Dynamic Robotic Leg

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Introduction:

Objective:
While wheeled robots excel in flat terrain, they perform very poorly at navigating a world created for humans. The problem of navigating multi-level environments, including stairs and unstructured environments such as a floor with debris or uneven terrain, has not been fully solved. Legged robots such as quadrupeds are able to excel in these environments. Specifically, dynamically stable robots hold a great deal of promise for navigating unstructured environments.

We propose to create a dynamic robotic leg stabilized on a test frame in order to demonstrate trajectories used for walking gaits. This project will demonstrate the feasibility of inexpensive walking robots and provide the starting point for a novel quadrupedal robot. We will control the leg with a hybrid position-force task space controller to demonstrate programmable compliance in the leg task space. We will use a modified version of the ODrive open source motor controller to control the torque of the joints. The joints will be driven with high torque off-the-shelf brushless DC motors. We will use high precision magnetic encoders such as the AS5047D to read the angles of each joint. The inverse dynamics calculations and system controller will run on a TI F28335 processor.

Background:
While research labs and companies have been developing dynamic legged robots for years— Boston Dynamics' Spot mini [1], Unitree's Laikago [9], Ghost Robotics' Vision [6], MIT's Cheetah [3], etc— all of these robots use custom motors and/or proprietary control algorithms which are not conducive to the increase of legged robotics development. With a well documented affordable dynamic robotic leg and controller we believe we can accelerate the development of legged robotics by reducing development cost and increasing involvement in the field.

High Level Requirements:

- The leg must be built with inexpensive (< $100) off-the-shelf motors without any modification other than adding hall sensors and changing connectors.
- The leg must be able to apply a desired force at its end effector (foot) in a desired direction through the use of a task space controller
- The leg must be able to execute pre-calculated trajectories in real time to demonstrate jumping and partial walking gaits.

Design:

The leg requires five main types of electrical components for operation: brushless DC motors to drive each joint, magnetic absolute encoders to report the angle of each joint, a motor controller to command a torque to each joint, a central processor to run the task-space controller, and a lithium polymer battery to power the leg and safely receive regenerative current.

The mechanical components of the leg will be 3D printed and kept simple to focus on the other aspects of the project. The majority of the mechanical design has already been completed since the start of the semester. The test frame will be built out of V-Slot aluminum extrusion.

The central control algorithms will run on a TI F28335 processor. We will purchase a development card carrying this processor and we will design a PCB to support the development card and route signals to the motor controllers and encoders. We will also create a separate PCB to hold each of the magnetic encoders.

We will also develop a simulation using pyBullet [2] so that we can test trajectories before applying them to the real leg. We have already developed a pyBullet simulation since the start of the semester with our current mechanical design.

Power Subsystem

The power system is required to supply suitable current to the motors and to power the motor controllers and central controller. A rechargeable battery will be regulated accordingly.

Battery

A 6S Lithium-Polymer battery will provide power that can be regulated as required.

Requirement: Must provide a minimum of 60A continuous current per motor. Provided voltage must stay between 25.2V and 19.2V.

Logic Power Delivery

The logic power delivery system will consist of a wiring harness to connect the battery to the Processor Breakout PCB.

Requirement: 18 AWG wire harness with 30A XT30 power connectors.

Motor Power Delivery

The motor power delivery system will consist of a wiring harness to connect the battery to each motor controller board.

Requirement: 12 AWG wire harness with 90A XT90 power connectors.

