Capstone Final Report
Visual Based Robotic Lawn Mower
L08
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1. Introduction

1.1 Motivation

A main inconvenience of existing robotic lawn mower on the market is that they all require boundary wires installed in order to define the operating areas. These wires not only cost extra, but also take quite a long time to set up. Another problem of the existing product is that they are only able to operate following randomized paths, which takes a very long time to cover the entire area, and may cause the lawn to look messy.

We want to improve the overall user experience by using image recognition technology to limit the range of movement instead, therefore eliminating the use of boundary wires entirely. And also improving cutting efficiency and the aesthetic presentation by introducing path planning algorithm.

1.2 Background

“Nearly 90% of Americans have lawns believe it’s important to maintain their yard”.

____《The Future of Lawn care》 (1)

“ 21% of Americans hate yard work or find it intimidating”.

____《The Future of Lawn care》 (1)

Consumer Robotic Lawn mower already have certain breaking developments in the recent decade. Most the existing product on the market already have the ability to cut and maintain the lawn automatically. A typical robotic lawn mower mainly consists of 3 parts: a lawn mower body, a charging station and boundary wires. In order to use the mower, customer must install boundary-wires along the yard border before first use so the mower’s range of movement can be limited. However, the inconveniences of wire installation and the mower’s inadaptability to possible landscape changes dramatically hinders customers’ satisfactions. Additionally, current products can only follow randomized paths, which makes the final result inefficient and aesthetically un-pleasing.

2. Project Goals and Planned Approach

2.1 Project Goals

Bronze:

Robotic lawn mower is able to detect boundaries using basic color recognition method. Preset boundary wires are not required and the path of the robot is randomized within the boundaries.

Silver:

Robotic lawn mower is able to perform all the bronze level functionalities but with advanced deep learning algorithm instead and the robot can now follow a pre-planned path to create patterns within the boundaries instead of following a randomized path. In addition, the robot is able to recognize obstacles as well as detecting moving objects inside the boundary. Basic safety features are not added based on the real-time visual image feedback.

Gold:

Robotic lawnmower is able to perform all the silver level functionalities with improved safety features and it is now customizable with different function modules. With a price tag attached, the automatic lawn mower is passable for sale on the market.

2.2 Planned Approach

We decided to start our project with a experiment prototype so we can test out various different approaches to our intended functions.

Hardware:

- Two DC motors controlled by an Arduino Uno
- An Arduino Uno 3 that is controlling all the hardware functions including precision control of the motors. It also receives and processes feedback from the ultrasonic sensor and RPI lidar.
- Raspberry Pi 3 model B+ with PiCamera module attached. The Raspberry Pi handles the live image processing and recognition. It then sends commands to the Arduino over serial communication.
- An IMU (Inertial Measurement Unit) with compass built-in for SLAM
- Two Speed Encoders connected to the motors as a secondary method for localisation

Software:

We decided to achieve lawn detection by using color detection. If the color detected can be considered green in a certain range, then the robot knows it is still within the operation area. We also decided the best way to detect lawn margin is by measuring the percentage that the green area takes up against the size of the entire frame.

We tested the DC motor controls with L293d motor driver. We accomplished the ramp up/down function using PWM control and we found the solution using two DC motors control the three-wheel prototype moving forward, backward and spin.

SLAM (Simultaneous Localisation and Mapping)is method we found that may help us achieve organized path planning.We found a particular algorithm named VINS-MONO which is open sourced by a team form Hong Kong University of Science and Technology. It a state of art slam method for single lense and IMU integration , that are fairly light weighted. However after taking several experience on Raspberry Pi, we found the delay caused by this method is way longer that we can accepte. So we had to give this method and turn to use image process to do random pathing for lawn cutting.

3. Actual Approach

3.1 Design

Hardware:

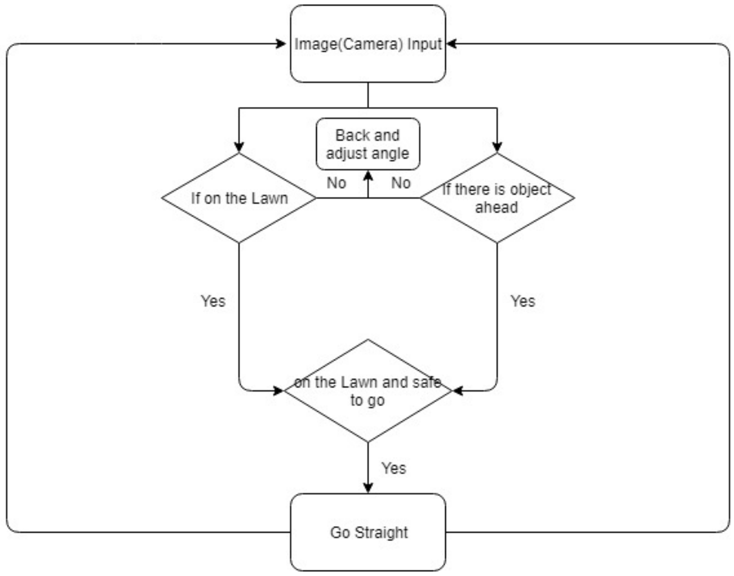
- Two DC motors
- Camera module

- 3 servo motors
- Raspberry Pi 3 Model B+
- PCF8591 AD Converter
- PCA9685 PWM/Servo Driver I2C Interface
- TB6612 Motor Drive
- Charging Station with built-in ultrasonic sensor and a Arduino Uno

Software:

Cutting Mode:

While in cutting mode, the lawn mower will keep processing the images and determine if it's on the lawn and there is no obstacle ahead, if it's true, it will keep going forward doing the work, otherwise, the lawn mower will back, turn certain degree and detect until it is far from the boundary. Then go straight again.

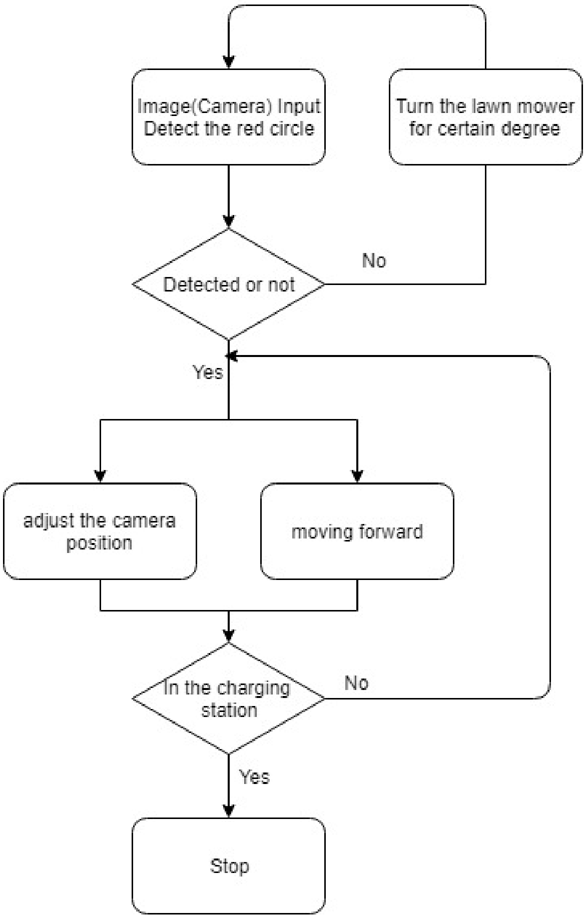


Block diagram for cutting mode

Finding Charging Station Mode:

The software will enter automatic charging mode when the battery is low and the camera will be tilted up to preset position. Then it will start scanning for the red circle. If the red circle is found, the position of the red circle appears in the screen will be calculated and the camera will adjust its position to put the center of the red circle close to the center of the screen. When the camera changing the position the front wheel will also change directions step by step in order to make the lawn mower facing the charging station. Meanwhile, the car will keep moving forward towards the red circle and when the red circle's diameter versus screen height ratio reach preset point, the lawn mower will stop and exit finding charging station mode.

