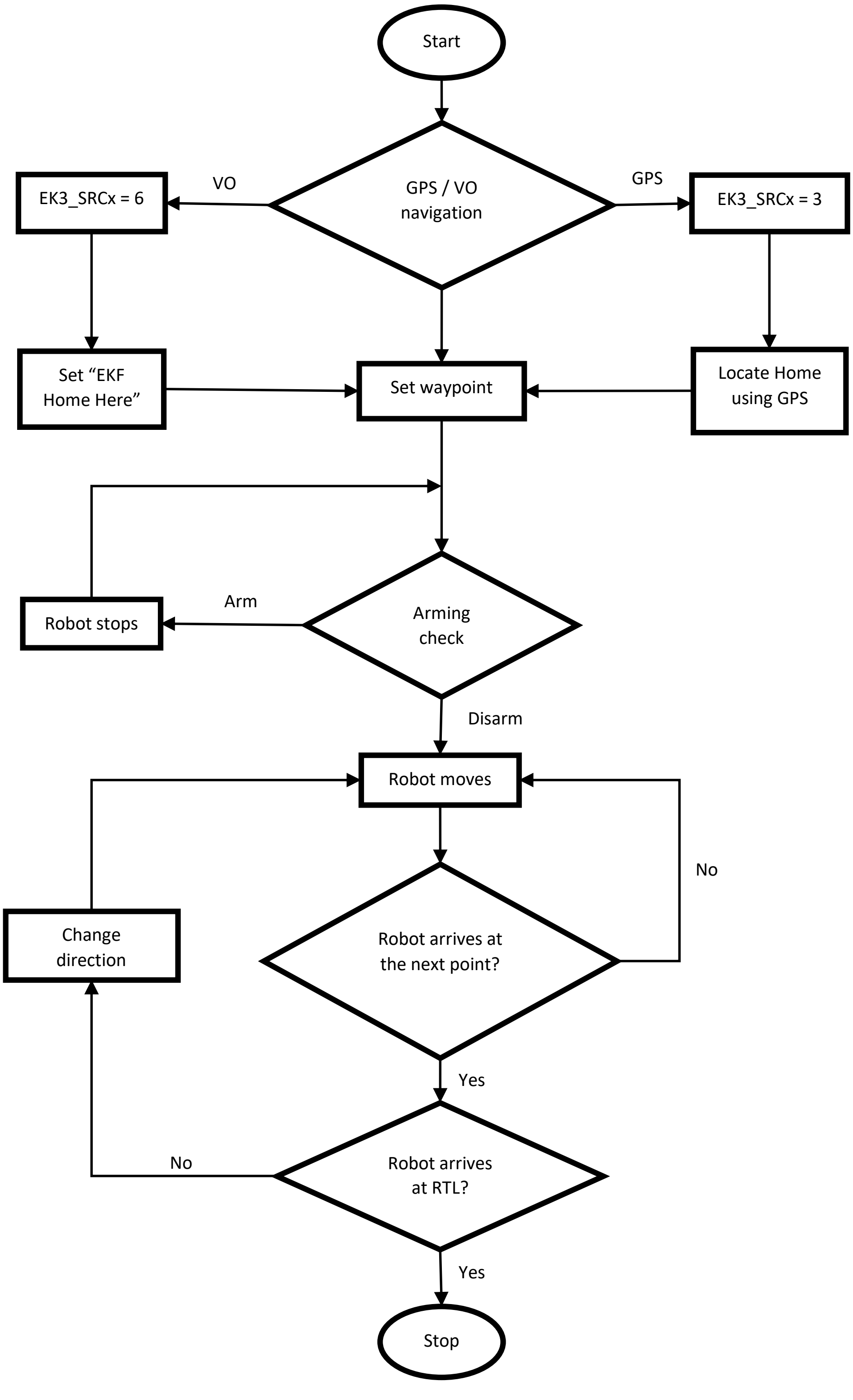

Figure 2: The flowchart for the UGV navigation process

3. Results and Discussion

3.1 Results

The waypoints that are set in the Mission Planner are also called the missions. In conducting the test, the flight mode is set to Auto Mode so that the UGV will follow the missions from point to point. Figure 3 shows the UGV navigating through the missions using the GPS navigation method where the points are set to 4 points where the first point is the initial point and the Return to the Launch point. The interconnection line between the two points is called a waypoint. The distance traveled between one point to the next point is approximately 5 meters. On the other hand, Figure 4 shows the UGV navigating through the missions using VO navigation.