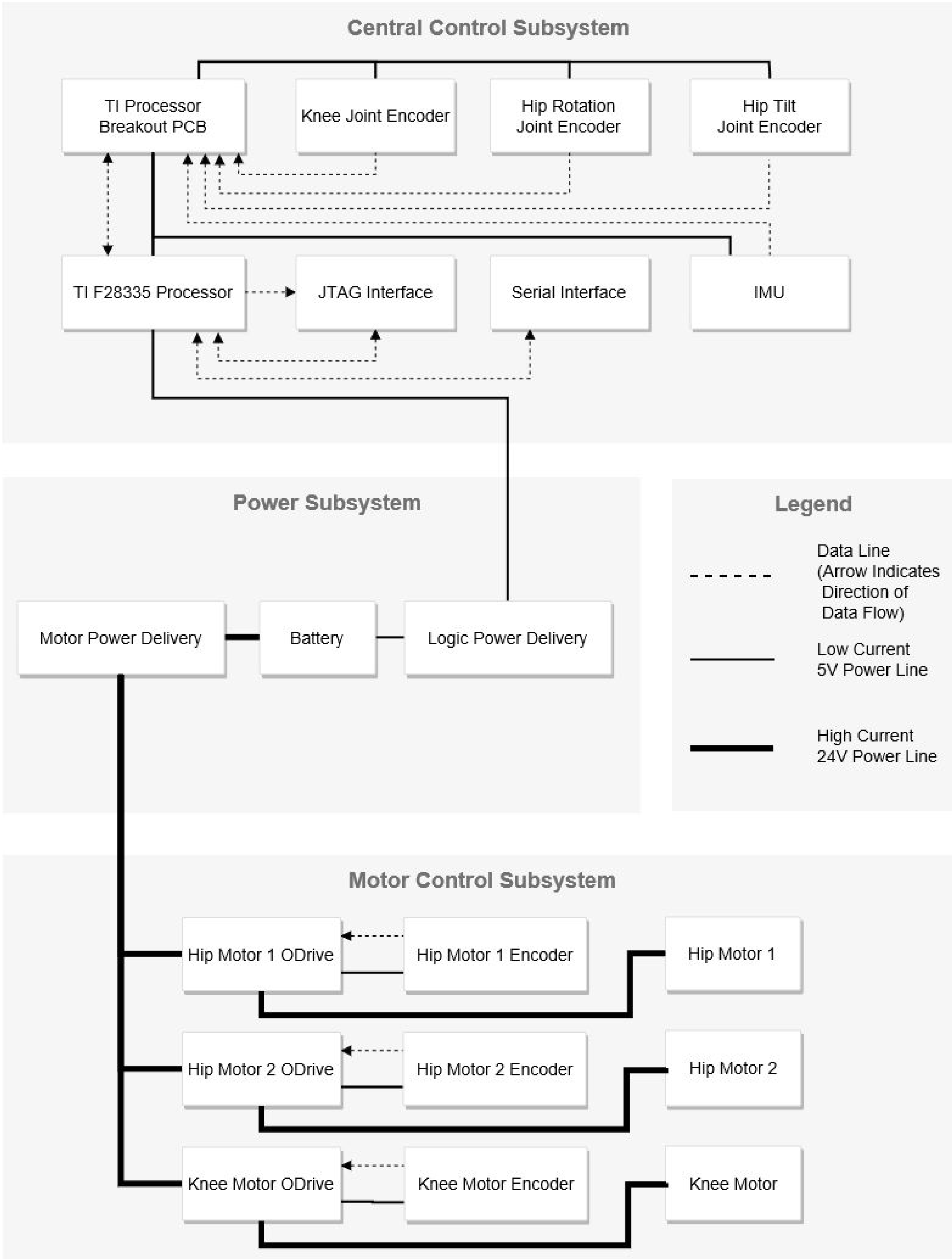

Figure 1: Block Diagram

Central Control Subsystem

TI F28335 Processor

We will use the *TMS320F28335 controlCARD* to run our task space algorithms and trajectories. The F28335 has support for all communication we need and will be able to handle the real time control required of our project.

Requirement: Must be able to perform all dynamics calculations for our task space controller in less than 1 millisecond.

Requirement: Must have a JTAG Interface for real time debugging and data streaming.

Requirement: Must have SPI support for reading joint encoders

Custom F28335 Breakout PCB

We will design a circuit board to break out the connections of the ControlCARD and provide power regulation and protection to the processor. The board will provide JTAG connection for programming and real time debugging. It will provide a serial port for streaming real time data to MATLAB or similar.

Requirement: Board must supply 4.9 to 5.1 volts to the ControlCARD.

Joint Encoders

We will use AS5047D magnetic absolute encoders to measure the angle of the joints. These encoders will report the angle directly to the F28335 processor.

Requirement: Must report angle with less than 0.5 degrees of noise.

Requirement: Must report angle with period of less than 1ms.

Inertial Measurement Unit

We will use an MPU-9250 IMU to measure the orientation of the “body”. While this IMU will not be used in our most simple test stand, it will be built in to prepare for the central controller to measure body orientation when we use two legs and more. We will use the digital motion processor on this IMU to provide us pre-filtered quaternion orientation data.

Requirement: Must report body orientation within 1 degree of true orientation.

Requirement: Must report angle with period of less than 1ms

Motor Control Subsystem

Motor Controller Boards

Each motor will be driven by an ODrive motor controller. This open-source board will be modified to suit our use case.

Requirement: Must be capable of driving a motor using torque-based control.

Requirement 2: Must deliver between 59A and 61A continuous current.

Motor Encoders

We will use AS5047 magnetic absolute encoders to measure the shaft position of each motor. These encoders will connect directly to each motor controller board to form a closed-loop feedback system.

Requirement: Must report angle with less than 0.5 degrees of error.

Motors

A motor will be mounted at each joint. KEDA 63-64 190KV motors will be used for initial prototyping and testing. These will potentially be upgraded to APS 6355 60KV motors for more consistent torque output and a lower gear ratio between motor and joint.

Requirement 1: Must allow for up to 60A continuous current without damaging the motor coils or softening the plastic enclosure. Active cooling can be added to meet this requirement if needed.

Requirement 2: Must have a torque constant of at least 0.05Nm/A.

Requirement 3: Must be less than or equal to 63mm diameter to fit in motor housing.

Requirement 4: Must allow for external encoder to be mounted on opposite side of output shaft.

Physical Design

We will 3D print the majority of the parts for the leg. The gear and pulley reductions will be accomplished with off the shelf components. Figure 2 depicts the baseline test setup for a two degree of freedom leg. Our test setup for a three degree of freedom leg will be very similar, however, we do not have any renders of a 3 degree of freedom setup at this time. Our test stands will be based on the stands depicted on page 82 of [8] and page 300 of [5].