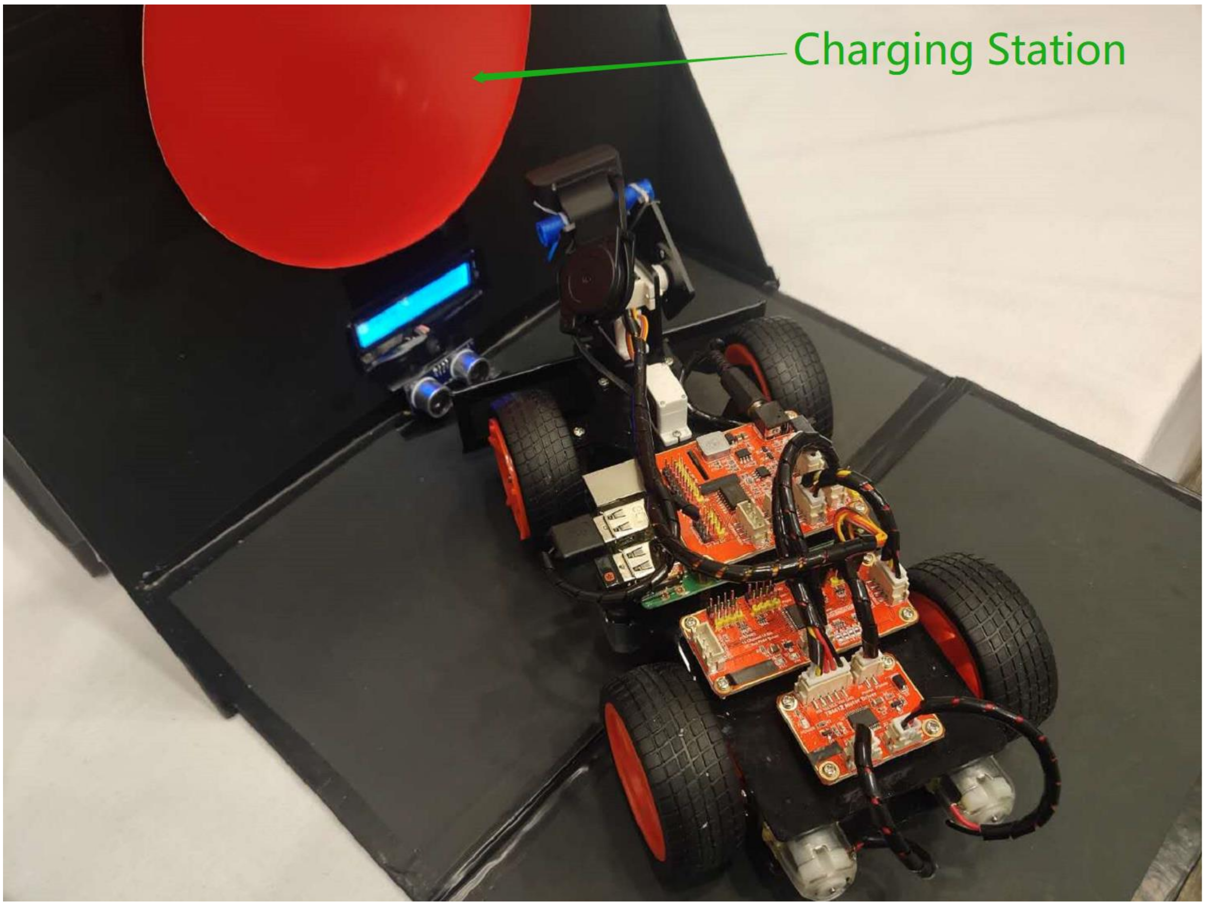
If the red circle is not found in the first scan, the lawn mower will turn certain degrees and detect again. After three times turning, the camera scan range can cover the whole 360 degrees.



Block diagram for finding charging station mode

Image Processing: Three of our main functions involved certain level of image processing. For lawn mowing and obstacles detection function, we first have our camera tilting down looking to the ground. And we use color detection algorithm to judge if the lawn mower is inside the operating area or not. More specifically, we will first preprocess the image to reduce all the noise, and reduce the effect of different lighting. Then we will segment out the green area, and draw a contour around it. And compute the ratio of green area with respect to whole area. For example, 90% of green area means we are inside the lawn or not obstacles blocking the way.

