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Design and Control of Autonomous Rover for Foliage Navigation

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Design and Control of Autonomous Rover for Foliage Navigation

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Abstract. Implementation of UGV in civilian applications is getting trendy and normalized due to its solid achievement in executing mission under harsh environments. The UGV foliage environment-oriented applications even attracted the people's attention in correspond sectors to ease their tasks with guaranteed performance. Given this, the development of the autonomous rover from sensors and control aspects with the consideration of foliage environment interest people to enhance its functionality. To ensure the sensor is not easily affected by the environment factor, the radar and the camera are selected to provide the environment perception to the rover. The approach for a linear Proportional-Derivative (PD) controller with the dynamic modelling of the UGV is also discussed in this paper. The study shows preliminary results that are working.

1. Introduction

In recent years, the modern electronics devices and related technologies get more advance and bring more convenience to humans. Along with the gradual process of engineering technology, tactics such as sensor techniques, control methods and intelligent techniques even enhanced provided a strong fundamental and feasibility of an Unmanned Ground Vehicle (UGV). The UGV or colloquially as autonomous rover is commonly developed for military and civilian applications such as search, rescue, agricultural irrigation and logistics in real world. The specific uses of UGVs in those applications increase the accuracy, efficiency and safety in all the tasks that are considered unhygienic, exhausting and dangerous for manual work. According to a recent report published by Allied Market Research, the global UGV market generates 2.12 billion dollars in 2020 and estimated to reach 6.04 billion dollars by 2030 with a compound annual growth rate (CAGR) of 11.4% from 2021 to 2030 [1]. This statistic shows the implementation of the UGV in different applications is getting extended with years and its performance guarantee the returns of the investment.

Certainly, the primary motivation of the UGV's development is to replace the functions and the risks undertaken by humans while executing tasks. This significant motivation brings in the UGV's main feature of no onboard human presence yet it can still be controlled by onboard computers or remotely by human via the ground control station (GCS) as the remote unit during the operation. To achieve this main feature, the UGV has to own certain level of intelligence in understanding the given commands, well-known the condition of its surrounding environment and behave as expected which are just like the brains, eyes and legs of a human being. The intelligence of UGV can be integrated via corresponding embedded, hardware and software system. Microcomputer and microcontroller with suitable peripherals are expected in controlling the UGV. Some other essential components such as motors, motor drivers, GPS module and remote controller are also required as a part of the UGV to perform the task.

As for the software system aspect, different intelligent techniques are needed to be brought into the operation of the UGV in ensuring its functionality and durability while executing tasks. Typically, these techniques can be categorized into four parts which are mission decision and navigation, environment perception, localization and path planning and chassis dynamics control [2]. The mission decision and navigation module help the UGV to understand the assigned task and calculate the navigation path from its global position to the destination location. Environment perception assists UGV in apprehend its surrounding environment information which is essential correlated with other modules to carry out the task. Generally, the surrounding information are usually obtained with the aid of equipped sensors such as cameras, radar, lidars and others with their respective sensation method. By retrieving the information and post-process them via the microcomputer, the UGV gains the obstacle detection and avoidance ability protecting itself from being damage at the same time executing complexity task with good performance.

While for the localization and path planning module, two approaches which are the usage of Global Navigation Satellite System (GNSS) receiver or relevant algorithms are commonly used on UGV depending on the application. Due to the mature GNSS system, the usage of GNSS receiver relatively ease the localization and path planning of UGV with only inputting the destination global coordinate. Its user-friendly and convenient integration properties hold its top position in the users' priority list of localization and path planning module. However, the GNSS receiver lost its function when it fails to receive the location information at places that block the line of sight of GNSS satellite shows distinct and critical shortcoming to the UGV. Thus, relevant algorithms including Simultaneous Localization and Mapping (SLAM), Monte Carlo Localization (MCL) and Distance Vector Hop (DV-Hop) are invented to provide an alternative to GNSS system [3]. Yet, these algorithms require high computational power microprocessor to process the information retrieve from the sensors equipped on the UGV.

The aforementioned modules help the UGV in understanding the external information along with the command assigned to it. Nonetheless, the UGV needs a property control system to govern the movement information receive and respond correspondingly to the command as expected. This leads to the chassis dynamics control module which the purpose is to control all the actuators of the UGV with the vehicle's distance rate information as input. This module helps the UGV to achieve the ideal speed controlling and navigation with desirable handling stability and dynamic behaviour. The importance of the robust and precise control of an UGV is critical when it is executing task especially in hazardous missions. Minor errors in those missions are not desirable as it could cause irreversible consequences which not only bring economically lost but also casualties. Thus, the precision control of the UGV's dynamic behaviour is always treated as the core and fundamental of the UGV system before heading to advance and complex applications.

As mentioned above, UGVs are commonly developed for specific civilian applications in present time to replace human in unhygienic, exhausting and dangerous manual work. With the UGV showing its potential and glowing performance in foliage environment, it has been imported into the agriculture sector lately with the concept of 'Smart Farm' to perform automatization agriculture tasks including fertilizing, planting, spraying and harvesting [4] [5]. Yet, it is often with unstructured, static and dynamic objects in a foliage environment which shall be distinct to determine objects' category. Further, the traversable and non-traversable objects as well as processable terrain are always required to be distinguished for the UGVs to avoid the object and navigate to its destination [6]. In a foliage environment, the tall grass or spaces between leaves are categorized as traversable and processable whereas objects such as tree trunks, humans, animals, water and pothole are not [7]. The difficulties in the environment and its commercial values have provided great research values and motivation to perform this research.

