Design Report- an autonomous mowing robot

Introduction

This report will discuss the design of an autonomous mowing robot that has to operate in a typical Vineyard within New Zealand. The robot should be capable of navigating fully autonomously with minimal human oversight. Furthermore, the robot should be able to operate on flat ground and some areas that have a 20-degree slope, regarding the day and night time. The autonomous mowing robot should have the ability to sense the environment and to choose safe and efficient paths to reach a destination [1]. This means the robot should be able to avoid obstacles and maximise its speed while remaining resilient to inaccuracies or noise from sensors and actuators [1]. In this report, physical requirements, sensing, localisation and path planning of the robot will be discussed. It will also be considered for the robot to be designed in a cost-effective way considering being realistic enough to enable multiple systems to be built for the various vineyards.

Size and locomotion

As the vineyard rows are typically spaced 1.5m to 2.5m, the autonomous mowing robot will be sized 1.2m x 1.2m. It is to allow comfortable movement of the robot without harming any vines while mowing. The robot will be designed with water-resistant materials so that it can operate under unpredictable weather conditions. The robot will have 4 wheels and can move on both flat surfaces and up the slope considering there are some areas of slope with 20 degrees. For the robot to navigate up the slope and in wet conditions, the robot wheels will have treads. Furthermore, since the vines are spaced tight and there is limited space at some row ends, an articulated steering mechanism will be implemented which allows sharp turns. Additionally, an efficient mowing mechanism is integrated into the robot’s design.

Sensing system

Due to agricultural expansive nature and fluctuating light conditions, the autonomous robot needs a robust sensing system. Feature identification in agricultural environments can be a tough task due to their vast and open nature with extreme variations in light [2].
LiDAR sensors, due to their high accuracy and resilience to light variations, are preferred over cameras, as highlighted in [6]. LiDAR sensors offer exact measurements with some basic data processing and identify the critical points required to discern crop rows [2].
In [3], a robot uses LiDAR sensors to identify crops and navigate autonomously in the field, ensuring the crops remain unharmed. [3] highlights the limitations of the camera and classic sensors, suggesting that LiDAR-based methods offer a cost-effective alternative, with the added benefit of being minimally affected by external lighting conditions.

In reference [4], the study analyses plant detection and mapping for agricultural robots which are similar to our project case. The robot described in [4] employs 3D LiDAR sensors emphasising the advantages of 3D LiDAR sensors over 2D LiDAR sensors.
The research points out that although robots that operate in indoor environments mostly rely on 2D sensors for map creation, self-positioning, and obstacle avoidance, they do not work well in outdoor conditions. The reason why 2D LiDAR falls short in the outdoor environment

is due to several different conditions of the outdoor environment such as not flat ground and differing weather conditions. While 3D LiDAR sensors offer advanced features compared to 2D LiDAR sensors, its cost makes it less feasible for our project where multiple systems should be built for the various vineyards. As a result, 2D LiDAR sensors are used for our autonomous moving robots. 2D LiDAR sensors can provide a 360-degree view around the robot so that it can detect vines, rows, and other obstacles with the advantages mentioned above. Hence, for the autonomous mowing robot, a 2D LiDAR sensor is placed on the top-middle part of the robot.

Reference [5] examines the application of 2D LiDAR sensors on both constructed and unconstructed roads. This research is similar to our project where vineyard rows are well-defined, constructed roads, and irregularities like slopes or gaps between vines represent the unconstructed roads. However [5] also highlights the limitations of the 2D LiDAR sensors, particularly its performance under bad weather and ground conditions. Factors like rain, fog, and wet ground can affect the accuracy of the sensor's range data.

As limitations are mentioned above, only using a 2D LiDAR sensor is not enough for the mowing robot to navigate fully autonomously in the vineyard for various outdoor conditions. Numerous researchers insist that no singular sensor can wholly depict and adequately capture all relevant features in a real-world environment [6]. To overcome this problem, it is recommended to employ sensor fusion, which is to combine data from varied sensor types [6]. Therefore, IMU is used as an additional sensor for the autonomous mowing robot at the robot's centre. Primarily, IMU is employed in devices to measure velocity, orientation, and gravitational force [7]. In our project, it can be used for navigating slopes, providing data on the robot's orientation, and ensuring stability and correct navigation on not flat ground. Another use of the IMU in navigational systems is to assist in the creation of a 3D map [8]. In [8], the researcher enhanced their robot's accuracy in sloping areas by integrating an IMU. The essential data, including angle and angular velocity, are processed through a simple IMU stabilisation filter.

Furthermore, the camera with night vision is attached to the front of our robot to operate in low-light conditions. This camera is used with machine learning algorithms later on for the decision-making process. The infrared/ ultrasonic sensors are also placed at the front, back and sides of the robot for short-range obstacle detection. The purpose of these sensors is to detect unforeseen obstacles such as animals. Infrared sensors and ultrasonic sensors are both widely used to measure distances [9]. While infrared sensors are more cost-effective and offer quicker responses than ultrasonic sensors, ultrasonic sensors provide more reliable obstacle detection and perform better under poor lighting conditions [9].
A combination of both infrared sensors and ultrasonic sensors positioned on the front, rear and sides of the robot in our project to ensure that the robot is equipped to handle the unexpected obstacles.

