Demonstration of Locomotion with the Powered Prosthesis AMPRO utilizing Online Optimization-Based Control

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ABSTRACT

This demonstration presents an unimpaired subject walking with a custom built self-contained powered transfemoral prosthesis: AMPRO, which is controlled by a novel nonlinear real-time optimization based controller. To achieve the behaviors that will be demonstrated, controllers that have been successfully implemented on bipedal walking robots are translated to the prosthesis with the goal of achieving natural human-like walking while minimizing power consumption. To achieve this goal, we begin by collecting reference human locomotion data via Inertial measurement Units (IMUs). This data forms the basis for an optimization problem that generates virtual constraints for the prosthesis that provably yields walking in simulation. Utilizing methods that have proven successful in generating stable robotic locomotion, control Lyapunov function (CLF) based Quadratic Programs (QPs) are utilized to optimally track the resulting desired trajectories. The parameterization of the trajectories is determined through a combination of on-board sensing on the prosthesis together with IMU data, thereby coupling the actions of the user with the controller. Finally, impedance control is integrated into the QP yielding an optimization based control law that displays remarkable tracking and robustness, outperforming traditional PD and impedance control strategies.

Figure 1: Transfemoral prosthetic: AMPRO.

1. BACKGROUND

There are approximately $222,000$ people in the United States alone that are transfemoral amputees [2]. Despite this large amputee population, the current market for commercial transfemoral prosthesis remains largely limited to energetically passive prosthetic devices, therefore, limiting the day-to-day life of amputees with increased metabolic cost and constrained locomotion capabilities [5]. As one of the most important applications of bipedal robotic research, powered lower-limb prosthesis capable of providing net power in conjunction with various prosthesis controllers have been developed in recent decades [3, 4]. However, despite the improvements that these smart controllers have achieved, there are still limitations related to the optimality of the controllers and the need for exhaustive clinical testing to determine control parameters. These issues motivate the main objectives of this work.

2. OBJECTIVE

The objectives of this work are twofold: a) to propose the method of using bipedal robots to test prosthetic controllers. A nominal walking gait is found for the robot platform

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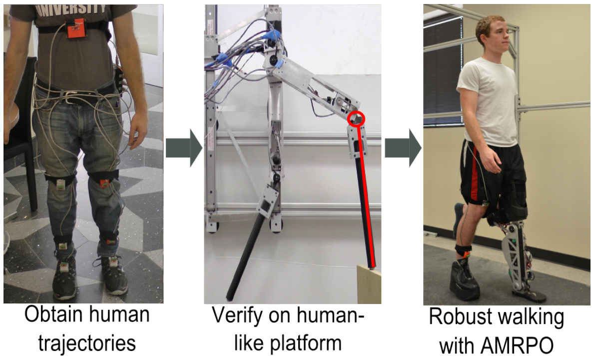

Figure 2: General procedure to obtain robust prosthetic walking.

which displays qualitatively human-like walking, and prosthetic controllers are tested on a "leg" of the robot. Through this method, we are able to present and test a novel online optimization-based transfemoral prosthesis control method: control Lyapunov function (CLF) based quadratic programs (QPs) coupled with variable impedance control; b) having verified the controllers on the robot platform, we take the next step to translate the complete methodology from realizing human-like robotic walking to achieve stable prosthetic walking on a custom-built self-contained transfemoral prosthesis device: AMPRO. The primary goal of this demo is to show that the proposed optimal controller will yield stable human-like prosthetic walking.

3. APPROACH

Motivated by disadvantages of impedance control, a novel prosthetic controller that combines the rapidly exponentially stabilizing control Lyapunov functions (RES-CLFs) [1] with impedance control is proposed with the goal of achieving better tracking and improved energy efficiency on prosthesis. This controller was first verified in simulation [6] then tested on a bipedal robot platform: AMBER, which was shown to be able to achieve stable "prosthetic" walking [7]. The controller is then realized on a custom-built prosthetic device: AMPRO. We begin with utilizing a custom motion capture system with Inertial Measurement Units (IMUs) to collect human locomotion trajectories. With the collected data, a human-inspired optimization problem is then leveraged to obtain a stable and robust gait for a specific test subject. IMUs are used to estimate human movements during walking thus providing human sensory feedback. Finally, the proposed controller is realized on the prosthetic device AMPRO. An illustration of the entire process demonstrated in this demo can be seen in Fig. 2.

4. RESULTS

Through the systematic methodology for translating human-inspired robotic walking to prosthesis, stable robust human-like prosthetic walking in both the laboratory and in real-world environments is achieved. The resulted walking is also robust to unknown obstacles. Gait tiles of a user walking over uneven terrain with obstacles is shown in Fig. 3. The prosthesis has been used to realize assisted walking continuously for 1 mile and is able to walk 3 hours with a single charge. The proposed controller also outperforms other existing controllers (such as PD) w.r.t. both tracking (23% improvement) and power consumption (25% reduction) [8].

Figure 3: Gait tiles of walking over obstacle.

5. CONCLUSION

The online optimization-based controller was realized on the prosthetic device AMPRO experimentally with improved tracking and power consumption performance. The procedure for testing this controller both in simulation and on the bipedal robot helped to predict and resolve many implementation issues before attempting to realize walking with a test subject. The presented procedure, therefore, has the potential to reduce the cost of clinical testing of prosthesis through the efficient development and testing of controllers.

6. REFERENCES

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