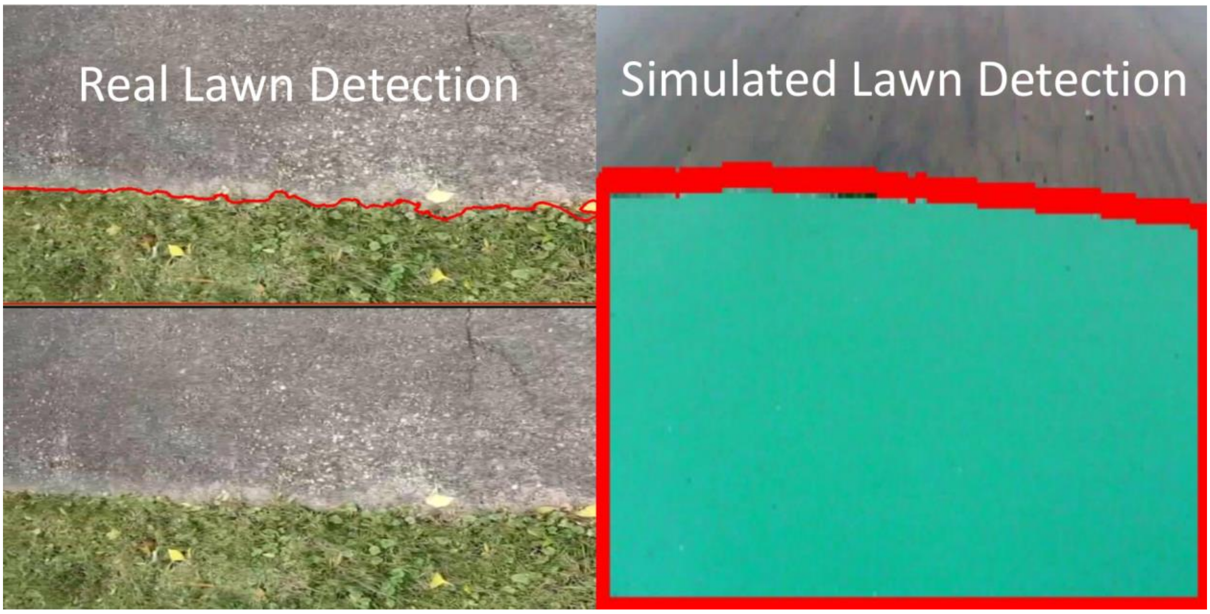
For the automatic charging function, we have the camera tilled up to looking for the charging station actively. It use shape detection algorithm. The target would be the red circle located on the charging station. Hough transform is used here to find the circle shape. After the circle is found, we will calculated the position of the circle center and feed the output to our control algorithm to navigate, simultaneously we will compare the diameter of the circle to the image height to decide when the robot need to stop.



Picture showing robotic lawn mower go back to charging station successfully.

3.2 Modeling/Simulation

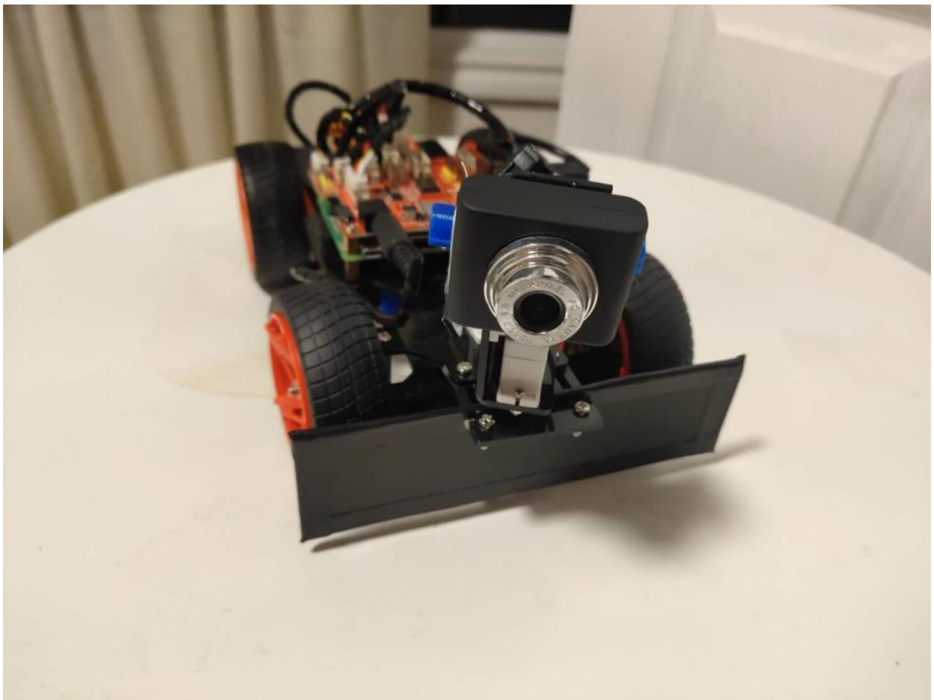
In the presentation we used green paperboard as our simulated lawn area for the purpose of demonstrating our robot indoor. But as you can on the left hand of the picture, we also test our algorithm on a real lawn, which also give us robust lawn detection result.



