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TIGERBOT VI

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ABSTRACT

Tigerbot will be a fully autonomous, untethered, humanoid robotic tour guide designed specifically for the RIT campus. As of 2015, there have been 5 iterations of Tigerbot with varying degrees of success. Tigerbot four is capable of walking, standing, and is moderately responsive to voice commands. Tigerbot five was a full design of a 22 degree of freedom, full-scale humanoid with one partially constructed leg. The goal of this iteration of Tigerbot was to construct a fully operational prototype of the lower body, based on previous or new designs. The prototype is capable of suspended walking and standing. The team has also created updated designs for Tigerbot and prepared documentation to assist future project iterations.

INTRODUCTION (OR BACKGROUND)

Following the work of five previous teams, Tigerbot VI was the second full-scale humanoid robot project in the Tigerbot series. The design work performed by the previous team was mostly scrapped in order to optimize the overall design. The previous iteration provided the majority of the research upon which Tigerbot VI was based. The motors, gearboxes, battery specifications, and printed circuit board designs were all provided by the previous team's work.

PROCESS (OR METHODOLOGY)

This section should describe the theoretical underpinnings for your project, assumptions made, methods used and experiments performed, along with an overview of the design process utilized – eg. customer requirements, engineering requirements, constraints, concepts, evaluation, analysis, building and testing. Be sure to explicitly call out applicable engineering standards.

ELECTRICAL

The electrical system was broken down into two major categories; hardware and software. The primary objective of the hardware implementation was a robust sensor network for Tigerbot. Due to the time constraints, the initial customer requirement of a full body electrical system was brought down to only a lower body implementation. Therefore, only the sensor network for the lower half to the chest cavity is presented. The sensor network consisted of six components: the Force Sensing Resistor (FSR) board, Analog to Digital Converter (ADC) board, Breakout board, two IMU boards, and the Teensy microcontroller (Teensy).

To develop a working leg that would emulate the motion of a human leg, a sensor network able to give feedback and communication to the robot was vital. Several sensors such as gyroscopes, accelerometers and IMUs were incorporated into the design however the primary feedback for a proper walking sequence comes from the FSRs. The FSRs were designed to be placed underneath the robot's foot on each corner. The FlexiForce A201 FSRs utilized in this project read resistance values in mega ohms when little to no force was applied, and read up to a few hundred ohms when about 120 to 130 pounds of force was exerted. A simple operational amplifier (op-amp) circuit with negative feedback was built to amplify the voltage and output a range between 0 to 5 V. The FSRs required a negative voltage supply, hence a DC-to-DC +5 V to -5V converter was also included on the FSR board. The fluctuations in reading from the FSRs indicate the position and rotation of the robot's foot to ultimately measure the center of mass of the robot. As the FSR board output analog voltages, an ADC board was needed to convert the analog voltage into a digital signal to pass to the Teensy via I2C communication lines.

Figure 1: PCB Solution to FSR Board (Left) and ADC Board(Right)

A 12 bit Texas Instrument ADC chip (ADC128D818) was used for the ADC board. The majority of the design for this board was completed by the previous project iteration. Since each FSR has one output and there are four FSRs on each foot, the ADC board needed to be able to handle multiple sensor inputs and relay the collected data to the microcontrollers. The designed board is capable of handling up to eight channels. Each sensor connector has a power pin, a data in pin and a ground pin. To ensure a flexible design each power out pin has a jumper to select a +5V or +3.3V supply to the sensor. There is also an additional jumper select to change the voltage reference to an external voltage of +5V. The key benefit of this TI chip was its I2C digital output. The +5 V power line on the ADC will come from the +5V on the FSR board and the +3.3 V from the Teensy. Organization and power management for all the PCB boards is handled by the Breakout board.

The IMUs contain both gyroscopes and magnetometers, allowing for a 3D understanding of the chip's position, interpreted by code as pitch, roll, and heading. The IMUs embedded in the hip and the feet will aid the FSR board in informing the Tigerbot of its current status including, how level the foot is, and what direction it faces. The ability to understand the pitch, roll, and heading of the foot, particularly, will aid future iterations of the Tigerbot in walking. Additionally, the IMU positioned in Tigerbot's hip will assist future iterations in fall detection. The IMU boards communicate on I2C busses, with the IMU in the hip communicating on the Teensy's secondary IMU bus, to avoid address conflicts.

The breakout board was designed to handle the conversion from the Teensy's +3.3V digital logic to the +5V digital logic of the Clearpath motors and to make the two separate I2C busses of the Teensy accessible to the sensors. The conversion was handled using NXP Semiconductor's 8-bit translating level-shifters (Part Number 74LVCH8T245PW), which were surface mounted to the breakout board. The second I2C bus is only accessible via surface mount connections to the teensy, which were connected to the breakout board via Molex, LLC surface mount header pins (Part Number 0015910140). Utilizing the second I2C bus also required many modifications to the sensor libraries used to poll the sensors. Additionally, several modifications were made to the breakout board after they were ordered after initial testing. These modifications include power connections and an addition of external pull-up resistors for I2C communication.