Consequently, the above factors lead to the research of design and control of a semi-autonomous rover for foliage navigation with three objectives. Critically reviewing the state-of-art sensors and identifying suitable sensors on the autonomous rover for localization purpose in a foliage environment is the core objective in this research. It is followed by implementing an PD control solution as the fundamental that achieve level 3 guided autonomous navigation for ground rover. A dynamics model of the skid-steering rover and an adaptive control method are adopted in this research to achieve the PD control system that enables smooth and stable dynamic behaviour during autonomous navigation. The final objective will be developing a remote pilot ground control station (GCS) for monitoring and controlling of the autonomous rover in foliage environment. A simple graphical user interface (GUI) of the remote pilot GCS will be designed and communicated to the autonomous rover via Mavlink protocol to gain control of the rover without using the radio controlled (RC) telemetry.

TABLE 1. Advantages and Disadvantages of Different Sensors

References	Sensors	Advantages	Disadvantages
[3, 5, 8 – 13]	Stereo Camera	• Wide field-of-view • High informative data (picture) can be captured • High time-of-flight (ToF) • Features extractable (information can be further processed)	• Low penetrating ability • Easily affected by weather and illumination conditions • High computational load • Short detection distance • Depth information cannot be obtained on single-colour featureless plane
[3, 5, 9, 13, 14]	RGB-D Camera	• Wide field-of-view • Depth information can be obtained • Higher precision compared to stereo camera as the distance from the object gets further (not more than 3m) • Features extractable (information can be further processed)	• Limited measuring distance to 3m • Errors in depth measurement increase with distance from the sensor • Reflective, absorptive and transparent surfaces cannot be captured • Interference occurs when the same scene is captured by 2 RGB-D cameras
[5, 8 – 11]	Radar	• Wide field-of-view • Sensation ability better than cameras and lidar sensor • Not easily affected by weather condition	• Low resolution for object identification • Low accuracy • Filters are needed for data pre-processing • Limited to colour and texture information
[3, 5, 8 – 12 , 15]	2D/3D Lidar	• Wide field-of-view • High data collection accuracy • Capable to work in low visibility (dim) environment • Depth information can be obtained	• Easily affected by harsh environment condition (E.g : low reflective target, rain, smoke, dust) • Cannot detect transparent material • Poor performance in detecting dark and specular object (absorbed or reflected most of the laser beam radiation.

An UGV is usually developed by taking the consideration of the application's requirements and the environment factors before it is put into specific application. Hence, critically reviewing different combinations of sensors has become the key part under the UGV's development to ensure it is capable dealing with different conditions happened during the operation. In a foliage environment, the UGV needs to be able in detecting different unstructured, static or dynamic objects and distinct their traversability. Thus, the UGV needs more capable and suitable sensors integrity to capture the information in the foliage environment. To better understand the sensor combinations, the core of the related studies has been critically analysed and summarized in Table 1.

The pros and cons of stereo camera, RGB-D camera, radar and lidar have been analysed and tabulated in Table 1. Lidars and radars that are capable in obtaining the depth information under low visibility environment should be highlighted as it allows the UGVs to operate in day and night at the same time performing obstacles avoidance function [8]. Besides, the robust function of radars in obtaining reliable information under harsh environment shall be emphasized as it is a critical safety factor that ensure the UGV has satisfying performance regardless of the operating conditions [11]. The colour feature of the RGB-D camera is also another shining point as obstacle can be detected and classified with its colour information. The feature extractable function of both cameras that can used for machine learning shall not be neglected as well which could be a useful function for different purposes.

Nevertheless, the sensors mentioned above come with its shortcomings that should be analysed critically to avoid sensor selection not applicable to the foliage environment. Both cameras and lidar sensors are easily affected by the worse weather or weak illumination conditions of the environment [8]. Low penetrating ability and failure in detecting reflective, absorptive and transparent surfaces of both cameras and lidars shall be taken into consideration as well for the obstacle avoidance as well as navigation of UGV in foliage environment.

The lidar mentioned in many of the UGV's related papers often refers to 2D or 3D lidars. The lidars can provide high accuracy and consistency result in detecting the object distance and performing 3D mapping via point cloud. However, the complexity in processing the data and high costs leads to its elimination from the selection. As compared to lidars, radars have lower complexity in processing the data as it emits and receives the radio wave to detect the objects. Radars also capable in measuring the speed and distance of the objects. The low complexity and the robust nature of radio wave in facing different environments become the reason of being selected [11]. Yet, the simplicity of radars is also the critical point that causes it not to be the most suitable sensor in UGV due to the complexity environment on ground. Many objects can be treated as obstacle which radar could not identify and classify them. Thus, radars are often needed to integrate with other sensors to provide environment perception to the UGV [10].

The colour feature and depth information of RGB-D camera is always the critical factor that people are selecting it for different purposes. The colour feature is compatible with the machine learning algorithm which provided much more functions that it carries to the UGV [14]. The unique feature of capturing the objects' colour aids in classifying the object types is a very good option to be implemented in UGV for obstacle classification and avoidance. Besides, it also provides depth information from an object which is replacing the function of other range detecting sensors. Yet, RGB-D camera with shining advantages also comes with its complexity in handling the data. Data from RGB-D camera is difficult to perform data integrity with other sensors and interference might occur.

