Mathematical Modelling and Control System Optimization of a Hexapod Robot

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Introduction

The work done in this project aims to improve the hexapod that has been developed in The University of Cape Town's Robotics and Agents Research Lab, by implementing an effective control algorithm such that the robot can move with a high degree of agility and precision.

The hexapod is designed to be used in search and rescue applications due to its advanced mobility.

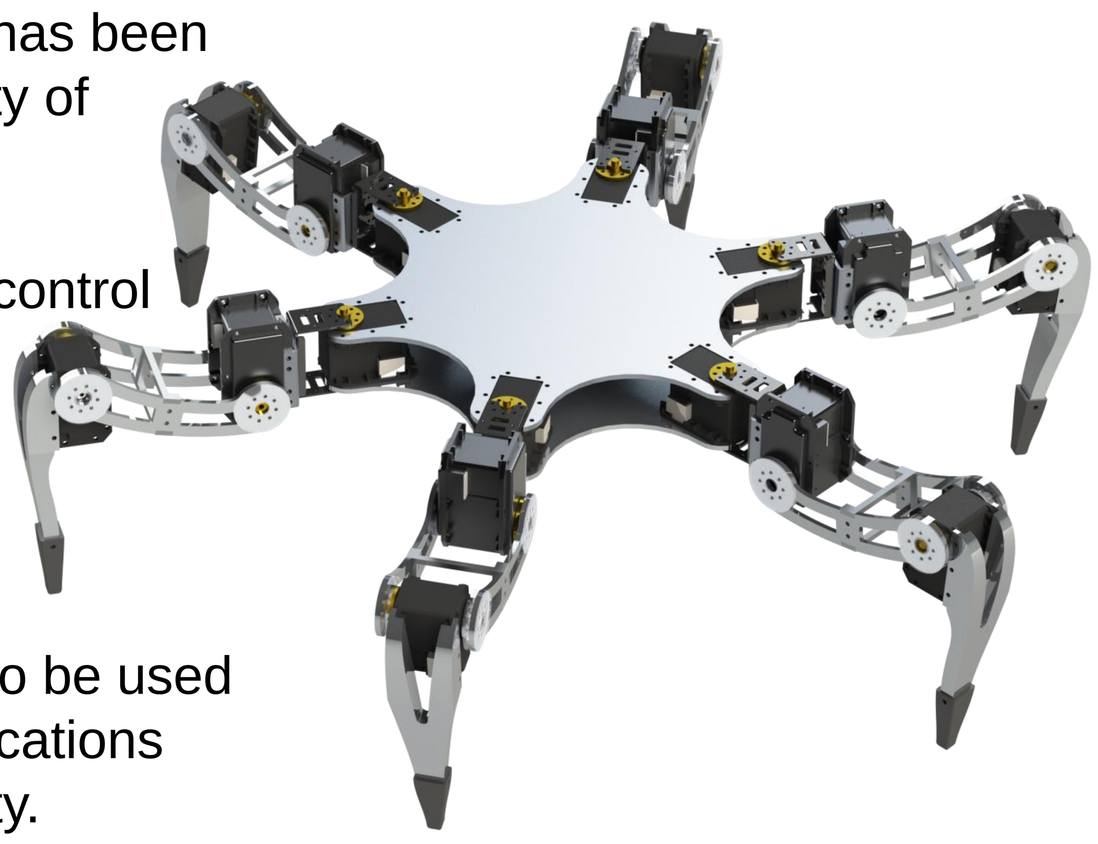

Figure 1: Hexapod Robot

Mathematical Modelling

Mathematical modelling of the robot was essential in order to develop an algorithm to achieve a smooth walking motion.

Kinematics and Dynamics

The forward kinematics of one leg was calculated using Denavit-Hartenberg notation [1] to assign coordinate systems to each joint of the leg. Using these coordinate systems a rotation matrix representing the forward kinematics was developed.

The leg joint angles were related to the foot XYZ position using inverse kinematics [2]. This was calculated with trigonometry as shown in figure 2 below.