In order to retrieve the information from the sensors, code from several sources was adapted and compiled on the Teensy. The ADC board was polled intermittently then the sensor took in this digital output and converted it to a decimal voltage which was displayed on the serial terminal. The IMUs utilized example Adafruit code, adjusted for the needs of the Tigerbot, and Adafruit's libraries for the 9DOF IMU board, the unified sensor library, the unified LSM303 library, and the unified LSGD20 library, the last two of which refer specifically to the chips present on the IMU boards. The LSGD20 and LSM303 libraries were augmented to utilize the publicly available augmented Teensy I2C library, downloadable from github user nox771 under the name i2c_t3. The codes written for Tigerbot VI are also available on the KGCOE github.

Based on the needs of this project, the team chose to use the SDSK Clearpath motors produced by Teknic. These motors are controlled using three signals from the Teensy microcontroller. These signals enable the motor, set the direction of the shaft, and assert motion of the shaft. In addition to these signals, the motors were configured using a program provided by Teknic. The motors were configured to take 1600 input pulses per revolution with a jerk limit of 100ms to create smooth motor motion that is also nearly silent. Several demonstration programs were created to show the capability of these motors within the final implementation of the lower body.

MECHANICAL

From customer requirements, the total robotic design will have 22 Degrees of Freedom (DOF) (4 DOF arms, 5 DOF legs, 2 DOF torso and 2 DOF head). This was amended part way through MSD I, to add a degree of freedom to the hip to twist the leg, in order for the robot to turn.

Based on previous design and customer suggestion, the first task for the mechanical group was to redesign the ankle joint. Last year's iteration designed an ankle that was too heavy and bulky for proper operation. Numerous solutions were developed, then analyzed to narrow down the options. One of the more promising solutions was to use linear actuators to drive the ankle degrees of freedom. After much discussion and calculation, linear actuators were ruled out.

Instead, the idea of directly driving one of the degrees of freedom, while driving the other degree of freedom with a belt and pulley setup was implemented. This was selected as it not only allowed for proper operation at proper speed, but could also be incorporated into the design well enough to keep a human look. The direct drive design was also used in the torso to twist the legs.

Once the redesign of the ankle was complete, a rough lower body design was developed. The material chosen was 6061 Aluminum, as it is lightweight yet, strong and relatively inexpensive. The initial design allowed the group to see how motors and gearboxes could be placed into the design while maintaining a human-like figure. To mimic human gait and form, the lower body needed two, six DOF legs (2 DOF ankle, 1 DOF knee, 3 DOF hips) as stated above.

Torque calculations were estimated initially using analysis and data from the previous year's team. These calculations were adjusted and tweaked with a more complete and more refined design. A factor of safety was incorporated into the calculations of maximum torque scenarios to ensure appropriate motor selection. The calculations incorporated the weights of motors, gearboxes, hardware, upper body and lower body material. This produced a more accurate maximum torque value for each joint in the current design.

The Teknic motors and Harmonic Drive gearboxes used in the final design of last year's group, are again seen in this year's design and prototype. The Teknic motors provide plenty of torque at sufficient speeds. The Harmonic Drive gearboxes are lightweight, small and have large gear ratios, which are needed to overcome the high torques seen in walking and movement.

As the design was continually optimized, the customer suggested an angled leg design, where the thigh angles in toward the center of the body from the hip to the knee. Research has shown that this aids in balance, as well as mimicking a more dynamic human gait. This suggestion was incorporated into the design by creating this angle with welded aluminum plates. The weld was a weak point in the structure, and therefore needed to be bolstered. Aluminum gussets were machined to support the weld. The majority of the machining required for the lower body was performed by the team, with the occasional help of the machine shop. This meant the team had to work around any issues from machined components, such as improper drilling/tapping of holes or alignment of parts, which was a delay that was not initially accounted for.

During assembly and testing, it was discovered that the gearbox design adopted from last year's group was insufficient and could result in early failure of the gearboxes. From communication with Harmonic Drive, a few suggestions for improvements were integrated into the current design in order to reduce this likelihood. It is important to note that not all suggestions from Harmonic Drive were used. This will be discussed further in the recommendations section.

For testing, a fall prevention rig was necessary in order for the robot to be tested safely. The initial thought was for a rig to be constructed, but, ultimately, scrapped once an engine lift was located in the machine shop, available for use. This engine lift was used in conjunction with a tow strap in order to properly secure the robot from falling and injuring itself or others.

An upper body design was developed to coincide with the current lower body design and structure. Two, four DOF arms, a two DOF head, and torso connection to the lower body was the basis for design. This upper body design allows the robot to get off the ground after a fall, one of the customer requirements for the project series. The upper body also helps in dynamic balance and being able to shift weight as the robot starts to lose its balance.