2. Equipment and programming interface

There are various of steering system selection for UGV with their respective pros and cons. The UGV discussed in this paper uses the skid-steering system that has high manoeuvrability, low mechanical complexity and low control complexity. The Mateksys H743-WING V2 flight controller along with the Electronics Speed Controlled (ESC) motor driver is used to control the UGV steering system via Pulse Width Modulation (PWM) signals. To gain the manual control of the rover, a RC receiver is connected to the flight controller and a RC telemetry is used to transmit the movement commands. Besides, a Global Positioning System (GPS) receiver is mounted on the rover and connected to the flight controller to receive the GPS signals and perform high accuracy navigation. As for the power source, a lithium-ion (Li-ion) battery pack with 7 cells (7S) in series is used to provide the nominal voltage of 24V and nominal capacity of 10Ah to the components inside the rover's body.

For the data processing, Nvidia Jetson Nano is selected as the microcomputer of the UGV to perform real-time data analysis, execute specific mission command and data communication with the Mateksys flight controller. Jetson Nano with Linux based kernel and python programming integrated development environment (IDE) provides a good platform in communication between the components. Besides, its outstanding performance in AI applications also aids in UGV's real time video processing of the surrounding environment. Different data communication protocols such as Universal Asynchronous Receiver-Transmitter (UART), Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI) protocol are also available on Jetson Nano which UART protocol is used in this paper to conduct effective communication with the flight controller.

As for the range sensors, the Acconeer XE132 radar and 8MP IMX219 camera module are selected to provide environment perception ability to the UGV. As the XE132 radar is well-integrated board with python programming, the data transfer is achieved via UART protocol to Jetson Nano. Its available python library also aids in data processing and communication among the python scripts. On the other hand, the 8MP IMX219 camera module is connected to the Jetson Nano to provide the vision of the surrounding with colour information to better understand the environment.

3. Methodology

As aforementioned, the radar and camera were selected as the range sensors to be equipped on the UGV. In the obstacle detection and avoidance task, the radar plays the core barrier role of the UGV in preventing collision and providing object distance information. The camera acts as the eye of the UGV by providing vision information of the surrounding condition. Both range sensors will operate simultaneously to determine the object distance and avoid from the collision. After providing the environment perception to the UGV, its dynamic behaviour will be controlled via the rover's controllers by developing its mathematical model and getting the optimal solution. The overall system integration is shown in Figure 1.

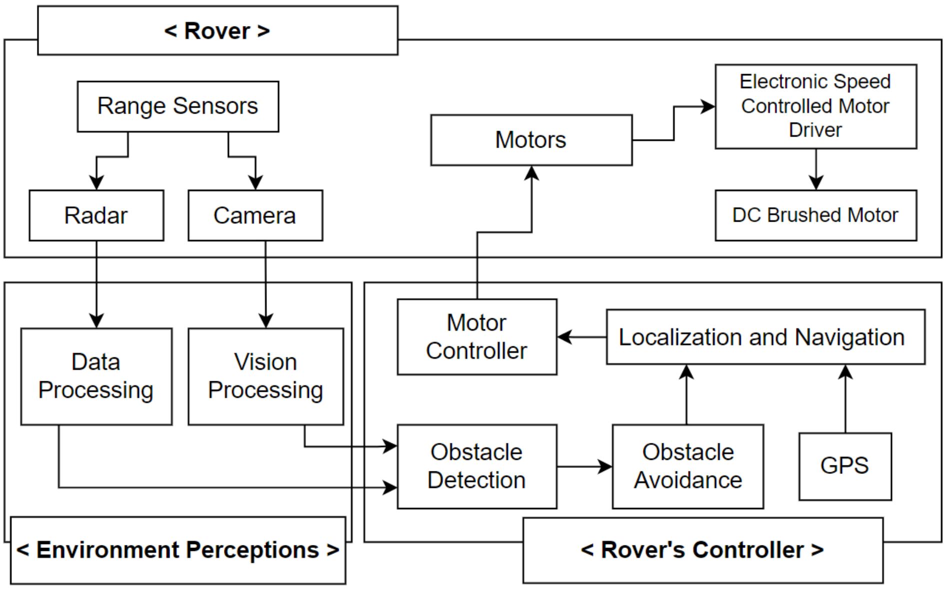

Figure 1. Block diagram of the autonomous rover integrated system

Other than that, a remote pilot ground control station will be developed to provide the pilot a better monitoring and controlling method remotely on the rover under operational mode. The ground control station includes the real time vision of the UGV, surrounding information and smart communication with the pilot to ensure the pilot is always well aware of the rover's condition. When the UGV encounters an obstacle, it will warn the driver and prompt the best suggestion of UGV's moving direction to avoid the obstacle at the same time proceed its navigation. The UGV's feedback with smart recommendation is designed to ensure the finally decision-making authority is in the driver's hand. This feature can maximize the UGV's autonomous level at the same time avoiding destruction of the UGV due to unexpected circumstances. The overall operational system of the UGV is shown in Figure 2.

