Real-time prosthesis control using PID embedded control system

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Introduction

- Powered lower-limb prostheses enable walking on varying terrains (e.g., level-ground, stairs, ramps).
- Advanced prosthetic control is required to detect movement intent and allow for volitional control.
- Intrinsic control relies on feedback from sensors to monitor the joint position in real-time.
- PID (proportional – integral - derivative) controllers are closed-loop feedback systems used to calculate error continuously and apply appropriate corrections.
- Movement to specific angles in EC motors is achieved through varying motor speeds.
- The purpose of this project is to develop an embedded intrinsic control system for autonomously operating a prosthetic leg.

Powered Prosthesis: Hardware

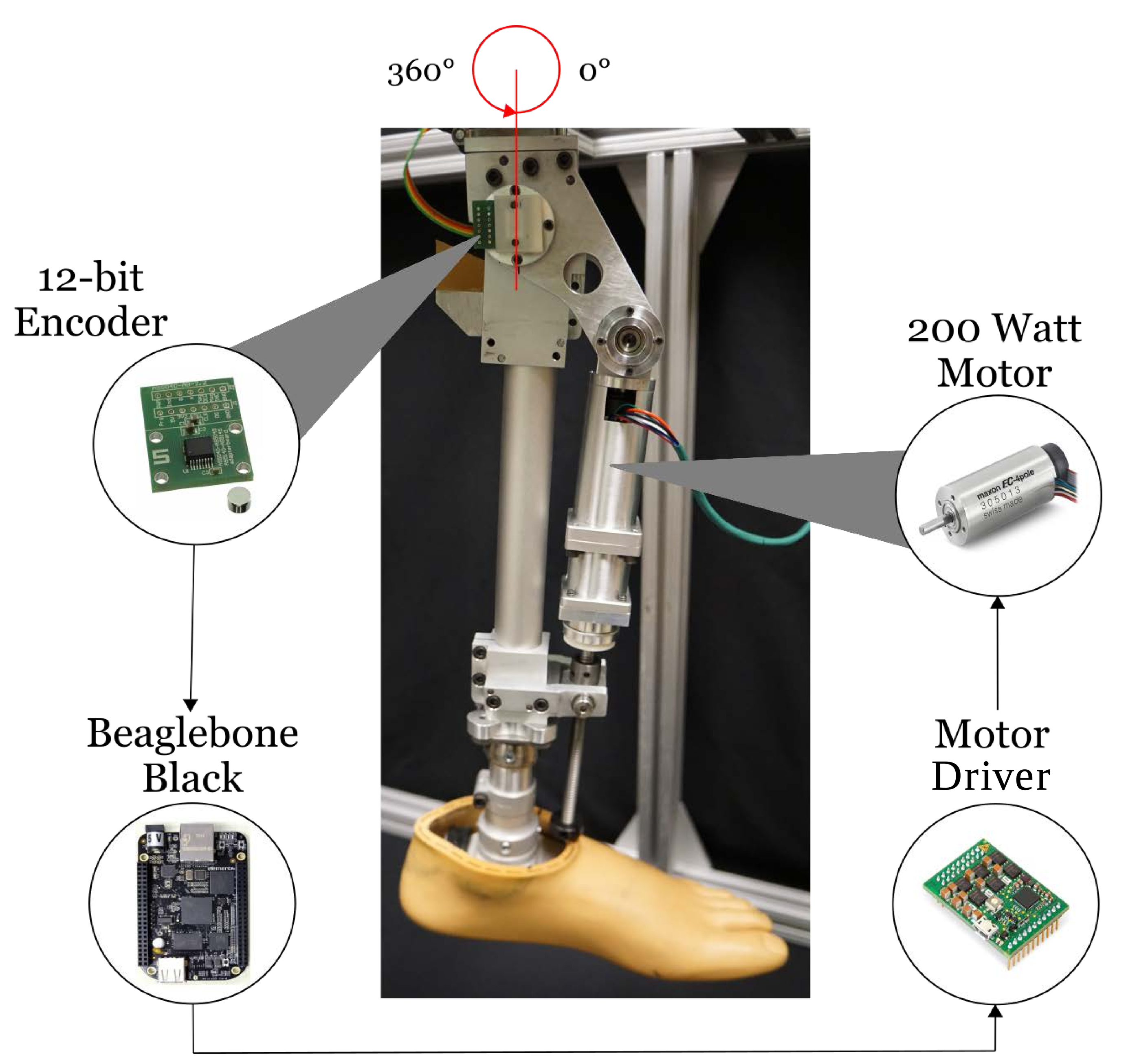


Figure 1: Powered lower-limb prosthesis instrumented with different power, sensor, and controller components. The angle is read by the 12-bit encoder, AS5045. This information is passed to the microcontroller, Beaglebone Black. The microcontroller enables specific pins on the motor driver, ESCON 50/5. The motor driver signals the motor to move or stop.

