Autonomous Golf Green Divot Locator Robot Project Proposal

Group 19 Team Members:
Ved Eti (vedeti2)
Michael Cherry (mcherry3)
Akhil Bonela (abonela2)

TA: Pusong LI

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1. Introduction:

Problem

Preserving the quality of golf greens is essential to ensuring a fair and enjoyable golfing experience. However, a common challenge that undermines this objective is the failure to repair ball marks. When a golfer's ball lands on the green, it creates a small indentation, or divot, in the surface. While it is customary for players to use a repair tool to fix these marks, not all golfers adhere to this etiquette. This neglect leads to an increase in divots and uneven patches on the green, which can have detrimental consequences for both the course and the golfers.

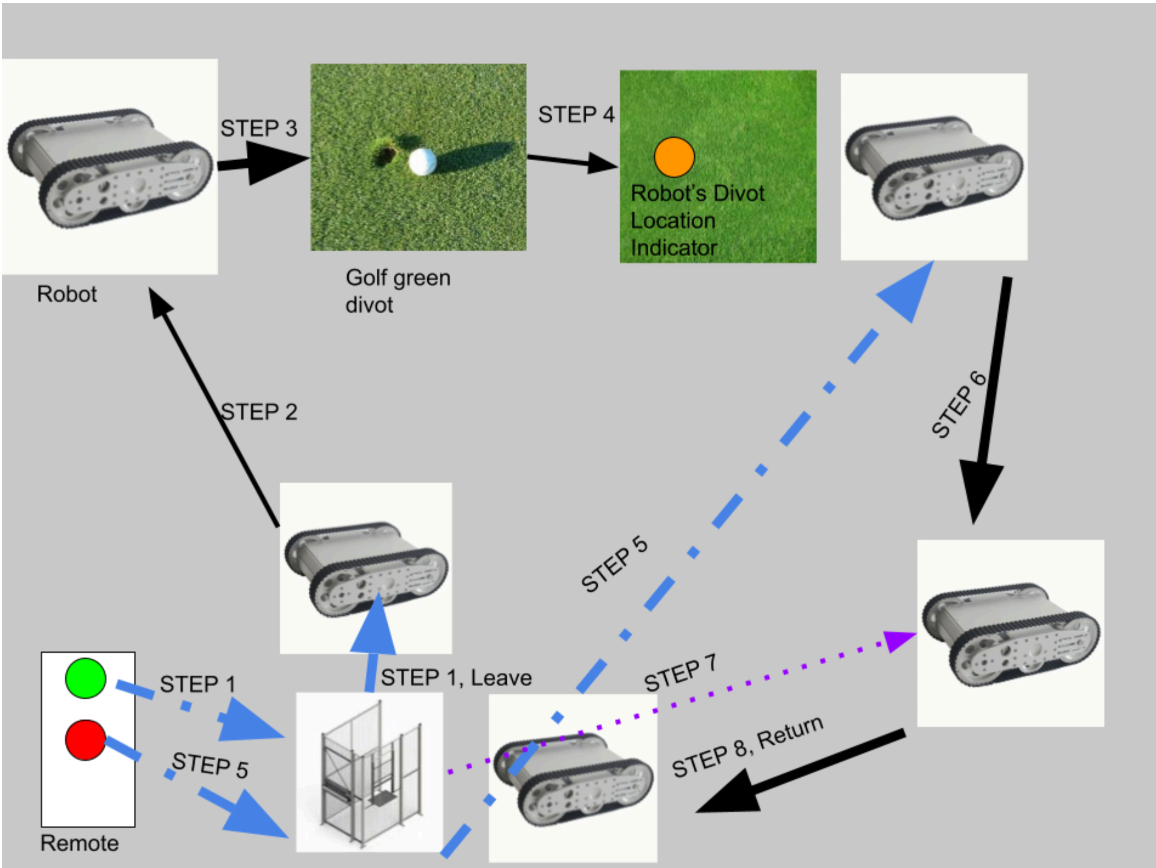
Unrepaired ball marks can significantly diminish the quality of a golf green. The divots disrupt the smooth flow of putts, making it more difficult for golfers to accurately judge distances and control their shots. Additionally, these marks can interfere with the green's drainage system, leading to localized water pooling and potential turf damage. Furthermore, the unsightly appearance of a green littered with divots can diminish the overall aesthetic appeal of the course, negatively impacting the golfing experience for all players.