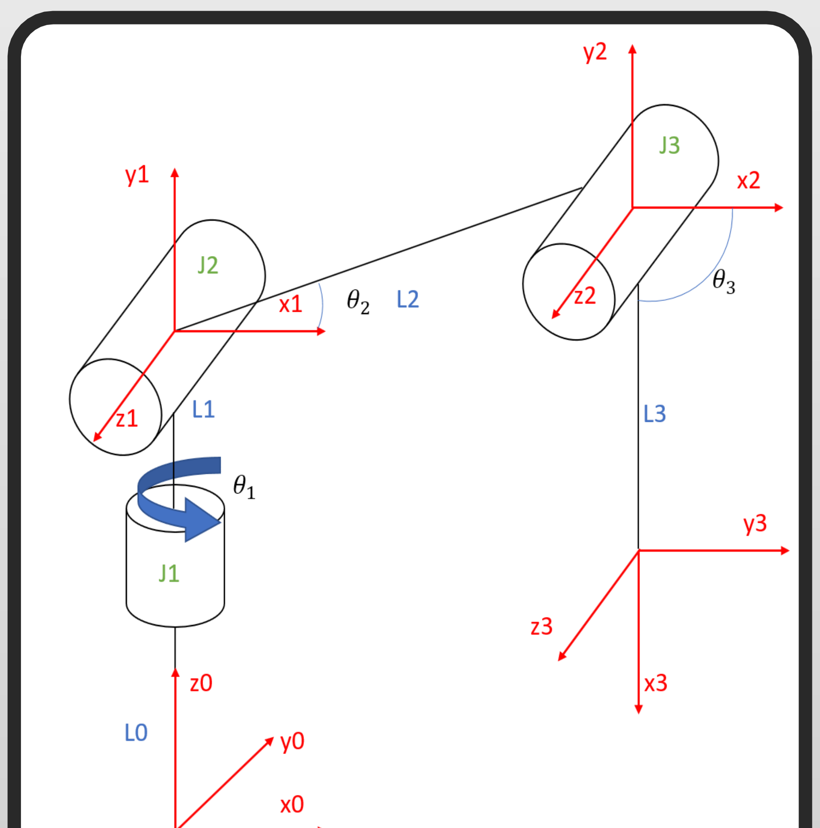

Figure 2: Leg Inverse Kinematics Angles

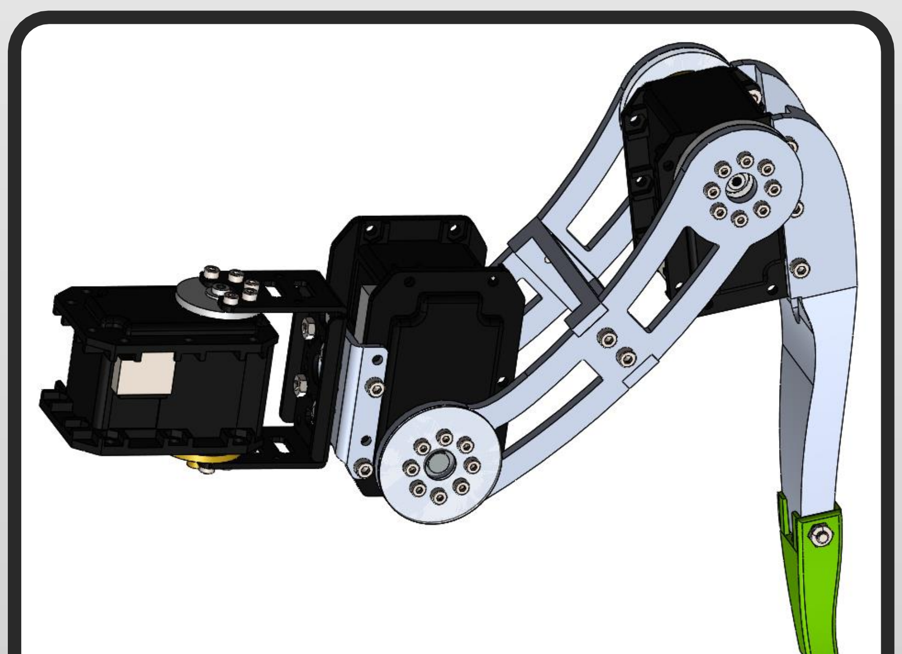

Figure 3: Hexapod Leg Rendering

This facilitated the creation of an algorithm for individual leg position control. Kinematics relating the hexapod body position to the foot position of each leg was developed.

A dynamic model for the leg was then developed using Lagrangian dynamics [3]. This model defines the relationship between joint torques and foot forces which can be used in gripping and friction force calculations.

Leg Trajectory Generation

Trajectory generation was used to generate a third order polynomial path [4] of motion for each leg; made up of the swing phase (where the leg is moving through the air) and the support phase (where the leg is touching the ground).