Control System

The desired angles were chosen by considering the initial resting angle and the degree changes that might be present in knee kinematics for level-ground or stair ambulation.

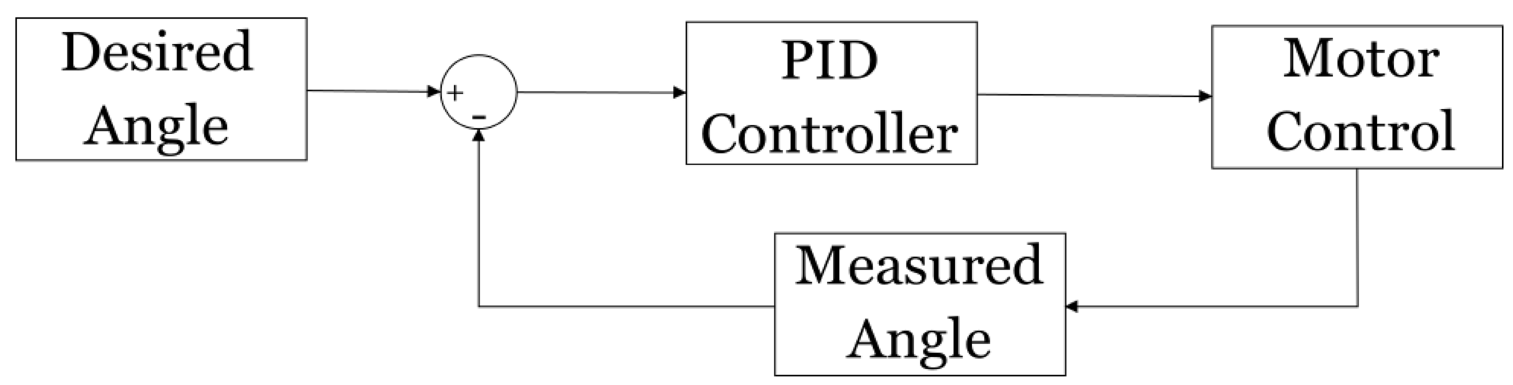


Figure 2: Embedded control system flow chart. Desired angle is input by user. Motor's speed altered to achieve desired angle. Encoder reads actual angle of joint. Error calculated from intended and measured angles then passed to PID controller. PID controller applies P, I, and D gains to error and passes new angle to motor control.