Localisation and navigation

The autonomous mowing robot will employ a SLAM (Simultaneous Localisation and Mapping) method for the localisation and navigation. While there are many sensor types such as IMU, camera, GPS and RGBD sensors, lidar-based SLAM has gained significant popularity [10]. This is because lidar sensors offer high accuracy and strong resistance to interference, and they remain unaffected by changes in lighting conditions. Using the 2D LiDAR data and IMU, SLAM algorithms for our autonomous mowing robot is useful since they help the robot understand its position within the vineyard and make decisions based on its current and past observations. Therefore, a LiDAR-based SLAM algorithm will be used for localisation and navigation.

A study [10] conducted an experiment on three different LiDAR-based SLAM approaches and found that Cartographer has higher accuracy compared to GMapping and Hector. While Gmapping resulted in higher map precision, it performed poorly when dealing with large and complex environments. Furthermore, Cartographer has advantages when working in large and complex areas which can be seen as useful for this project that involves large vineyards. Another study [11] also conducted an experiment on different SLAM techniques and concluded that Cartographer is more advantageous regarding mapping effects, data processing, and sensor requirements. Once processed through the algorithm, the robot can produce a 2D grid map with a 5cm precision [11]. The Cartographer algorithm is composed of two parts: Local SLAM and Global SLAM. Within the Local SLAM segment, data from odometry and the IMU are employed to estimate the robot's position and this estimation serves as the starting point for Lidar data scanning and matching [11]. After the motion filtering, individual frames of Lidar data are layered to create a submap [11]. For enhanced map accuracy, the robot aligns the IMU's coordinate system with the ROS system tracked by the SLAM algorithm and odometer to release the pose coordinates [11].

Therefore, the autonomous mowing robot will employ the Cartographer SLAM algorithm to ensure the robot performs well under conditions that need mapping in large and complex vineyards with unpredictable external factors.

Path Planning

Real-time obstacle detection is essential for our autonomous mowing robot, given the dynamic nature of vineyards. Although static maps provide a foundational layout, they cannot account for new or temporal obstacles. In [11], they used a cost map in the planning process since the constructed map is static and does not update obstacles in real-time. A cost map consists of three main layers: the Static Map Layer (containing the original map data), the Obstacle Map Layer (showcasing real-time sensor-detected obstacles), and the Inflation Layer (which enlarges obstacles based on a set parameter, ensuring safer robot movement). The path planning of the robot in the greenhouse was divided into two parts: global and local planning. This dual-phase approach ensured the robot could avoid both static obstacles from the map in the global phase and new or dynamic obstacles in the local phase.
According to [12], search algorithms like A* or Dijkstra are commonly used with the cell decomposition method to search for a path. When employing A*, this approach consistently produces the most optimal path based on the desired requirements [12].

For our autonomous mowing robot, the use of a cost map will be implemented as using only static maps could not detect and avoid new or dynamic obstacles. Given that the robot is working within a vineyard, unexpected challenges like animals or humans may happen, making the use of cost maps essential. Moreover, the A* algorithm will be used to determine the most optimal and efficient path for the robot.

Safety Systems

There are some safety systems that should be considered when designing the autonomous mowing robot. As the robot is designed to be capable of navigating fully autonomously with minimal human oversight, the robot itself should have a safety system to prevent accidents and keep the vineyard undamaged.
Firstly, the robot is designed to have an emergency stop button to stop its operations immediately in risky conditions. The robot should be stopped when it behaves unpredictably or is about to collide with an unexpected obstacle. The robot should also have a remote control system where humans can operate the robot in unforeseen challenges or to navigate the robot out of risky situations. Furthermore, the robot itself should be alert when the obstacle suddenly approaches the robot’s path or something comes too close.

Conclusion

In conclusion, the design and development of an autonomous mowing robot that has to operate in vineyards are discussed in this report. Due to the nature of agriculture, the autonomous mowing robot will be sized 1.2m x 1.2m with 4 wheels that have treads and have an articulated steering mechanism and an effective mowing mechanism.
The robot will be 1.2m x 1.2m sized with 4 wheels with treads. It will also have an articulated system and an effective mowing system. The robot will be equipped with a 2D LiDAR Sensor positioned at its top-middle centre, an IMU sensor located at the centre, a night-vision camera at the front, and infrared/ultrasonic sensors positioned at the front, rear and sides. The robot will employ the Cartographer SLAM algorithm for its navigation and localisation, and a costmap and A* algorithm for path planning. The cost estimate considering all sensors and materials, would be around $5000 which makes it suitable to be used in many vineyards.

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