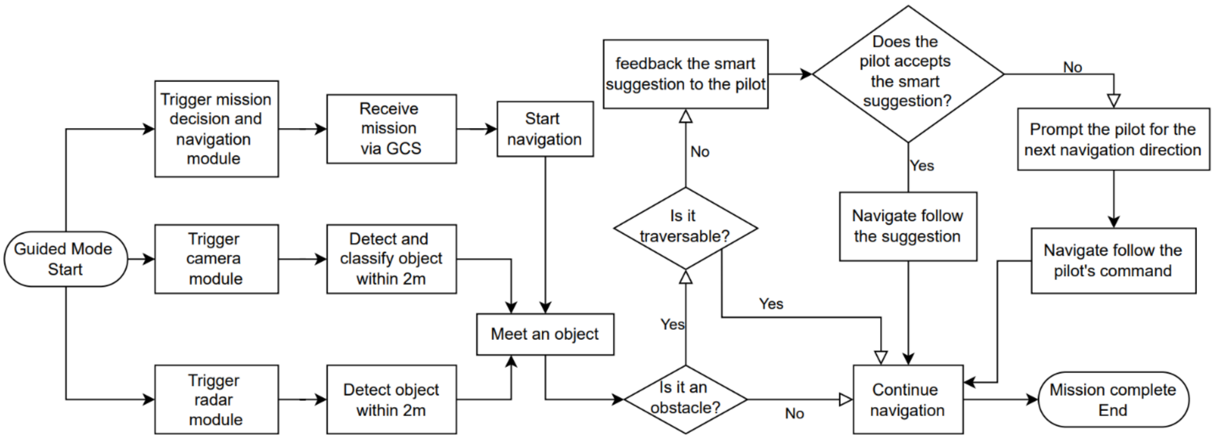

Figure 2. Flowchart of the level 3 autonomous rover operational system

3.1. Radar Information Processing

The Acconeer XE132 evaluation kit radar module consists of a A111 60GHz pulsed coherent radar (PCR) which provides high accuracy of the depth information within 10m and about 50° horizontal field of view. Besides, it comes along with its own microcontroller unit and python programming interface which ease the analysis and transfer process of the data to the microcomputer in Linux basis. To better understand the operation of the radar, the mathematical concept of the radar signal transmission and the signal processing is discussed below.

The radar module emits 60GHz PCR signals that travel at the velocity, v_{rf} of approximately 300 m/s. The calculation of the depth information as shown in Equation (1) utilizes the time elapsed between the transmission and reception of the reflected signal, t_{delay}, when the transmitted radio signals get reflected by an object. As the signals transmit to and reflected by the object, the distance of the signals travelled have been doubled as shown in Figure 3. Thus, a division of 2 is needed to get the accurate distance of the object.

$$Distance, d = \frac{t_{delay} \times v_{rf}}{2} \tag{1}$$

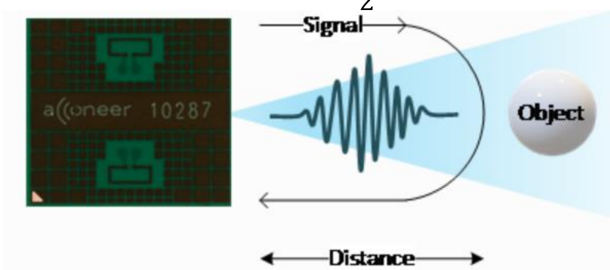

Figure 3. Illustration of the transmission and reception of the radio wave

The amplitude of the reflected radar signals is digitalized and quantized to eliminate the noise in the complex ground environment and the information is stored in numpy array in python. The range interval with certain step length is pre-configured in advance to determine its detecting range and data length per sweep during the operation where their relation is shown in Equation (2). As the reflected radar amplitude is quantized, it will be stored in corresponding data length over every sweep as illustrated in the example below. To obtain the depth information, Equation (3) is used by extracting the position of the highest amplitude, $dl(A)_m$ within the data length which is reflected by the object.

$$Data\ length, dl = \frac{range\ interval}{step\ length} \tag{2}$$

$$Distance, d = starting\ interval + [step\ length \times dl(A)_m] \tag{3}$$

The accuracy of the depth information can be further improved by reducing the step length which resulting in higher data length. To deal with multiple objects detection within the detecting range, the method above can be enhanced by setting the threshold value of the radar amplitude and return its data length position.

3.2. Skid-Steering model of the Autonomous Rover

To develop the control solution of the UGV, it is essential to understand the mathematical relations between the electrical and mechanical parameters of the UGV by constructing its dynamic modelling. Figure 4 shows the rover's skid-steering model in global frame with some of the essential control parameters to construct its state-space model.

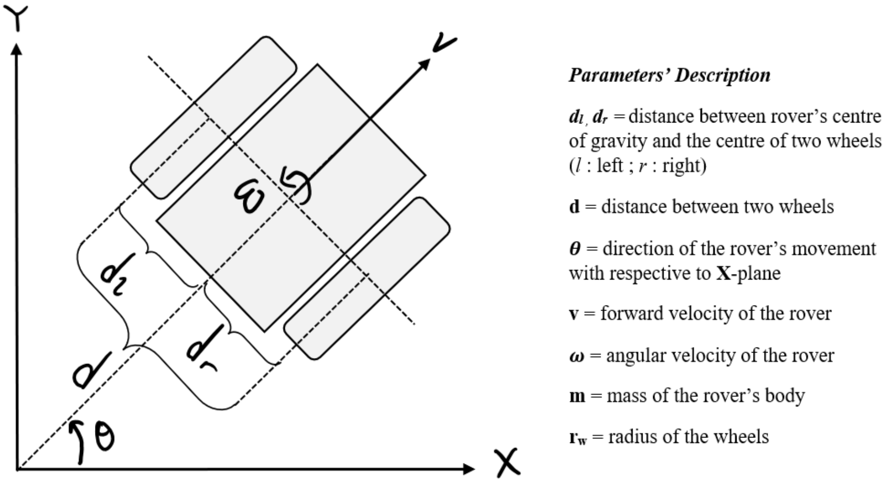

Figure 4. The dynamic model of the UGV and its parameters.