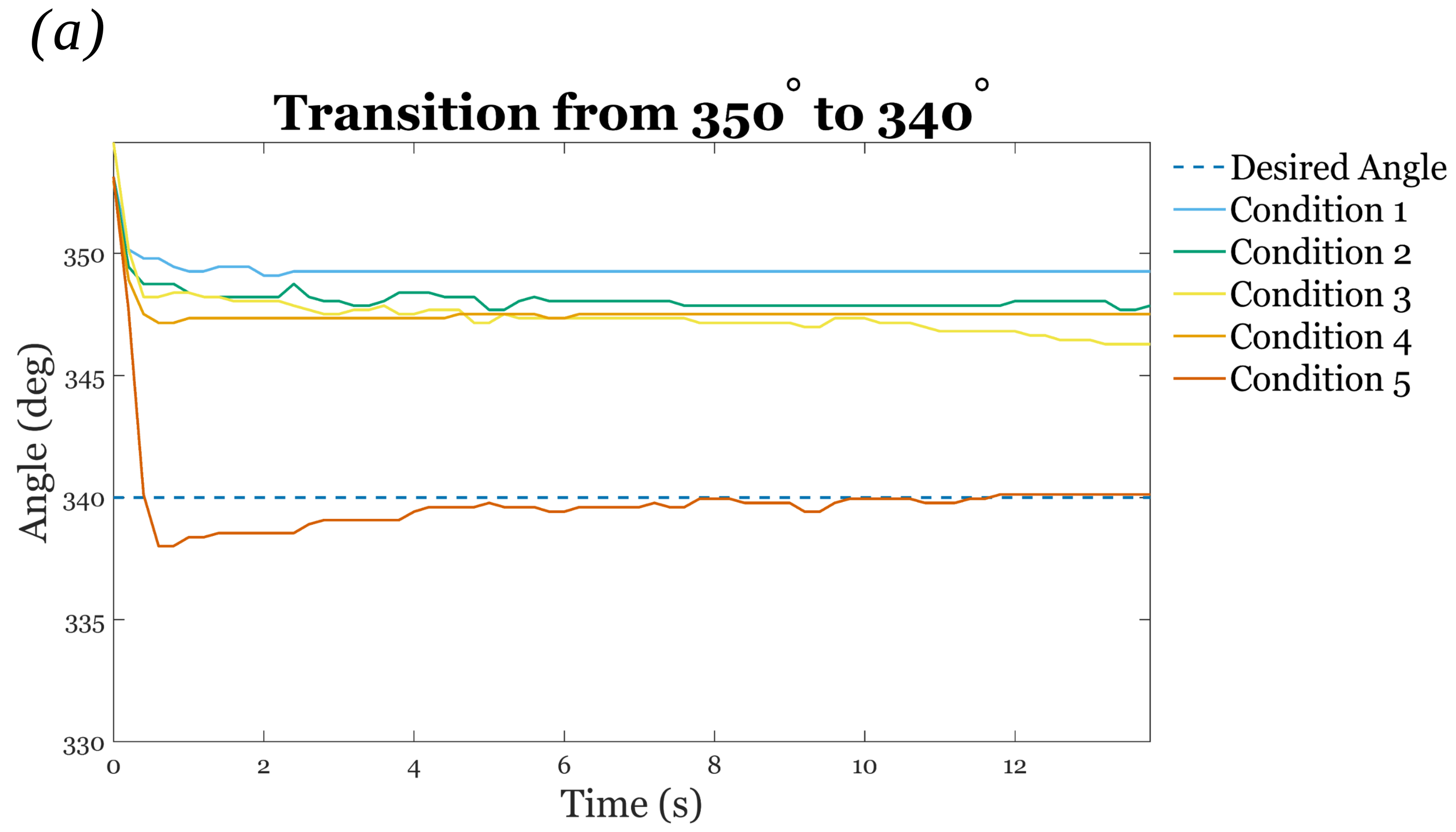
	Low P Gain	High P Gain	I Gain	D Gain	N
Condition 1	350	800	0	0	100
Condition 2	350	900	0	0	100
Condition 3	350	900	5	0	100
Condition 4	350	1000	0	0	100
Condition 5	250	2000	5	0	100

Table 1: Table of gain values for each condition. Low P gain is applied when an angle is increasing. High P gain is applied when an angle is decreasing. N represents the filter coefficient.

Results

PID controller can be used to provide responsive error correction.

(a)



(b)