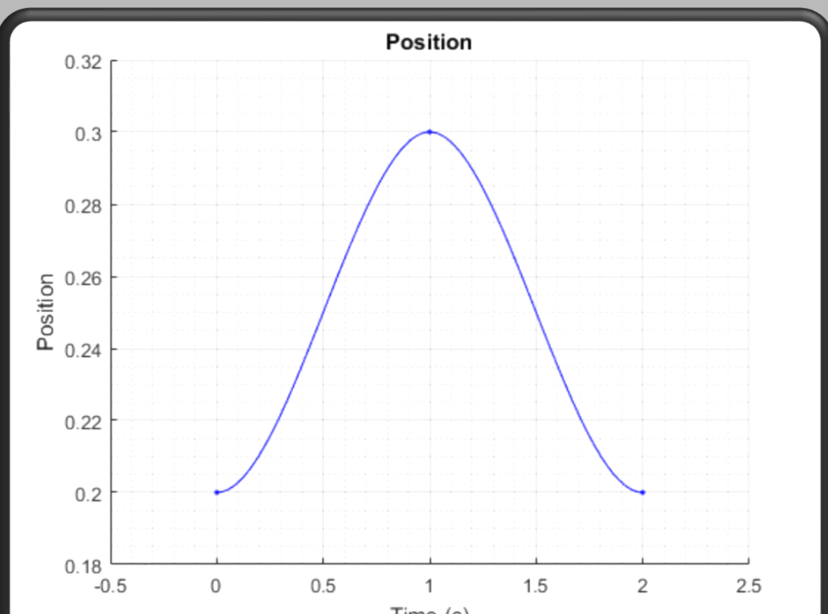

Figure 4: X-Z plot of the foot position during the swing phase of a leg

This allows for a smooth motion when moving the foot between points as seen in the position plot in figure 4.

A tripod walking motion was achieved by moving each leg through the points in their respective paths.

Controller and Peripherals

The hexapod includes a central **microcontroller**, a **wireless transmitter** for remote control and an **accelerometer** module.

STM32F4 Microcontroller

An ARM microcontroller is used as the main controller of the hexapod; programmed in object orientated C++. This allows for an instant start-up time of the hexapod and fast processing of commands [5]. The controller calculates the inverse kinematics of each path point, for all legs, in real time and sends this data to all 18 Dynamixel motors via serial communication.

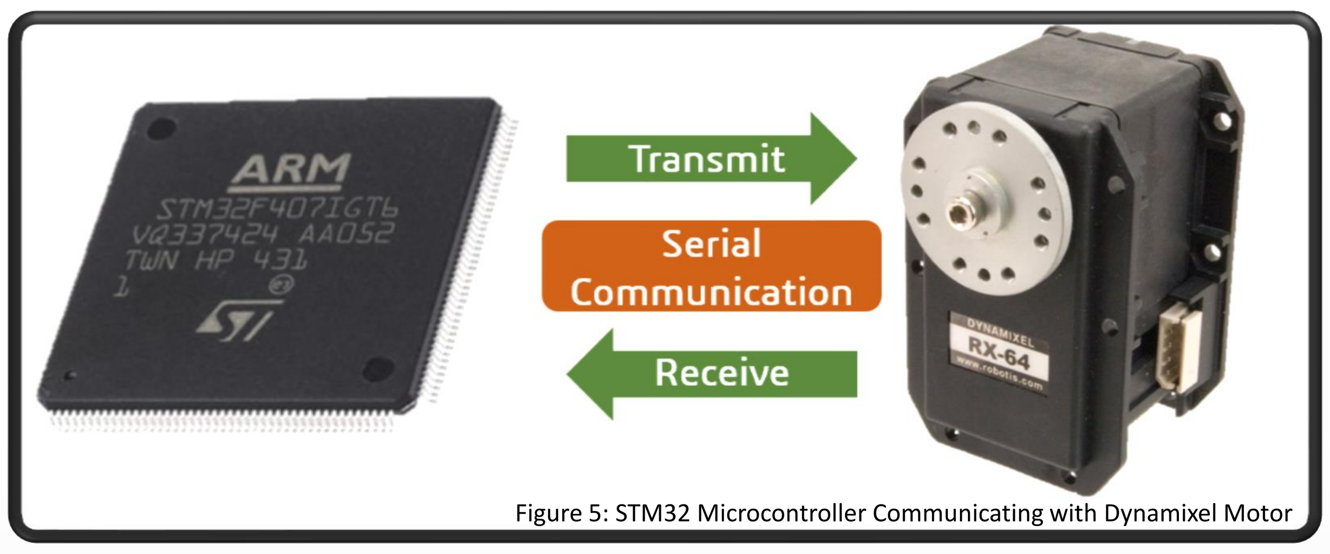

Figure 5: STM32 Microcontroller Communicating with Dynamixel Motor

This allows for the implementation of adaptive walking as all calculations can be adjusted and updated, in real time, as the hexapod moves.

