Information, Communication, and Modeling Technologies in Prosthetic Leg and Robotics Research at Cleveland State University

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Abstract. This paper analyzes the role of information and communication technology (ICT) and computer modelling in the education of engineering students. Special attention is paid to research-based education and the implementation of new modelling methods and advanced software in student research, including course work, diploma projects, and theses for all student categories, including Doctoral, Master's, and Bachelor's. The paper concentrates on the correlation between student research and government priorities and research funding. Successful cases of such correlations with specific description of computer modeling methods for the implementation of prosthesis and robotics research projects are presented based on experiences in the Embedded Control Systems Research Laboratory in the Electrical Engineering and Computer Science Department in the Washkewicz College of Engineering, Cleveland State University, USA.

Keywords: ICT, computer modeling, research-based education, student project, prosthesis research, governmental priority
Key Terms: Academia, Research, MathematicalModeling, ComputerSimulation, Experience

1 Introduction

Information and communication technologies (ICT), mathematical modeling, and computer simulation play a significant role in higher education. Most advanced educational systems in the world are oriented toward the implementation of educational processes of modern ICT and software for modelling and simulation in various fields of human activity, including science, engineering, and technology. This approach is required for the efficient training of students at various levels: undergraduates, gradu-

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ates, and doctoral students. Many international conferences on ICT and its applications for education are devoted to the use of computer modeling, open-source software, pedagogical e-learning, web-based e-learning, course-centered knowledge management and application in online learning based on web ontology, on-online learning in enterprise education, simulation languages, modeling and simulation for education and training, improving education through data mining, 3D software systems, 3D visualization, wireless communication, experimental teaching of program design, different approaches in teaching programming, web-based computer-assisted language learning, and so on.

It is important that university and IT-industry participants of conferences try to find efficient solutions for the abovementioned computer-modeling-based educational problems. For example, participants from 178 different academic institutions, including many from the top 50 world-ranked institutions, and from many leading IT corporations, including Microsoft, Google, Oracle, Amazon, Yahoo, Samsung, IBM, Apple, and others, attended the 12th International Conference on Modeling, Simulation and Visualization Methods, MSV-2015, in Las Vegas, Nevada, USA.

If IT industry today supports higher education, then tomorrow's IT-based companies, government research agencies, and national laboratories will obtain the high-quality graduates that they need. New achievements in ICT require continuous tracking by educators, and implementation in education.

Successful introduction of ICT to higher education based on research-oriented education and training is considered and analyzed in this paper. The focus is on the role of computer modeling and simulation in prosthesis and robotics research for increasing student quality, including grading their practical skills, and including efficient professor-student interactions.

2 Literature Analysis and Problem Statement

Many publications are devoted to teaching methods and approaches based on ICT and computer modelling, for increasing the efficiency of their interrelation: qualitative modeling in education [3], computer simulation technologies and their effect on learning [21], opportunities and challenges for computer modeling and simulation in science education [31], web-based curricula [4] and remote access laboratories, computer-based programming environments as modelling tools in education and the peculiarities of textual and graphical programming languages [15], interrelations between computer modeling tools, expert models, and modeling processes [41], efficient science education based on models and modelling [9], educational software for collective thinking and testing hypotheses in computer science [23], and others.

Many publications are devoted to improving teaching efficiency for specific courses by introducing modern ICT and computer modelling technologies. In particular, modelling supported course programs, computer-based modelling (AutoCAD, Excel, VBA, etc.) and computer system support for higher education in engineering [8]; software to enhance power engineering education [32]; computer modeling for enhancing instruction in electric machinery [20]; computer modelling in mathematics education [37]; GUI-based computer modelling and design platforms to promote interactive learning in fiber optic communications [42]; RP-aided computer modelling for architectural education [33]; teaching environmental modelling; computer modelling and simulation in power electronics education [24]; and a virtual laboratory for a communication and computer networking course [19].

Special attention in the literature [5] is paid to the role of ICT and modeling technology in education and training in the framework of research-based curricula. This educational approach deals first with educational directions such as robotics, mechatronics, and biomechanics (RMBM) [12, 30, 38]. The correlation of RMBM with ICT and modeling are underlined by results such as: a multidisciplinary model for robotics in engineering education; integration of mechatronics design into the teaching of modeling; modelling of physical systems for the design and control of mechatronic systems [38]; biomechanical applications of computers in engineering education [30]; computerized bio-skills system for surgical skills training in knee replacement [6]; computer modelling and simulation of human movement [22]; computer modelling of the human hand [17]; and design and control of a prosthesis test robot [26, 27].

The main aims of this paper are given as follows.