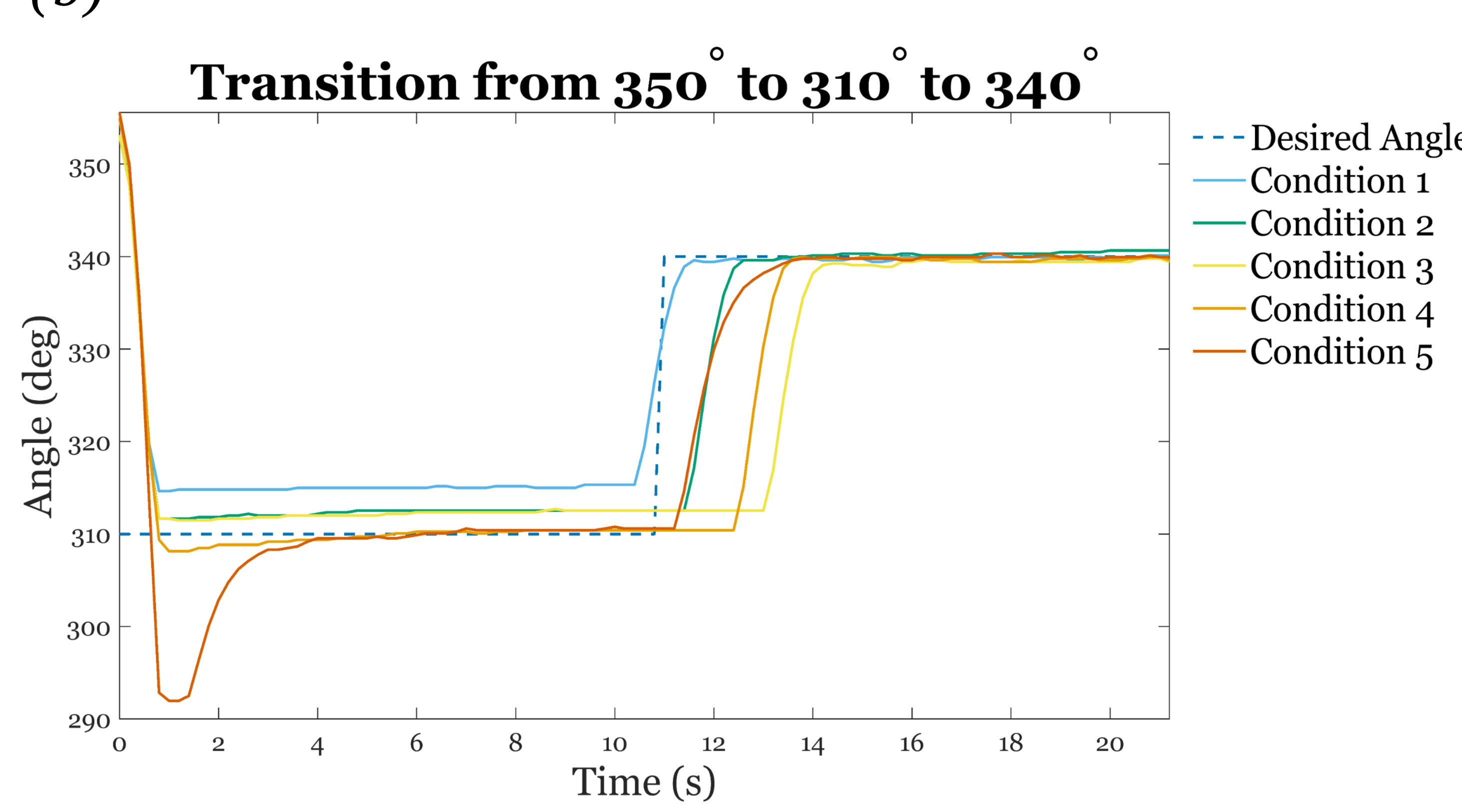


Figure 3: Examples of angle changes of joint. (a) Leg begins at roughly 350° and attempts to reach and sustain its position at 340°. (b) Leg begins at roughly 350° and attempts to reach and sustain its position at 310° for approximately 10 seconds. Leg is then signaled to move to 340° and maintain its position.

Target Values

Settling Time < 5 s, Rise Time < 0.75 s, Overshoot < 0.5 %

	350° to 340°			350° to 310°			310° to 340°		
	Settling Time (s)	Rise Time (s)	Over-shoot (%)	Settling Time (s)	Rise Time (s)	Over-shoot (%)	Settling Time (s)	Rise Time (s)	Over-shoot (%)
Condition 1	2.310	0.658	1.110	10.568	0.431	10.508	11.534	0.641	0.101
Condition 2	20.669	2.733	1.619	1.473	0.509	12.994	13.964	0.815	0.0
Condition 3	17.192	12.536	2.595	2.673	0.507	12.994	14.156	0.766	0.106
Condition 4	20.461	0.361	1.727	4.383	0.527	14.325	13.490	0.758	0.051
Condition 5	11.720	0.314	3.770	5.771	0.426	14.488	13.465	1.347	0.106

Table 2: Table of step information values for each condition. Settling time is the time it takes for the error to fall to 2%. Rise time is the time it takes for the response to change from 10% to 90% of the steady-state response. Overshoot is the percentage of time the response overshoot the target angle.

Conclusions and Implications

- This study implemented a PID controller for continuously regulating the joint angle of a prosthetic leg.
- Higher P gains were required to counteract gravity.
- Additional modifications are necessary to accurately reach the desired angles.

Future Works:

- Expand to follow a predefined knee trajectory
- Develop real-time gait segmentation using IMU for finite state control and specialized PID gains for each phase
- Develop an EEG-EMG neural machine interface for natural control of the prosthesis

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