Solution

Our proposed solution involves developing an autonomous robot equipped with advanced sensing and marking capabilities. This robot will be designed to traverse the golf green at the end of the day, when the golf club closes. Using stereo cameras, the robot will accurately locate divots by analyzing the differences in depth between the surrounding turf and the indented areas.

Once divots are identified, the robot will use a custom-designed marking tool to clearly indicate their locations. This tool will leave a visible mark on the green, guiding golfers to repair the divots before their next shot. By automating the process of divot identification and marking, our robot will significantly reduce the manual effort required to maintain the quality of golf greens while ensuring that all divots are promptly addressed.

Visual Aid



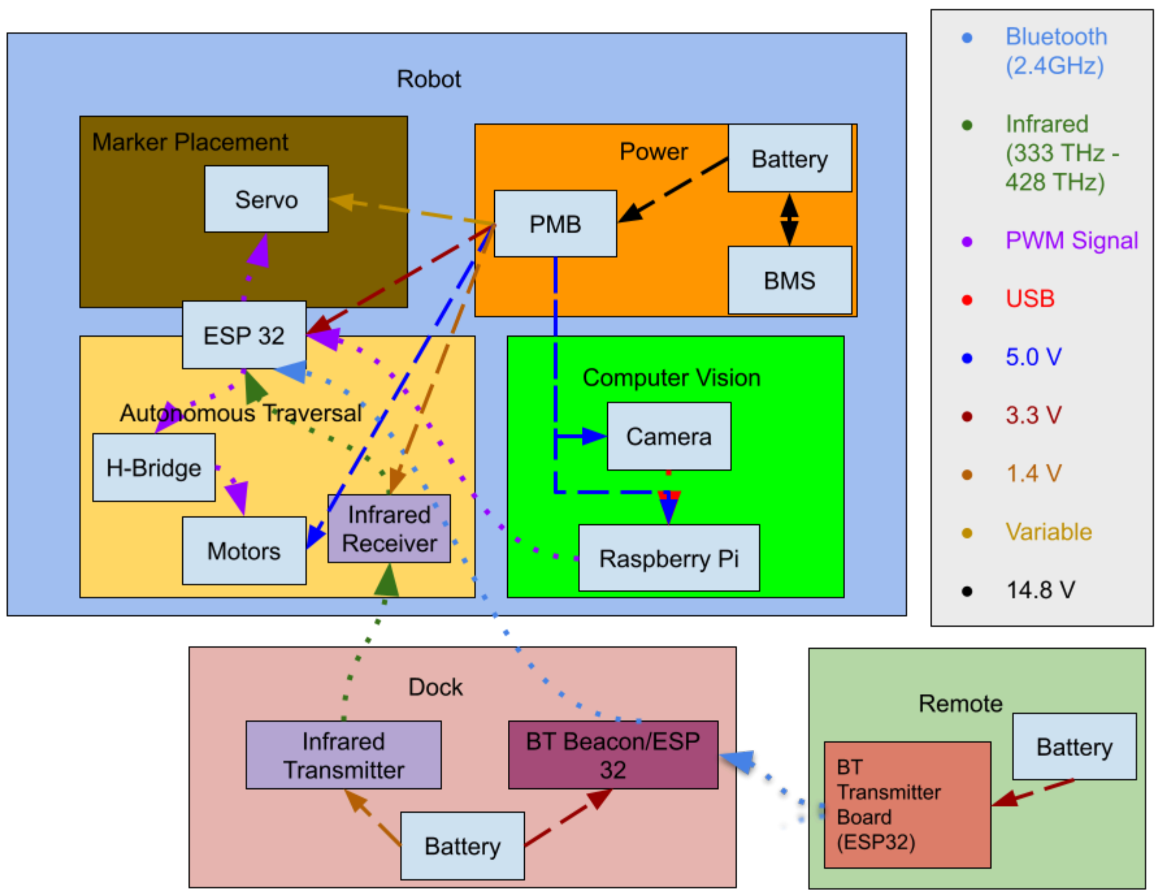
Blue arrows indicate Bluetooth Signals, Purple indicates infrared signals, black is overall traversal of the robot