The results from the VO navigation (Figure 4) are compared with the GPS navigation (Figure 3) and tabulated in Table 1. Throughout the test, Test Batch 2 shows the nearest distance traveled compared to GPS navigation (2.5 meters) for each waypoint. Also, it can be seen that the average distance traveled by UGV using VO navigation in Test Batch 2 has the least distance deviation or error which is 0.21 meters compared to Test Batch 1 and Test Batch 3.

Figure 3: The waypoints for the UGV when moving using GPS navigation

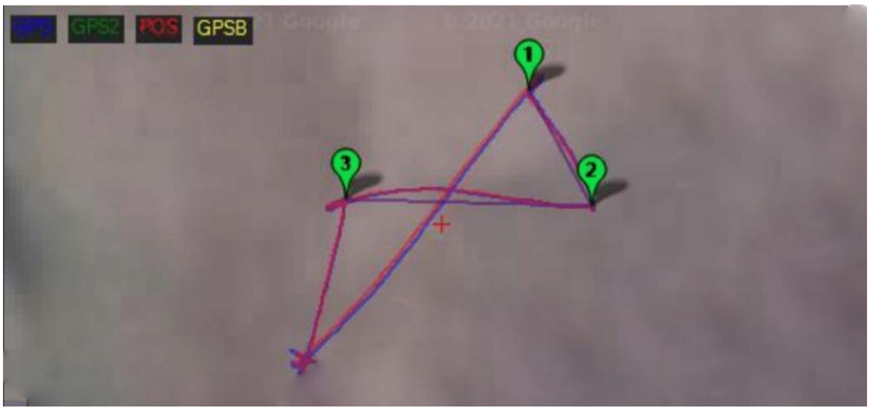

Figure 4: The resultant route when the UGV moves using VO navigation

Table 1: The error between the distance set waypoints (GPS navigation) and the distance travelled by UGV using VO navigation

Test Batch	Waypoints	Distance travelled by UGV using VO navigation, m	Error, m
1	1	2.25	2.5 – 2.26 = 0.24
	2	2.27	
	3	2.27	
	4	2.25	
2	1	2.27	2.5 – 2.29 = 0.21
	2	2.29	
	3	2.29	
	4	2.31	
3	1	2.26	2.5 – 2.26 = 0.26
	2	2.26	
	3	2.27	
	4	2.25	

3.2 Discussion

Based on the best result obtained which is Test Batch 2 in Table 1, the PID tuning is separated into two parts which are the Steering Rate's section and the Speed/Throttle's section with the configuration of Turn Radius in the Steering Rate's section is set to 1.5 and the other parameters are set as default. Hence, based on Figure 5, for Steering Rate's section, the best value for the P value is 0.00528620, the I value is 0.14430414055, the D value is 0.019767, the IMAX value is 79, and FF value is 0.811. On the other hand, for Speed/Throttle's section, the best value for the P value is 0.9681, the I value is 0.9966, the D value is 0.0484, and IMAX value is 140.

Steering Rate
P 0.005
I 0.144
D 0.020
IMAX 1.000
FF 0.811

Steering Mode
Turn Radius 1.5

RC7 Opt ArmDisarm
RC8 Opt Auto
RC9 Opt Steering
RC10 Opt Loiter

Speed/Throttle
P 0.968
I 0.997
D 0.048
IMAX 1.000
Accel Max (m/s/s) 1.0
Brake Enable
Cruise Speed 2.0
Cruise Throttle 50

Throttle and Motors
Motor Type Normal
Throttle Min (%) 0
Throttle Max (% 100

Navigation
WP Speed 2.0
WP Radius 2.0
WP Overshoot 2.0
Turn G Max 0.600
Lat Acc Cntl Perio 8
Lat Acc Cntl Damp 0.75

Figure 5: The optimized PID tuning which resulted from the best output in Test Batch 2

4. Conclusion

As this project was finished, the UGV that was compatible with the VO-camera for the visual-based navigation and GPS receiver as the data evaluation purpose was able to be built. During the testing, the devices were not having issues regarding their placement whether they were dislocated, loosen, or broken down. Also, the performance of the VO-navigation can be achieved and when compared to GPS navigation, the least error produced by VO navigation is 0.21 meters. The results of VO navigation can be further improved by using different values of PID gains, data filters, and camera technologies. Plus, the low-cost multi-sensor approach which is combining the VO camera and another passive sensor such as an ultrasonic sensor can produce robust navigation as the ultrasonic sensor can provide range detection.

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