As the control of the rover's movement is respect to the rover's coordinate and its current heading, which is known as local frame, it is essential redefine a new coordinate system that is origin from the rover body and follows along the rover's movements. The new coordinate system is defined with the subscript of b with respects to the corresponding axis signifying the rover's coordinate as shown in Figure 5. As the local frame of the rover, xb and yb will translate and rotate together with respect to the global frame, therefore the relationship between global frame and local frame can be formulated as shown in Equation (4).

$$\begin{pmatrix} x_b \\ y_b \end{pmatrix} = R \begin{pmatrix} x \\ y \end{pmatrix} \tag{4}$$

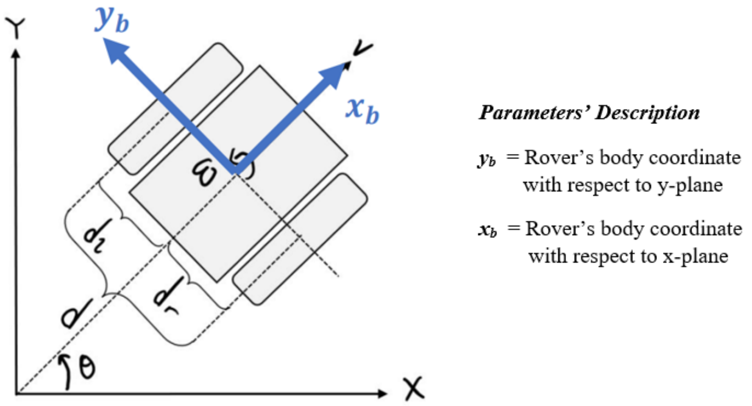

Figure 5. The redefined coordinate system (local frame) with respect to the global frame.

R as shown in Equation (5) is defined as the 2D rotational matrix which represent the translation and rotation of the rover [16].

$$R = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \tag{5}$$

As the rover moves in 2D plane, the only two concern parameters are the forward displacement, $\boldsymbol{x_b}$ and rotational angle, $\boldsymbol{\theta}$ where their relations with the rover's velocity, $\boldsymbol{v}$ and angular velocity, $\boldsymbol{\omega}$ can be formulated as shown in Equation (6) and (7).

$$\dot{x}_b = v \tag{6}$$

$$\dot{\theta} = \omega \tag{7}$$

To understand the dynamic behaviour of the rover, it is essential to understand the force acting on its centre of gravity where the forces can be studied as shown in Figure 6 and the relations between the forces are formulated in Equation (8). As the forces of the rover are produced by the mechanical torque of the wheels, the relations between the forces and torques can be formulated in Equation (9).

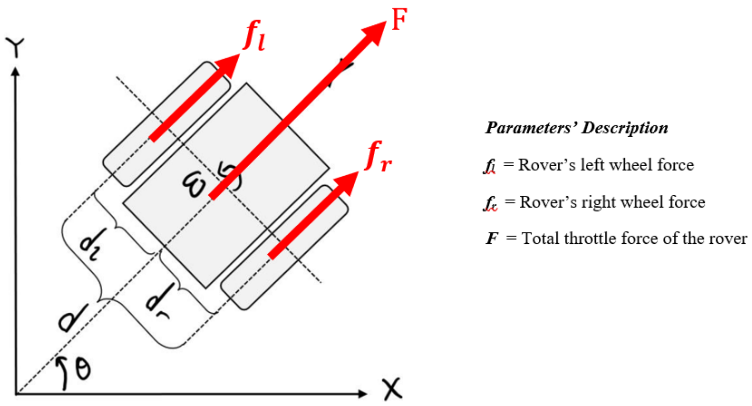

Figure 6. Force acting on rover's centre of gravity.

$$\vec{F} = \vec{f_l} + \vec{f_r} \tag{8}$$

$$\tau = d\,f\,sin\theta \tag{9}$$

where $\boldsymbol{\tau}$ indicates the mechanical torque of the wheels, *d* indicates the distance which can be represented as the radius of the wheel in this case and $\boldsymbol{f \sin \theta}$ is the force perpendicular to the wheel. Since the angle between the applied forces and the wheels are always equal to 90°, thus the $sin\ \theta$ is always equal to 1 and Equation (9) can be related the left and right forces of the rover's wheels as shown in Equation (10) and (11). The subscript of $\boldsymbol{l}$ and $\boldsymbol{r}$ indicate the left and right side of the rover, and $\boldsymbol{r_w}$ indicates the radius of the wheel. As both wheels are identical, thus the radius of the wheels is considered to be the same.