High-Level Requirements

1. Be able to create a robot that is compact and light enough to traverse the golf course green without damaging the golf green
    a. Want size to be with in 18”x18”x18” and have it weigh under 15lbs
2. Have the robot be able to effectively indicate to the user, either visually or programmatically, where it “thinks” a hole/divot in the golf green is, and place a marker, accurate to within +/- 3 inches
    a. The diameter and depth we hope to successfully locate and indicate is about 1-1.5 inches in radius and 0.5-0.75 inches in depth
3. Have the dock/cage successfully transmit signal to the robot to return on press of user’s remote, and be accurate to within +/- 6 inches of the center of the cage/dock

2. Design

Block Diagram:



Subsystem Overview

- Stereo Camera - Used to detect the edges of golf greens, and divots (Amazon.com: Synchronized Dual Lens Stereo USB Camera 1.3MP HD 960P Webcam 3D VR Web Camera Module with 1/3 CMOS OV9715 Image Sensor Industrial Camera USB2.0 Lightburn Camera Plug&Play for Android,Linux,Windows : Electronics)
- Micro-Controller - (A chip from the ESP32-S3 series)
- Raspberry Pi - Used for additional computer power for computer vision tasks

- Servo - Divot Marker Dropper (Amazon.com: Miuzei 20KG Servo Motor High Torque RC Servo Metal Gear Waterproof for 1/6, 1/8, 1/10, 1/12 R/C Model DIY Car Robot, DS3218, Control Angle 270° : Toys & Games)
- Battery - Zeee 14.8V 4S Lipo Battery (50C 3300mAh) with an XT60 plug
- BMS System - 14.8V 4S 30A 18650 Lithium Battery BMS PCB Integrated Circuits Protection Board
- Robot Chassis - Prebuilt chassis with motors (Amazon.com: Metal Smart Robotic RC Tank Chassis Kit with 4pcs DC TT Motors for Arduino UNO R3, Raspberry Pie, STEAM Education, TT04 Crawler Tank Car Chassis Platform for Adults Teens (Black) : Everything Else)
- Casing for Components - Plan to use 3-D printed materials
- Servo - used for dispensing of our indicator for where robot detected a divot
- https://www.amazon.com/Dorhea-Arduino-Helicopter-Airplane-Walking/dp/B07Q6JGWNV/ref=sr_1_2?dib=eyJ2IjoiMSJ9.k4VWdZRCZ96RvpDDgAhRCKlUAarsyiCsh_I3xDueLWhNCgW4An1nib_OqIY3YOyk0dM2CTRvD81cJid8AgJLhA9JRmiqxF39ZvTu3aKEaDrzlc6Z-Rv4OIa-rOw6jeUiGOjk45Od6jDTXPkUdR-oaRAxRRztbQFMyVIwP_oHrUYdXBtJ4QNeIOwRDVmQ_dtkPc_zn3mdU9cA8IMq-o1sphWzWaxVqBD4d7O0BbvbYGRsX-sZWRC00Sf0zV_4tgkZ9sWyDKLt9N8rCZuhAf1L9xwjIHB5C2ZnhdiDtwLgmcc.HpzXK2VIr18swMt-vKQxr_FyETqybIqBrkjt4Tzr47Y&dib_tag=se&keywords=3.3V%2Bservo&qid=1726735265&sr=8-2&th=1
- 3.7 Volt Rechargeable Battery 3000mAh Battery 2Pack Large Capacity Batteries for Headlamp,LED Flashlight,Mini Fans etc (Flat Top,Blue)… - Amazon.com: AFSONGOO 3.7 Volt Rechargeable Battery 3000mAh Battery 2Pack Large Capacity Batteries for Headlamp,LED Flashlight,Mini Fans etc (Flat Top,Blue)… : Health & Household
- Gikfun 5mm 940nm LEDs Infrared Emitter and IR Receiver Diode, GL5516 LDR Photo Resistors DIY - Amazon.com: Gikfun 5mm 940nm LEDs Infrared Emitter and IR Receiver Diode, GL5516 LDR Photo Resistors DIY : Industrial & Scientific