(a) Description and analysis of research-based education based on the experience in the Embedded Control Systems Research Laboratory at the Electrical Engineering and Computer Science Department at the Washkewicz College of Engineering at Cleveland State University (CSU), USA, with a focus on undergraduate, graduate, and doctoral student participation in prosthesis and robotics research, which is funded by the US National Science Foundation (NSF);

(b) Analysis of applied ICT and modeling technologies and advanced software, as well as their implementation in student research, including course work, diploma projects, and Doctoral, Master's, and Bachelor's theses;

(c) Focus on the correlation between student research and government science priorities based on successful cases of ICT and advanced modelling implementation in US government-funded prosthesis research, with particular focus on undergraduate, graduate, and doctoral student participation in prosthesis and robotics research.

The rest of this paper is organized as follows. Section 3 presents a general description of the prosthesis research project granted by the US NSF. In Section 4 the authors consider the implementation of ICT in prosthesis and robotics research at CSU. The paper ends with a conclusion in Section 5.

3 NSF Project "Optimal Prosthesis Design with Energy Regeneration" for Research-Based Education

CSU's research project "Optimal prosthesis design with energy regeneration" (OPDER) is funded by the US NSF (1.5M USD). Professors and students from the Department of Electrical Engineering and Computer Science, and the Department of Mechanical Engineering, are involved in research according to the project goals, which deal with the development of: (a) new approaches for the simulation of human limb control; (b) new approaches for optimizing prosthetic limb control, capturing energy during walking, and storing that energy to lengthen useful prosthesis life; (c) prosthesis prototype development.

The human leg transfers energy between the knee, which absorbs energy, and the ankle, which produces energy. The prosthesis that results from this research will mimic the energy transfer of the human leg. Current prostheses do not restore normal gait, and this contributes to degenerative joint disease in amputees. This research will develop new design approaches that will allow prostheses to perform more robustly, closer to natural human gait, and last longer between battery charges.

This project forms a framework for research-based education. Doctoral, graduate, and undergraduate students are involved in research such as: the study of able-bodied gait and amputee gait; the development of models for human motion control to provide a foundation for artificial limb control; the development of electronic prosthesis controls; the development of new approaches for optimizing prosthesis design parameters based on computer intelligence; the fabrication of a prosthesis prototype and its test in a robotic system; the conduct of human trials of the prosthesis prototype.

The role of student participation in all aspects of the research is significant for increasing their qualifications for their careers, for presentations at conferences, for publishing in journals, and for research with professors who can help them be more successful in building their future careers in industry or academia. In the next section we describe the student contribution to prosthesis and robotics research at CSU.

4 Student contributions to prosthesis and robotics research

Seven cases of student research in the framework of the OPDER project are described in this section.

Evolutionary Optimization of User Intent Recognition for Transfemoral Amputees. Powered prostheses can help amputees handle multiple activities: standing, level walking, stepping up and down, walking up and down a ramp, etc. For each walking mode, a different control strategy or control gains are used to control the prosthesis. It is important to infer the user's intent automatically while transitioning from one walking mode to another one, and to subsequently activate the suitable controller or control gains. Pattern recognition techniques are used to address such problems.

In this research, mechanical sensor data are experimentally collected from an able-bodied subject. Collected signals are processed and filtered to eliminate noise and to handle missing data points. Signals reflecting the state of the prosthesis, user-prosthesis interactions, and prosthesis-environment interactions are used for user intent recognition. Principal component analysis is used to convert data to a lower dimension by eliminating the least relevant features. We propose the use of correlation analysis to remove highly correlated observations from the training set.

We use K-nearest neighbor (K-NN) as a classification method. K-NN is modified and optimized with an evolutionary algorithm for enhanced performance. In the modified K-NN, the contribution of each neighbor is weighted on the basis of its distance to the test point, and the history of previously classified test points is considered for classification of the current test point. This modification leads to better performance than standard K-NN. Optimization techniques can be used to tune the parameters and obtain a classification system with the highest possible accuracy. We choose biogeography-based optimization **(**BBO) as the evolutionary optimization algorithm for this purpose. The optimization problem is to minimize the classification error.

We use MATLAB to implement user intent recognition. BBO is a stochastic algorithm, so it requires several runs to optimize the parameters. The optimization process may take multiple days, so we use parallel computing to reduce the optimization time from 7.77 days to about 20 hours [11]. To test the proposed method, multiple sets of experimental data were collected for various gait modes: standing (ST), slow walking (SW), normal walking (NW), and fast walking (FW). Fig. 1 illustrates the experimental setup for able-bodied subjects. Hip and ankle angles, ground reaction force (GRF) along three axes, and hip moment, comprise the six input signals which were used for user intent recognition. Fig. 2 shows an example of test data for a walking trial lasting approximately 18 seconds, which included different walking modes.