3.3 Implementation

The camera is connected directly to the Raspberry Pi and there is the hat circuit board with the PCF8591 AD Converter build in on top of the Raspberry Pi. Then there is a PCA9685 PWM/Servo Driver with I2C Interface which connects the hat circuit board and the TB6612 DC motor drive. Three servo drivers are connected to the PWM/Servo Driver and two DC motors are connected to the TB6612 DC motor drive.

All the code are written in python and saved inside the raspberry pi memory. We use WIFI to connect the PC to Raspberry Pi and run the code. There is also server & client code implemented for the lawn mower calibration and testing.



Assembled lawn mower

4. Critical Problems Encountered and Solved

The Effect of Illumination Variation on Lawn detection:

The ability to detect lawn area graphically is a key characteristic of our project, , initially we using basic color recognition in the RGB color space to detect the existence of lawn(Green Color). However, during the implementation we found that different illumination conditions varies lawn detection result dramatically. For instance, a same area of lawn, during good illumination condition, has RGB value of[119, 182, 6], and on a cloudy day the for the same lawn the RGB value becomes [79, 246, 45]. (variation [50%,35%,650%]), As can be seen, all 3 values of RGB changes dramatically when lighting changes. The reason is that RGB space is highly redundant and correlated: all 3 channels hold luminance information, reduce code efficiency. In order to increase of the efficiency of the program and better the green color detection, we decide to use HSV color space, where only one channel contains luminance information, thus is more flexible to illumination changes. Combined with other filters and image processing techniques, we had generated a python based program that is able to detect the operation area in different illumination conditions effectively.

Colour area feedback optimization:

During the image processing, we calculate the area of the defined colour range. However, we noticed that the area feedback is not always correct(for example, the area is 12000 but one feedback shows it’s zero) when we monitored the output of the calculate area. Since we have multiple frames feedback in one second and there is also delay and noises, optimize the colour area feedback is a must to detect the boundary precisely. In order to solve the problem, we changed our algorithm to compare the area calculation and output the result close to the mode. By implementing the optimization, the area feedback error reduced dramatically and the lawn mower working more consistent.

Implementing multiple Servo motors and DC motors:

We have used two servo motors for camera position adjustment and one servo motor for lawn mower direction control. There is also two DC motors for the forward and backward movement. In order to deal with the multiple motors in the same time we choose the I2C protocol which has the capability dealing with multiple master and slaves on the same bus.

5. Conclusion

At the end, we have created a robust robotic lawnmower which is able to perform autonomous lawn mowing, obstacles avoidance and automatic charging function. It can detect the boundary using RGB detection and avoid obstacles by image processing. When the battery is low it can return to the changing station by image recognition. The pathing algorithm is random pathing and by adjusting the robot turning angle, we can increase our cutting efficiency accordingly.

This table shows estimate cutting time for our lawn mower with a 10cm cutting blade and a typical lawn mower with average 35cm cutting blade.

EFFICIENCY

Estimate Cutting Time (hours)	Cutting Width 10 cm	Cutting Width 35 cm
250 SqFt	1.8 h	0.5 h
500 SqFt	3.5 h	1 h
1000 SqFt	7 h	2 h

Efficiency chart showing estimate cutting time for blade size of 10cm and 35 cm respectively

6. Future Plan

6.1 Technical Improvements

We can get rid of our random path planning algorithm and adopt SLAM (Simultaneous Localisation and Mapping) which not only improves the efficiency of our automatic lawn mower but it also allows for organized path planning. As a result, we will be able to create beautiful patterns while mowing the lawn.

The boundary detection can be improved by implementing machine learning. We can import trained data to help the boundary detection using image processing.

In addition to the lawn mower itself, the charging station could also be improved. Currently, we rely on visual recognition for the lawn mower to return to the charging station. To make it more robust, we could make the charging station to emit a signal. Depending on the strength and direction of the signal that the mower receives, our robot can know the location of the charging station and the distance from the mower to the charging station.

6.2 Potential Market Value

The global robotic lawn mower market is estimated to reach values of around $3 billion 2023, growing at a CAGR of more than 15% during 2017-2023. As we discussed the motion at the beginning of the report.

6.3 Specific Usage

Simultaneous Localization And Mapping (SLAM) approached are employed in autonomous driving vehicles, underwater robotics, and newly different kind of robotics. In other words,

for a completely autonomous robot, the key is considered by many the ability to simultaneously localize a robot and map their surrounding environment accurately.
The visual based SLAM robotics are broadly used in different area, for daily usage, similar to our capstone project automatic lawn mower, there are many products using the same developing techniques such as automatic snowplow, self-driving automobile and drone.