Autonomous Traversal

This subsystem is mostly going to be interfacing with our microcontroller (ESP 32), our motors, an H-Bridge chip, and the Raspberry Pi. All of the computer vision tasks will be performed on the Raspberry Pi, as our microcontroller will not have enough computational power. The output of the computer vision to either detect the edges of the golf green or a divot will then be sent to the ESP32 microcontroller through general GPIO pins. The microcontroller will then give out instructions for the robot if it detects a golf green, interacting with an H-Bridge motor driver, allowing us to turn around and change the direction of the robot, and continue sweeping the area. This will act very similar to a common roomba, and robotic vacuum cleaners. We repeat this process until we traverse and check the entire green.

We plan on using a pre-produced chassis listed above in our component list so that we don't have to spend time making and manufacturing our own chassis with motors. We will add our own microcontroller, PCB for power distribution, and battery to the chassis, and use the chassis mostly for the mechanical build.

Image Processing

The image processing module will mostly have two tasks, identify divots, and identify edges of golf greens. It will pass along information about what it detects to the Raspberry Pi so that we can either use the traversal module to move the robot, or the marker placement module to place markers down. The two components of the computer vision/image processing submodule are the Raspberry Pi and a stereo camera. For the divot sensing, we plan on using the stereo camera as a method to estimate the changes in depth. As per our research, we plan on using semi-global block matching for our depth perception, which seems like can tell the difference between uneven surfaces on the ground. We will also use the camera feed for the green detection to make sure the robot does not go outside the green. For this we plan on using some thresholding to differentiate between the current surface it is on and the other surface it sees. We plan on using various Python libraries such as Pytorch and Opencv, which are both too computationally intensive for a microcontroller.

Power

The robot utilizes a Zeee 14.8V 4S Lipo Battery (50C 3300mAh) with an XT60 plug, paired with a 14.8V 4S 30A 18650 Lithium Battery BMS PCB Integrated Circuits Protection Board. This combination provides reliable power management and safety features for the robot. LiPo batteries are chosen for their high energy density, which allows for a compact and lightweight battery pack, ideal for mobile robots. The BMS safeguards against overcharging, over-discharging, short circuits, and overcurrent, ensuring the battery's longevity and the robot's safe operation. There will also be a custom PCB Power Management Board (PMB). The PMB is responsible for distributing regulated power to all sub-systems. The dock and remote will both use a 3.7 Volt 3000mAh Rechargeable Lithium-ion (Li-ion) Battery as a power source.

Marker Placement

The marker placement subsystem will be used as our interface between the system responsible for dispensing our ball divot location indicators and the robot’s microcontroller. This system will use a servo, which will be connected to the ESP 32 microcontroller. The microcontroller will receive a signal from the Raspberry Pi from our image processing subsystem which will signal if a divot has been located.

Remote Begin & Return to Location / Dock

We will create a remote controller that will interface with the robot’s dock / cage to give the user the ability to tell the robot when to begin traversing the green and also when to return back to its cage / dock. The remote will be using bluetooth to communicate with the robot’s dock / cage, and not the robot itself. This will give us more flexibility with meeting the size and weight limits we have set for the robot and allow us to explore other options for signal transmission if bluetooth does not have a range or reliability we are content with.

