Individual Contributions and Conclusions

The Garden Bot comprises of multiple software, electrical and mechanical subsystems that are further composed of numerous components. In order to realize the proposed system, the design and implementation of these subsystems were divided into separate tasks and distributed among the members of the design team. As the team was composed of two computer engineering students and two electrical engineering students, the logical approach was to allocate tasks based on and experience gained from relevant course material, cooperative education rotations and personal projects. Therefore, my personal responsibilities were focused on testing and configuring the sensor systems hardware and software as well as developing the state machine loop in the code. Other pertinent systems that I implemented in the code include the general-purpose input-output (GPIO) configuration, pin mapping and I2C (Inter-Integrated Circuit) communication protocol configuration. Additionally, my co-op and other personal experiences enabled me to contribute to many of the electrical and mechanical subsystems. This included designing several of the electrical circuits relating to power switching, GPIO expansion and integration of the sensor hardware, implementing those designs on a printed circuit board (PCB), and modeling the chassis of the robot. These tasks were greatly beneficial in increasing my knowledge of electrical circuit design and enabled me to share my experiences with the design team, which improved our skillsets and resulted in a more developed project.

The first of my responsibilities for the project included the integration of multiple sensors into the system. One of the critical sensors include an array of ultrasonic sensors for measuring distance and weed detection. Two sensors were mounted on the front of the robot facing forward and one additional sensor was mounted on each side of the robot, which were used in conjunction for navigation, obstacle avoidance and initial positioning. Electrical modification of the sensors was necessary, where a voltage divider was used to protect the microcontroller against overvoltage. Code was developed to send signals, measure duration of returning signals reflected from nearby objects and use the speed of sound to calculate a fairly accurate distance measurement. The code for these sensors also required a timeout, which limits the range of the sensor and protects against long, blocking function calls that can stall the operation of the bot.

Another sensor that I implemented into the system was a near-infrared reflection sensor to aid with weed detection. Similar to the ultrasonic sensor, this device is suitable for distance measurement, though the properties of the sensor are better suited in the Garden Bot's application for measuring the intensity of reflected infrared light from plant leaves. In contrast to a time-based measurement, I configured the microcontroller's analog-to-digital converter (ADC) to measure analog voltages from the sensor. When positioned above a leafy plant, such as a weed, the amount of reflected light will increase, resulting in an increased voltage measured from the phototransistor within the device.

The final critical sensor used in the system is an inertial measurement unit (IMU), which incorporates a gyroscope, accelerometer and magnetometer to take positional readings from the robot. The main purpose of this sensor is to aid with maintaining straight-line navigation when traveling along the rows of crops within a garden. By taking initial measurements after the robot completes its corner detection algorithm, the robot can ensure that it only travels parallel or perpendicular to the stored direction. Another similar application of this sensor is to make accurate pivots when supplied with a specific angle, where the robot takes a starting measurement before the turn and rotates until the sensor reads within a set threshold. An additional use-case of the IMU is to take measurements from an internal temperature sensor to supply the robot's webserver with an accurate temperature reading from the garden.

The final task from my area of focus included co-authoring the design and implementing the code of the robot's internal state machine. This included determining the responsibilities of each state, ensuring proper transitions between states and managing the operation of blocking and non-blocking components through multiple loop iterations. The state machine closely followed the flowcharts outlined in the design report, which includes states for initialization, evaluation, stopping, charging, searching for weeds and destroying weeds. The system enters the state machine through the evaluation state, where it should transition to stop and initialize the robot. Safety statuses are also built into the state machine in order to stop the system in the event of user interaction during operation.

In addition to these tasks, I also designed and constructed several electrical subsystems, which further required software implementations. One of the electrical subsystems that I developed is a power-switching circuit that latches the robot's power supply. Upon initial startup, the user manually presses and holds a button on the robot to power-on the system. When activated, the microcontroller latches the same pin as the button and notifies the user via an indicator LED that the system is fully active and the button can be released. The system can then unlatch the power upon reaching an appropriate state in the software control loop or when the user makes that request via the webserver connection. Another electrical subsystem I developed is a GPIO expansion module, which uses an array of shift registers and multiplexers to increase the microcontroller's available IO. Two shift registers were used in series to enable simultaneous control to the selector inputs of multiple multiplexers. Each multiplexer connects to one IO at a time and allows bidirectional control over the pin. For example, the input pin of an ultrasonic sensor was connected to one multiplexer and the sensor's output pin was connected to the corresponding pin on a separate multiplexer. By outputting the correct selection sequence through the shift registers, both pins were directly connected to the microcontroller, allowing normal operation with both devices.

Another important contribution I provided was designing the printed circuit board for the project. This was a multistage assignment that required the use of several tools and extensive prototyping. Firstly, all of the circuits were hand-drawn and prototyped on breadboards in order to ensure their functionality. After the circuits were tested and any modifications or improvements were made, I was able to move the circuit diagrams to the PCB design software. I decided to use KiCad, which is a free and open-source PCB design software that contains all of the required tools for producing the circuit board. First, I constructed the circuit schematic for all of the electrical subsystems, which I separated by application. This enabled me to connect local groups of elements using wires and join groups of elements with labels. After running all the appropriate connection tests, I assigned the appropriate footprints to each of the components, generated a netlist and exported my schematic to the PCB layout editor. Here, I move the components to a reasonable layout, setup the design rules to match the PCB manufacturer specifications and began the process of routing the PCB. The final step after completing the PCB routing was to generate the Gerber files and order the boards from a PCB manufacturer, which I selected to be JLCPCB.

My last significant responsibility that I contributed was the design of the mechanical system for the robot. This included designing the chassis, wheels and various mounts for sensors and other components. I used Fusion 360, which is an intuitive computer-aided design (CAD) tool, for 3D-modeling the frame and components of the robot. These components would be 3D-printed using PLA filament, which would provide a durable and lightweight frame for mounting all of the Garden Bot’s components. In order to fit on the printer’s bed, the chassis was divided into two separate halves, which incorporated a mechanism in the center to join the two parts together. The wheels were modeled in order to satisfy the engineering requirement relating to the vertical clearance of the robot as well as to act as a self-centering rail to keep the treads attached to the robot. The final design was printed with a twenty-percent infill and with minimal support structures to reduce any abrasive surfaces that could interfere with normal operation.

From the variety of tasks that I completed and the contributions that I provided to this project, I am able to draw several individual conclusions about the Garden Bot. Firstly, it is imperative that I acknowledge the range of knowledge and experience required to complete a project of this size. The involvement of team members and their contributions within their areas of focus is essential to developing a project with a large number of subsystems. The marketing and engineering requirements established by the design team guided the development of the robot, while providing enough freedom and flexibility to experiment using multiple approaches. In this manner, the Garden Bot's design was refined to operate as anticipated, with potential for future changes and development.