$$f_l = {}^{\tau_l}/_{r_w} \tag{10}$$

$$f_r = {}^{\tau_r}/_{r_w} \tag{11}$$

According to the Newtons' Second Law, the force acted on the rover's body is the time rate of change of momentum which can be comprehended as the product of the rover's mass multiply with its acceleration as shown in Equation (12) [17].

$$\vec{F} = m\overrightarrow{(\dot{v})} \tag{12}$$

By relating Equation (8) and (12), the relation between the acceleration in terms of mass and torque can be formulated as shown in Equation (13).

$$\begin{gathered} m\overrightarrow{(\dot{v})} = \vec{f_l} + \vec{f_r} = \frac{\tau_l + \tau_r}{r_w} \\ \overrightarrow{(\dot{v})} = \frac{1}{mr_w}[\tau_l + \tau_r] \end{gathered} \tag{13}$$

Referring to Figure 6, the torque of the rover relates to its rotation can be described in Equation (14) as the rotation of a skid-steering will cause two wheels rotate at different directions. According to the Newton's' Second Law for Rotation, the torque of body can be described as the product of its moment of inertia, I and the angular acceleration, $\dot{\omega}$ as shown in Equation (15) [18].

$$\tau = f_r d_r - f_l d_l \tag{14}$$

$$\tau = I\dot{\omega} \tag{15}$$

By manipulating Equation (15) and relates it to Equation (14), (10) and (11), the angular acceleration of the rover with respect to the torque of the wheels can be formulated as shown in Equation (16).

$$\dot{\omega} = \frac{1}{Ir_w}[-\tau_l d_l + \tau_r d_r] \tag{16}$$

With so, all the interested parameters of the rover with respect to their outputs are formulated. By combining the Equation (6), (7), (13) and (16) into matrices form, clearer relations of the parameters are given as shown in Equation (17) and its state dynamic equation is shown in Equation (18). As the main concern output of this model would be the rover's forward displacement, $\boldsymbol{x_b}$ and rotational angle, $\boldsymbol{\theta}$, the output matrix equation is formulated as shown in Equation (19) and its state output equation is shown in Equation (20).

$$\begin{bmatrix} \dot{x}_b \\ \dot{v} \\ \dot{\theta} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_b \\ v \\ \theta \\ \omega \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{mr_w} & \frac{1}{mr_w} \\ 0 & 0 \\ -\frac{d_l}{Ir_w} & \frac{d_l}{Ir_w} \end{bmatrix} \begin{bmatrix} \tau_l \\ \tau_r \end{bmatrix} \tag{17}$$

$$y = \begin{bmatrix} x_b \\ \theta \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_b \\ v \\ \theta \\ \omega \end{bmatrix} \tag{18}$$

With Equation (17) and (18), the complete matrix of the rover's dynamic state space model is ready to be converted into transfer function which represent the dynamic system of the rover. The overall block diagram of the closed-loop control system of the rover is shown in Figure 7.

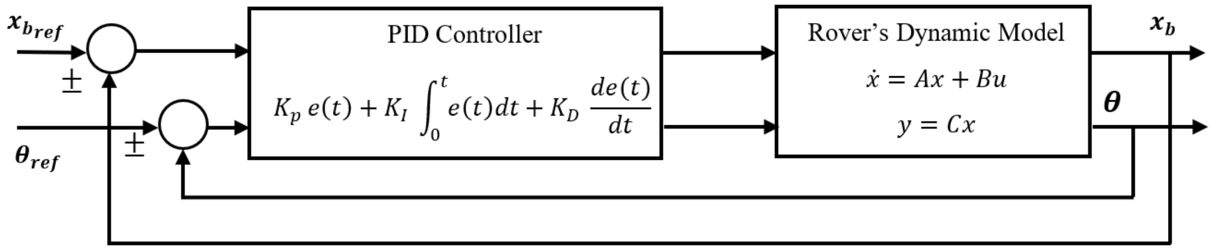

Figure 7. Closed-loop control system of the UGV

3.3. Remote Pilot Ground Control Station

The remote pilot ground control station is developed to provide an environment that is convenient in monitoring the UGV's operation and to gain even more control of the rover remotely rather than RC telemetry. Real time vision information can be transmitted back and displayed on the monitor so the pilot is always aware of the rover's environment condition. A simple illustration is shown in Figure 8 to better visualize the overall idea.

Figure 8. Illustration of a simple remote pilot ground control station

To perform the manual control of the rover without user RC telemetry, the python library – tkinter provide the convenience by running the python script on the Jetson Nano. Jetson Nano that is connected to the flight controller of the rover will transmit the command in real time to the flight controller and perform as expected. The flowchart of the control algorithm is shown in Figure 9.

Other than python Tkinter library to achieve manual control, a python GUI is also developed to include other features such as displaying data and vision processing result from Jetson Nano, control of the flight controller's servo output, different missions button linking to the respective python scripts. The python GUI is expected to provide more convenience at the same time user-friendly to the pilot to reduce the control complexity to the minimal. With so, the industrial value of the UGV is further expanded as its control not only limited to the experience pilot but also any other users who are new to it.