Subsystem Requirements

Autonomous Traversal:

As mentioned before, this subsystem is in charge of controlling the movement of the robot as it traverses the gold green. The main bridge between this subsystem is the ESP32 microcontroller and the Power distribution board. The ESP32 microcontroller will receive signals from the Raspberry Pi that detail signals of finding either a divot or detecting the edge of the golf green. We plan to use two GPIO pins from the Pi and connect it to the microcontroller. The microtoller will be programmed to send respective signals to the H-bridge motor controller; either stop if a divot is detected or turn the robot around if the edge of the green is detected. Please see the computer vision subsystem module description for This subsystem is vital to completing the high-level requirements, including the return to the dock, traversing the green without causing damage, and stopping to place a marker at the location of the divot. Removing any of the components (Microcontroller, motors, H-Bridge) will cause failure to the system, and will not meet our high-level requirements. Removal of motors will cause our robot to be stationary, not allowing us to traverse the green and mark the divots. Removal of the H-bridge motor driver will not allow us to control the motors effectively using the microcontroller and will require using either a Raspberry Pi or multiple microcontrollers. The microcontroller is extremely important, as it is the component that takes the detection signals, and tells the motors and h-bridge how to maneuver the robot. The Raspberry Pi can also be used in place of the microcontroller and was our preferred choice, but is not allowed for the design of the project.

The last part of the autonomous traversal is an infrared receiver. This fulfills the last high-level requirement, being able to return to the dock with a level of accuracy. This part is connected to the microcontroller and will direct the robot to move towards the dock. More information on how exactly this will work is given in the Dock subsystem module. Please see power subsystem requirements for details on specific power requirements of components in the autonomous traversal subsystem.

Requirements:

1. Be able to traverse the golf green with no human interference, and make sure not to go off of the green.
2. Being able to stop when a divot is found.
3. Being able to track back to base when called back.

Image Processing:

As mentioned before, the two components of image processing are the stereo camera and a Raspberry Pi. The stereo camera that we plan on using will be connected to the Raspberry Pi through a USB port. The Raspberry Pi will then be using various algorithms such as frame segmentation and semi-global block matching to detect uneven surfaces on the ground and be able to differentiate between the green of the golf course and the other portions of the course. Depending on whether the algorithm detects a divot or if the robot is veering off of the green the Pi will have two GPIO pins that will connect directly to the microcontroller via a PWM signal.

Requirements:

1. Use segmentation to detect golf greens and regular grass.
2. Use the stereo camera to detect the depth of a potential divot.
3. Send correct signals to the microcontroller to signify if regular grass or divot is detected.

Marker Placement

The computer vision subsystem interfaces with the ESP32 microcontroller to be told when a divot has been located, and to move to that location. The robot will be set up in the position relative to the hole such that when the ball divot indicator, which will be of similar effect to a coin, poker chip, etc. will be vertically aligned with the divot. Once in position the ESP32 will use PWM signals to power the servo and rotate it to dispense our divot indicator. We aim to have our indicators be within 3 inches of error from where an actual divot within our size parameters is detected.

Requirements:

1. Get signal from Microcontroller to servo.
2. Place the divot marker within 3 inches of the divot location.

Remote Begin & Return to Location / Dock

We plan on using another esp32 to act as a bluetooth transmitter that tells the robot to begin traversing the course and also be told when to stop and return to its “dock”. We intend to create or purchase a cage/little enclosure of some sort for the robot to safely reside in near the golf green and return to when done.The press of the ON/BEGIN button will, if it is reliable and practical, send a signal to the dock rather than the user. The dock will have a bluetooth beacon that will be turned off by this signal. The turning off of the bluetooth beacon at the doc will be the method to which it tells the robot to start moving. This makes the user’s input the critical variable for the microcontroller to begin running the necessary code for the robot to move on the green and run computer vision algorithms. To accurately return to the dock, we will utilize a combination of bluetooth and infrared beacons for the best combination of range with bluetooth and accuracy with infrared. The interfacing of the infrared system will work very similar to that of the bluetooth system.

Requirements:

1. Create a docking station for the robot to start from and return to.
2. Use a bluetooth remote to communicate with the docking station to deploy/recall robot

3. Create infared sensor system to guide robot back to the docking station.

Power:

The power subsystem is responsible for supplying reliable and consistent electrical power to all components of the autonomous divot repair robot. It consists of a Lithium Polymer (LiPo) battery pack with an integrated Battery Management System (BMS) and a Power Management Board (PMB).