Figure 2: Robotic Leg 3D Model

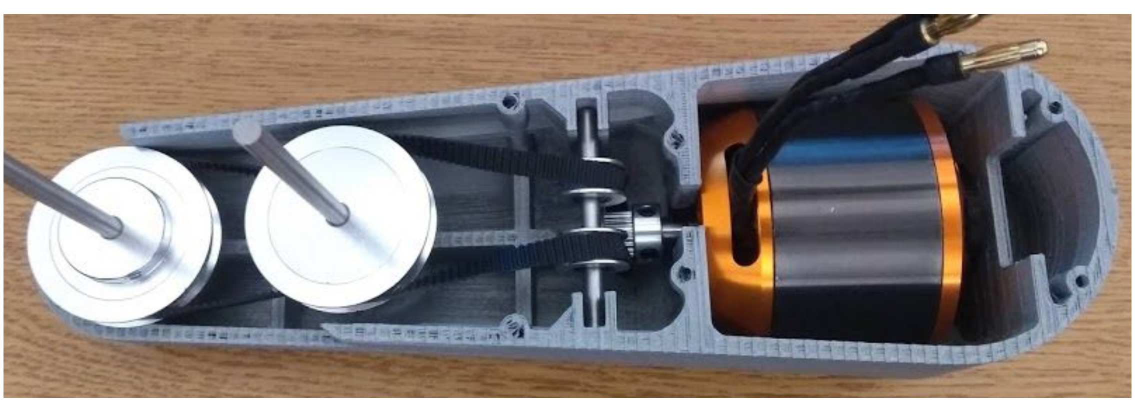

Figure 3: First Upper Leg Prototype Print

Risk Analysis:

We believe the most significant hardware risk to the successful completion of our project is achieving a constant torque output from the motors. To achieve this goal we will have to interface encoders with our motor controllers to accurately commutate the current and we may need to add a feedforward controller to compensate for the torque ripple of our motors if the leg is not performing well enough without it. Another challenge of the project will be to process the data from our encoders and IMU fast enough to update the torque effort of our joints every 1 millisecond.

Safety and Ethics

Within our project, there are several potential safety hazards.The first concern that we will deal with is disabling the robot leg if it begins to move unexpectedly. To mitigate this issue we will include an emergency stop button which will disable power to the motors. Additionally, our motor controllers will have a failsafe enabled that disables the motors if no communication is received after a predetermined number of missed packets or time. Another safety hazard that we must consider is the inclusion of Lithium batteries within our design. Batteries may swell and become too hot to the point of ignition if they are misused. Furthermore, the inclusion of the battery prevents the regenerative current of the motor stopping from damaging the overall electrical system of the robot. Additionally, we can put a power resistor to dissipate any large extraneous currents.A robotic leg by itself does not prove to have ethical challenges, however, once the leg is applied to a mobile platform, it may present ethical challenges. Isaac Asimov founded the idea of robots and established the Three Laws of Robotics, being 1) A robot may not injure a human being or, through inaction, allow a human being to come to harm; 2) A robot must obey the orders given it by human beings, except where such orders would conflict with the First Law; and 3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws[4]. An autonomous mobile platform could be designed using our legs which could be used as a mount for a weapon, or as a vehicle to perform illegal surveillance. These acts would violate the IEEE code of ethics, specifically, code 1 and code 9. [7]. We would prevent our designs from being used for harmful purposes by withholding our leg and technology associated with it from the public sphere. We would vet potential consumers of our product so that we can prevent it being used for purposes we find to be in violation of our ethics. At the same time, our research could be used for positives as well, for example, having met with officers of the UIPD, we have discussed future applications of our robotic leg, such as the integration of the leg onto a mobile reconnaissance platform. This platform would provide increased safety to the officers by distancing them from potential threats such as explosive devices or hidden suspects.

Citations

[1] Boston Dynamics. (n.d.). SpotMini. Retrieved February 7, 2019, from https://www.bostondynamics.com/spot-mini

[2] Bulletphysics, & Coumins, E. (2019, February 06). Bulletphysics/bullet3. Retrieved from https://github.com/bulletphysics/bullet3/tree/master/examples/pybullet

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[4] Deng, B. (2015). Machine ethics: The robot's dilemma. *Nature News*, *523*(7558), 24.

[5] Ding, Y., & Park, H. W. (2017). Design and experimental implementation of a quasi-direct-drive leg for optimized jumping.

6] Ghost Robotics. (n.d.). Legged UGVs | GR Vision Series. Retrieved February 7, 2019, from https://www.ghostrobotics.io/robots

[7] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 29- Feb- 2016].

[8] Kalouche, S. (2016). Design for 3d agility and virtual compliance using proprioceptive force control in dynamic legged robots. *no. August*.

[9] Unitree. (n.d.). Laikago. Retrieved February 7, 2019, from http://www.unitree.cc/e/action/ShowInfo.php?classid=6&id=1