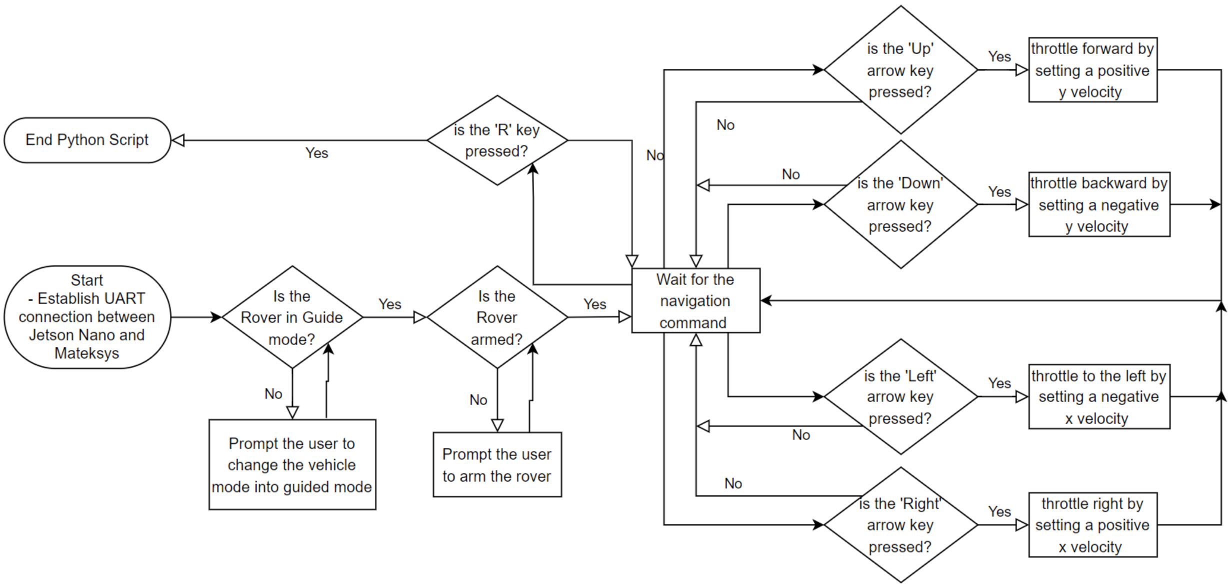

Figure 9. The flowchart of Python Tkinter library keyboard control algorithm

4. Results and Discussion

This section discussed the preliminary results that are working as correspond to the methodology

4.1. Radar Information Visualization

To validate the mathematical concept of the radar depth extraction method as mentioned above, the python scripting of the XE132 radar module with the pre-configured parameters has run a testing in a random simulated foliage environment. As shown in Figure 10, the detecting range interval of the radar is pre-set from 0.2 m to 1 m with the step length of 400 µm which produce 2000 data length. By implementing the depth extraction method, the feedback depth information shows high accuracy and reliability with the deviation of 5 cm. This shows that the implementation of radar on UGV as the defensive barrier is highly felicitous although it only feedbacks the depth information.

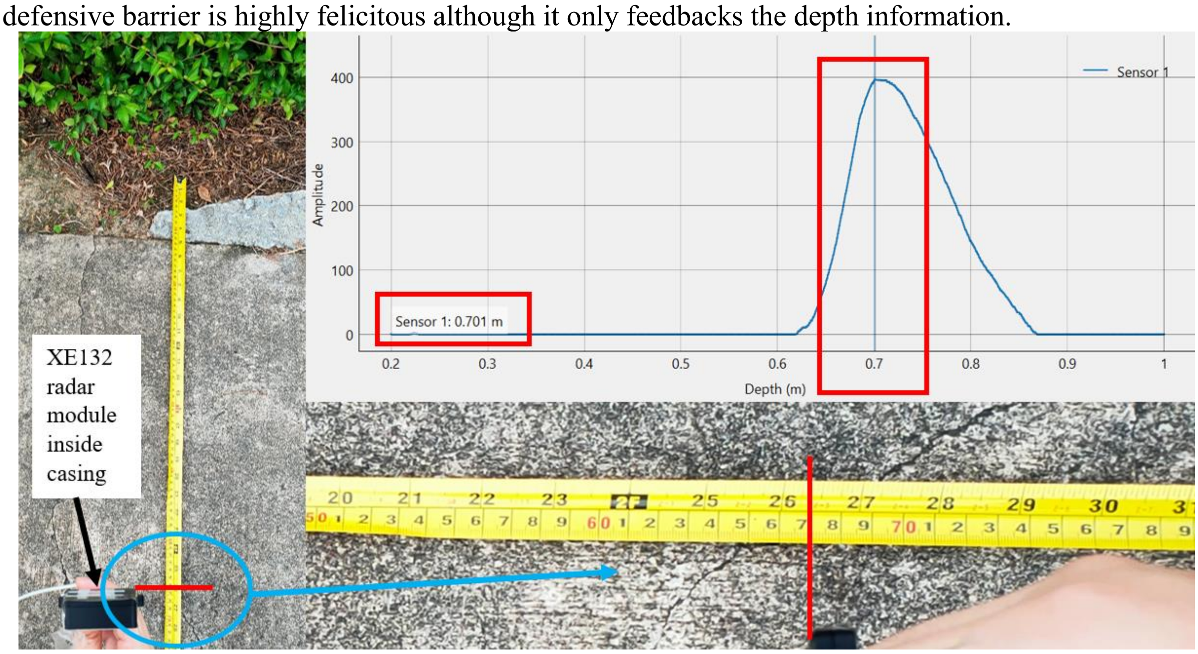

Figure 10. Radar accuracy testing on bushes

4.2. PID Controller Design

After getting the mathematical dynamic model of the rover, the closed-loop control system with the PID controller provides stable and desirable dynamic behaviours during the operation. The changes of the PID controller of the rover are shown in Figure 11 and the results are showed in Figure 12.