The power subsystem interfaces with all other electronic components in the robot. It supplies regulated voltage through designated power connectors on the main control board or directly to individual components. The dock and remote both consit of a Li-ion battery directly connected to the ESP32 microcontrollers.

Requirements:

1. Minimum Current Output: The power subsystem must be able to continuously supply a minimum current that meets the combined demands of all the robot's components.
    - Minimum Current = Σ (Typical Operating Current) + 20% buffer
    - Minimum Current = (250 + 80 + 500 + 100 + 4*250 + 30) mA * 1.2 = 2352 mA
2. Regulated Voltages: The power subsystem must provide well-regulated voltages to each component according to their specifications.
3. The PMB will need to include voltage regulators to convert the battery voltage (14.8V nominal) to the required voltages for each component:
    - 5V regulated output for Stereo Camera, Raspberry Pi, and the 4 TT DC Motors
    - 3.3V regulated output for the Micro-Controller

Components	Typical Operating Voltage (V)	Typical Operating Current (mA)	Required Voltage (V)
Stereo Camera	5.0	250	5.0
Micro-Controller (ESP32-S3)	3.3	80 (active)/20 (idle)	3.3
Raspberry Pi (Model 4)	5.0	3000 (peak)/500 (idle)	5.0
Servo Motor	Variable	500 (peak)/100 (holding)	Variable
TT DC Motor	5.0	250	5.0
Infrared Emitter and Receiver Diode	1.4	30	1.4

Tolerance Analysis

Our biggest risk is being able to sufficiently power all of the components on our robot, docking station, and remote control. If any of these systems fail, and do not have enough power / or too much power to continue working as intended,o our project will not be able to work as intended. To combat this, we plan on using a printed circuit board that acts as a power distribution board to regulate the voltage. Since we have components that operate in different voltages (3.3 V, 5 V,6 V), we need to add in some voltage regulators. For example to calculate the power dissipation of such a regulator can be found by using the following formula: $P_d = i_{out}*(V_{in} - V_{out})$.

In addition to the voltage, it is also necessary to regulate the amount of current supplied to each component. As calculated, the minimum current required to power all of the components is 250 + 80 + 500 + 100 + 4*250 + 30. We also want to make sure that we have some sort of buffer to make sure that the current does not fall below the required current to ensure this we would have enough current to ensure smooth operation. We calculated keeping a 20 percent buffer would be sufficient ,a dplan to make sure atleast 2352 mA is being supplied to the system at all times.

3. Ethics and Safety

Ethical Concerns

1. Privacy and Data Protection:

The robot's use of cameras to map the golf green and identify divots raises potential privacy concerns. We will implement robust data privacy measures to mitigate these risks, including anonymization techniques and secure data storage. Furthermore, we will obtain permission from golf club owners and operators prior to deploying the robot.

2. Accountability and Liability:

A critical ethical consideration is determining who is responsible for the robot's actions and any potential damages. We will establish clear guidelines for the robot's operation and potential liability to address this issue. Additionally, we will implement safety features to minimize the risk of accidents or damage.

3. Environmental Impact:

The robot's use of batteries and potential for accidental damage to the golf green raises environmental concerns. We will select environmentally friendly battery options and design the robot to minimize its impact on the golf course. We will also implement safeguards to prevent accidental damage.

Safety Considerations

1. Robot Safety:

The robot must be designed and operated safely to prevent accidents or injuries. To ensure robot safety, we will adhere to relevant safety standards, such as those outlined by the Robotics Industries Association (RIA). We will also implement safety features like obstacle avoidance and emergency stop mechanisms.

2. Human Safety:

The robot must not pose a risk to human safety. To mitigate the risk of human injury, we will ensure that the robot is designed and operated to minimize the risk of collisions or other hazards to golfers or course staff.

3. Property Damage:

The robot must be designed to avoid damaging the golf course or its infrastructure. To prevent property damage, we will implement safeguards to prevent damage to trees, irrigation systems, or other valuable property.