ELECTROMECHANICAL

The cables provided for the Teknic motors are designed to connect one motor to one power supply. In the design, these cables were cut and re-wired per the motor manual in order to provide enough power for the motors in each leg from one power supply. The power travels from the top row of each connector, out through the bottom row of each connector moving down the leg until each of the six motors is powered. In order to ensure that the system would not overload the power supply, a power consumption analysis was performed. Rewiring the cables in this way allows for improved wire management and lower cost to power the motors.

Boards and sensors needed to be incorporated into the design for ease of access and ease of wiring. Four Teensy breakout boards were used, two located in the torso and two located in the thigh. The two located in the torso were exclusively for the motors. These are located under the power supply shelf. This shelf is removable so that the boards remain accessible. The other two Teensy boards were for the sensors. These are fastened to the thigh plates, as there was room there to place them. This also allowed for less wiring for the sensor implementation as most sensors are in the feet, and wiring does not have to run up the full lower body to the torso.

A wire management solution was desired to keep the aesthetics clean and tidy. The power cables, as well as the control cables, were woven into the design, utilizing cutouts through the aluminum plates. This way, there were no cables outside the design and it allowed for free movement of all joints with no chance of pulling out a cable from a connection. Additionally, cable ties were used to keep all wiring neat.

CONCLUSIONS AND RECOMMENDATIONS

Electrical

The breakout board's organization should be updated to better suit changes made in assignation of motor driving pins that occurred after testing. Currently, several connections to a single motor have been separated across the board, however these changes were necessary to optimize the motor driving from a software perspective. Space should also be allotted for the 24 pin ground bus, which was neglected in the current revision. Furthermore, the option should be available to drive the +5V and +3.3V connections on the level shifters from the Teensy itself. The I2C busses were modified to include 220 Ω resistors, which may be unnecessary, as the teensy has internal level shifters controlled via software.

The FSR circuit design is robust and adaptable by future iterations. However to get a better output voltage reading between the desired output of 0-5V, the 1M trim potentiometer (feedback resistor on circuit) can be replaced with a similar trimmer with better range to allow for high resolution to the output. The code to read the FSR voltages and IMU axis are real time and only display the readings every second, therefore in the future when trying to interface the whole robot, those values need to be stored to evaluate and analyze. In the final product, the idea behind the FSR and IMU outputs are that they are the primary feedback for the leg to determine if it is falling or in balance. Essentially in this iteration, all the sensors are able to communicate with the Teensy Microcontroller but the next step is for the Teensy to interact with the motors according to feedback from the sensors.

Ideally, the system should run on a battery and Tigerbot five provided a fair amount of research on the type of battery to explore. The battery should be able to power all 12 motors for the lower body and the remaining upper body motors. When selecting a battery consider power consumption in addition to overall weight of the battery.

Mechanical

Although linear actuators were ruled out for this iteration, they still offer great mechanical advantage. For different (slower, less torque) joints, linear actuators could offer greater benefits than a motor and gearbox setup.

The Harmonic Drive (HD) gearboxes are lacking a few design features that were suggested by HD. The biggest suggestion not used in the design is a housing for the gearbox. This housing provides structural stability, proper alignment, and debris prevention. The housing would need to be a custom application, so all housings would need to be designed and machined by a following iteration. Another option is to use a different gearbox Harmonic Drive offers, however these gearboxes are more expensive but could be implemented easily.

A more optimal test rig can be implemented to allow for easier testing. The engine lift was used since it cost the team nothing and was available. However, the engine lift is a bit difficult to move and only supports straight line testing. If a portion of a following teams budget is put toward a test rig, more fluent and possibly even safer testing can occur.

Finally, a more accurate machining technique is recommended. The waterjet machine was used for this iteration, followed by finish machining with a mill. This however made assembly much more difficult because the tolerances seen with the waterjet machine are not precise enough. Utilization of the CNC machine is recommended. Tolerances seen with the CNC machine will allow for a much smoother assembly. This also has its drawbacks as only a limited size part can be placed in the machine.

Software

In this iteration, the goal was to simplify the software as much as possible to achieve a walking motion. Future iterations should explore more complex solutions with more autonomous capabilities, such as ROS. Most of the software was developed by analyzing human motion, writing code to simulate these motions, then verifying the proper outcome. Additionally, future teams will benefit from creating a better way to return the robot to a home position after each step. The sensor libraries may also benefit from additional exploration, as they were minimally augmented to allow for the operation of the second I2C bus. More functionality may be found in the gyroscope of the hip given greater scrutiny.

REFERENCES

Within the text, references should be cited in numerical order, by order of appearance. The numbered reference should be enclosed in brackets. For example: “It was shown by Prusa [1] that the width of the plume decreases under these conditions.” In the case of two citations, the numbers should be separated by a comma [1,2]. In the case of more than two references, the numbers should be separated by a dash [5-7].

References to original sources should be listed together at the end of the paper, and should include papers, technical reports, books, prior team projects, personal discussions, websites (not Wikipedia), and software. References should be arranged in numerical order according to the sequence of citations within the text. Each reference should include the last name of each author followed by his or her initials.

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