Wireless Transmitter

The wireless transmitter is an RF1100-232 module. It transmits serial data between the hexapod and a computer at a speed of 433MHz. This data includes position and orientation commands from the computer and feedback signals (such as motor temperatures and torques) from the hexapod.

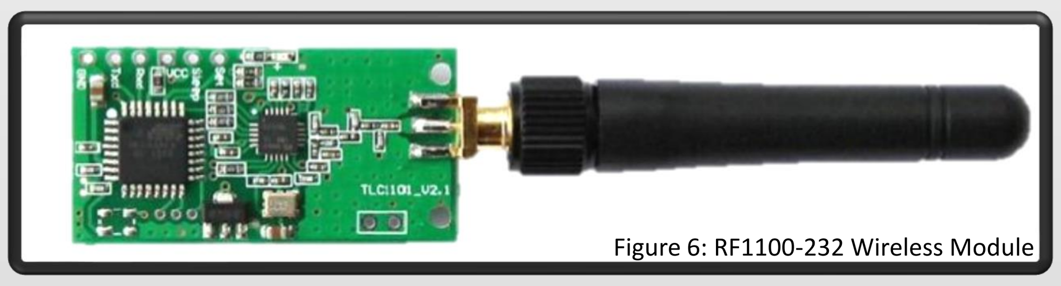

Figure 6: RF1100-232 Wireless Module

Accelerometer

The accelerometer module is an XSens Mti-28A. It allows for accurate position and orientation measurement in 3 axes. These measurements are fed into a PID [6] controller which allows the orientation of the hexapod to be set and maintained. Currently the Hexapod is set to maintain a level body even if the ground is not level.

Figure 7: XSens Mti-28A Accelerometer

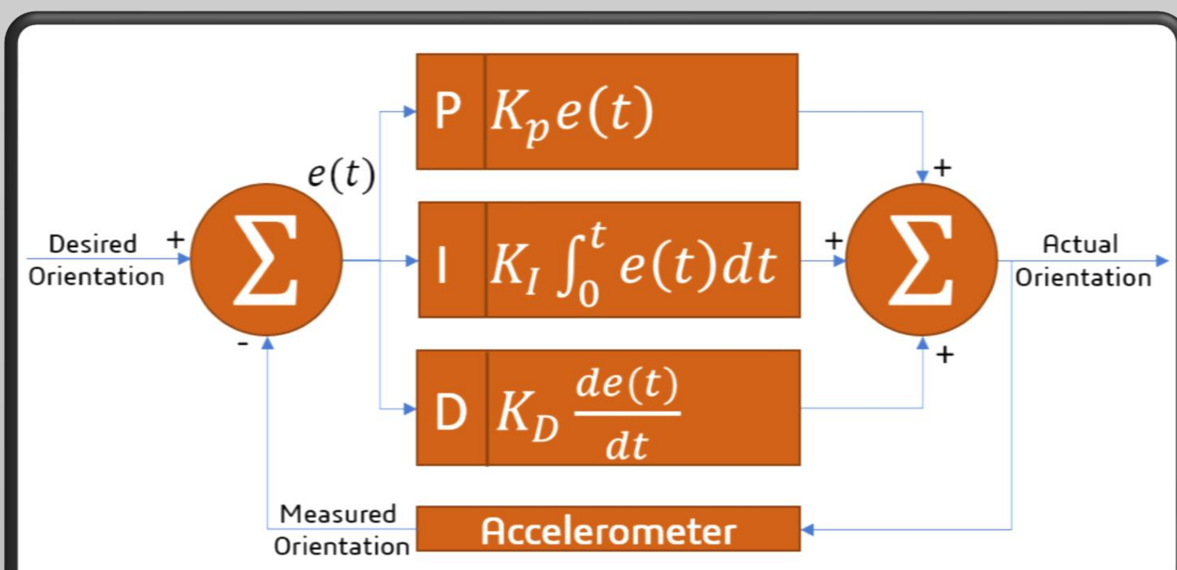

Figure 8: Orientation PID Control Loop

References

[1] A. P. Gracia, "Kinematics of Robots," 2007.
[2] M. M. U. A. a. M. A. R. Ahad, "Inverse Kinematics Solution for a 3DOF Robotic Structure using Denavit-Hartenberg Convention," 2014.
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[6] O. Aydogdu and M. Korkmaz, "A Simple Approach to Design of Variable Parameter PID controller," presented at the International Conference on Advancements in Information Technology, Singapore, 2011.