Fig. 1. Experimental setup: data collection for able-bodied subjects

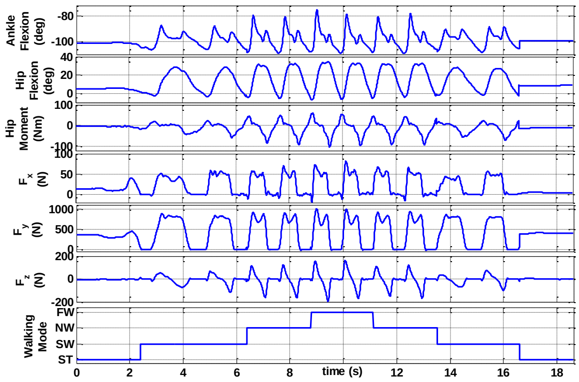


Fig. 2. Sample test data showing four different gait modes and transitions: ST (standing), SW (slow walk), NW (normal walk), and FW (fast walk)

Fig. 3 shows the performance of the classifier using both simple K-NN and optimized K-NN. Classification error for optimized K-NN is 3.6% which is improved from 12.9% with standard K-NN.

In conclusion, K-NN was modified to enhance the performance of a user intent recognition system. An evolutionary algorithm was applied to optimize the classifier parameters. Experimental data was used for training and testing the system. It was shown that the optimized system can classify four different walking modes with an accuracy of 96%. The code used to generate these results is available at http://embeddedlab.csuohio.edu/prosthetics/research/user-intent-recognition.html. Further details about this research can be found in [11].

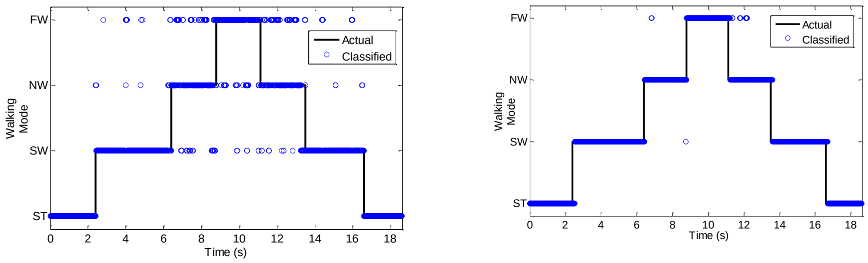


Fig. 3. Classifier results for optimized K-NN 3.6% error (right), improved from 12.9% with standard K-NN (left)

Stable Robust Adaptive Impedance Control of a Prosthetic Leg. We propose a nonlinear robust model reference adaptive impedance controller for a prosthetic leg. We use an adaptive control term to compensate for the uncertain parameters of the system, and a robust control term so the system trajectories exhibit robustness to variations of ground reaction force (GRF). The algorithm not only compromises between control chattering and tracking performance, but also bounds parameter adaptation to prevent unfavorable drift. The acceleration-free regressor form of the system removes the need to measure joint accelerations, which would otherwise introduce noise in the system. We use particle swarm optimization (PSO) to optimize the design parameters of the controller and the adaptation law. The PSO cost function is comprised of control signal magnitudes and tracking errors.

The prosthetic component is modeled as an active transfemoral (above-knee) prosthesis. This model has a prismatic-revolute-revolute (PRR) joint structure. Human hip and thigh motion are emulated by a prosthesis test robot. The vertical degree of freedom represents human vertical hip motion, the first rotational axis represents angular thigh motion, and the second rotational axis represents prosthetic angular knee motion [26, 27]. The three degree-of-freedom model can be written as follows [36]:

$$M\ddot{q} + C\dot{q} + g + R = u - T_e \quad (1)$$

where $q^T = [q_1 \quad q_2 \quad q_3]$ is the vector of generalized joint displacements (q_1 is the vertical displacement, q_2 is the thigh angle, and q_3 is the knee angle); u is the control signal that comprises the active control force at the hip and the active control torques at the thigh and knee; and T_e is the effect of the GRF on the three joints.