Figure 11. Changes of the PID values of the rover: (left) before modelling; (right) after modelling.

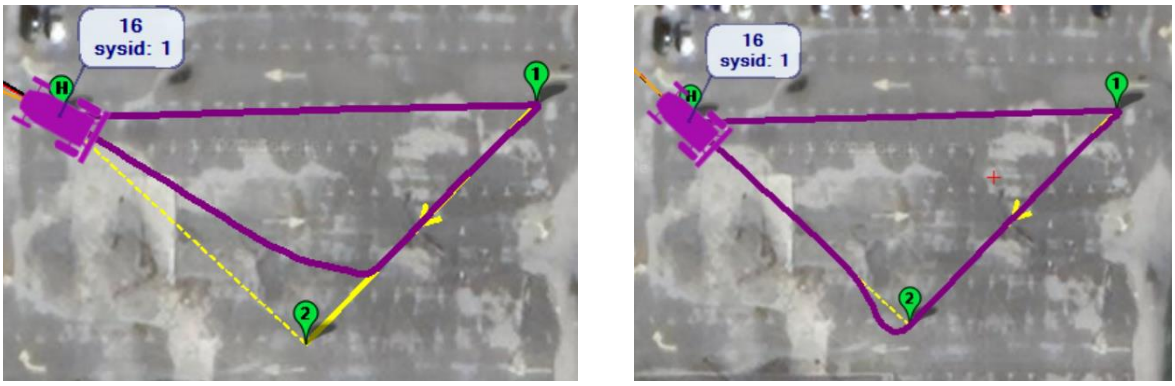

Figure 12. Rover's dynamic behaviour before (left) and after (right) PID tuning

As shown in the figures above, after the PID tuning, the rover shows better dynamic behaviour while navigating to the waypoints. Although the overshooting of the behaviour occurs from waypoint 2 back to home, it shows much better stable and desirable motion as compared to previous.

4.3. Python Scripting Control

Following the method as proposed, the manual control algorithm coded to instruct the autonomous rover is well scripted in python. Figure 13 shows the simulated results with the simulation application – Software In The Loop (SITL) inside Mission Planner. Although there is still no actual testing on the rover, but the simulation shows convincing results which has high feasibility in practical. The development of the manual control algorithm also provided the fundamental of the remote pilot ground station which to gain better control of the rover other than RC telemetry.

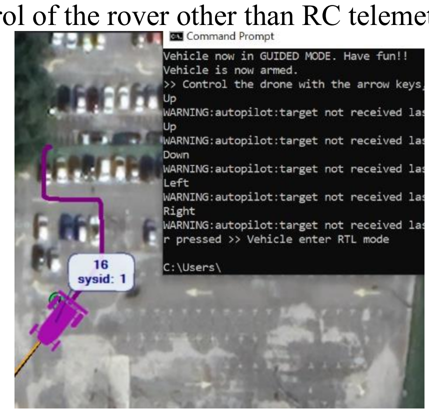

Figure 13. Illustration of rover's movements in SITL

The results show the overall manual control of the rover via python scripting. The vehicle speed is pre-set to be 5m/s as each command is given to the rover. By inputting the relative command, the ground speed of the vehicle in x and y plane will changes accordingly to respond the command. When the 'R' key is pressed, the vehicle mode will be changed to return to launch (RTL) which drive to the home location as pre-configured.

4.4. Practical Significance
As the technology gets more advance, it is doubtless that the implementation of the mobile robot is unpreventable and surely become the trend in not long future. Among all the unmanned vehicles, the UGV shows its high practicability to be implemented in different applications especially in foliage environment. A high intelligent level UGV that can replace human in executing difficult and tedious tasks is what people are looking for. By implementing the high intelligent level UGV in foliage environment, many of the health and safety factors can be ignored at the same time guarantee the tasks are completed with high precision and efficiency. However, to achieve achieving autonomous navigation, the development of a reliable and efficient obstacle avoidance system is unpreventable. A mature and intelligent autonomous navigation system that include obstacle avoidance will also be the solution to many applications that required to be in foliage environment. This is a strong motivation that could provide conveniency to not only military and agriculture but also the development for other aspects.

5. Conclusion
Overall, the preliminary results discussed in this paper show partial success of the implementation of controlling a semi-autonomous rover to operate in foliage environment. After reviewing the literature in detail, the sensor combination, radar and camera is selected to be equipped on the UGV. Both sensors are able to provide the environment perception ability to the rover which further enhance its functionality. The selected radar shows precision depth information which provided a strong defensive barrier to the UGV in avoiding collision. Besides, the high integrity of the radar also shows its potential in further processing the environment data which will be the next focus. Other than that, the dynamic model of the rover is constructed which provided a desirable PID controller to control the dynamic behaviour of the UGV. Finally, the basic control of the remote pilot ground station is also built which shows desirable results. With the latest integrated equipment, it is expected the obstacle detection and avoidance of the semi-autonomous rover could be achieved in foliage environment.

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