The contribution of this research is a nonlinear robust adaptive impedance controller using a boundary layer and a sliding surface to track reference inputs, in the presence of parameter uncertainties. We desire the closed-loop system to provide near-normal gait for amputees. Therefore, we define a target impedance model with characteristics that are similar to those of able-bodied walking:

$$M_r(\ddot{q}_r - \ddot{q}_d) + B_r(\dot{q}_r - \dot{q}_d) + K_r(q_r - q_d) = -T_e \quad (2)$$

where q_r and q_d are the state of the reference model and the desired trajectory respectively. Since the parameters of the system are unknown, we use a control law [36]

$$u = \widehat{M}\dot{v} + \hat{C}v + \hat{g} + \hat{R} + \hat{T}_e - K_d \,\mathrm{sat}(s/\mathrm{diag}(\varphi)) \quad (3)$$

where the diagonal elements of φ are the widths of the saturation function; s and v are error and signal vectors respectively; $\widehat{M}$, $\widehat{C}$, $\widehat{g}$, $\widehat{R}$, and $\widehat{T}_e$ are estimates of

M, C, g, R, and T_e respectively. The control law of Eq. (3) comprises two different parts. The first part, $\hat{M}\dot{v} + \hat{C}v + \hat{g} + \hat{R}$, is an adaptive term that handles the uncertain parameters. The second part, $\hat{T}_e - K_d \,\mathrm{sat}(s/\mathrm{diag}(\varphi))$, satisfyies the reaching condition and the variations of the external inputs T_e.

We use PSO to tune the controller and estimator parameters. PSO decreases the cost function (a blend of tracking and control costs) by 8%. We suppose the system parameters can vary ±30% from their nominal values. Fig. 4 compares the states of the closed-loop system with the desired trajectories when the system parameters vary. The MATLAB code used to generate these results is available at http://embeddedlab.csuohio.edu/prosthetics/research/robust-adaptive.html [2].

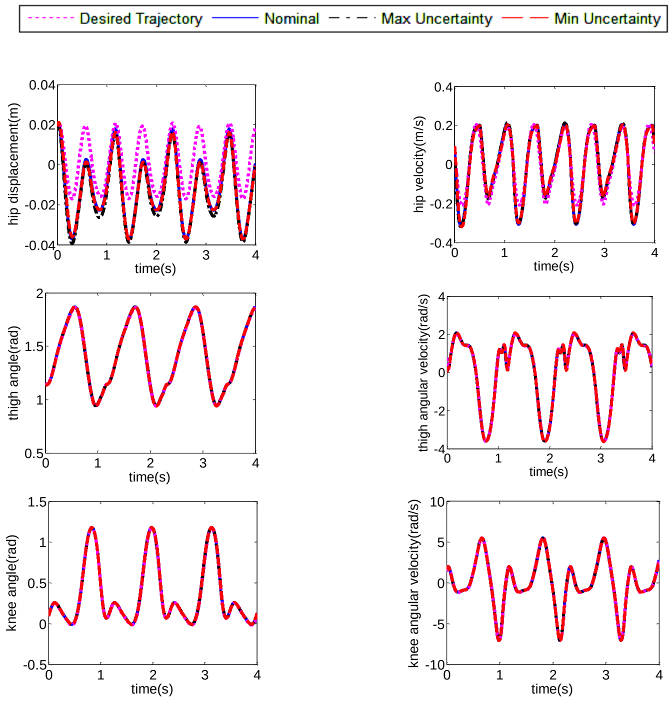


Fig. 4. Tracking performance for the joint displacements and velocities

Hybrid Function Approximation Based Control for Prosthetic Legs. The combination of a prosthesis test robot and a prosthesis and how their respective controllers could be combined to yield a coupled stable controller is addressed in this research. The prosthesis test robot was assumed to be controlled by a regressor-based controller while the prosthesis was assumed to be controlled by a regressor-free controller. We address this problem by first defining a framework on which two controllers could be combined where the controllers are indirectly dependent on each other. We propose a theorem that yields a stable robotic system by the combination of the prosthesis test robot and the prosthesis leg.

The mathematical proof depends on using the open loop dynamics of the system to develop the closed loop system dynamics using the control law developed in the theorem. We then employ a Lyapunov function to verify the stability of the robotic system with the proposed controller. We also evaluate the transient response of the system by evaluating the upper bounds for both the Lyapunov function and the error vector.

We use MATLAB/Simulink to model the robotic system and then simulate the system's behavior when the proposed controller is applied; see Fig. 5 and Fig. 6.

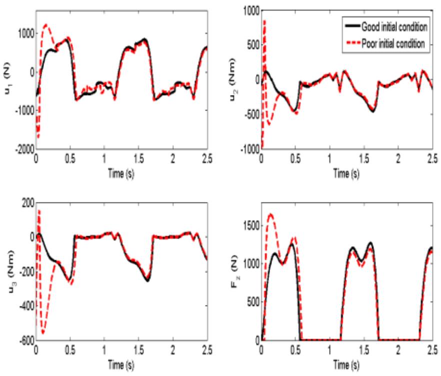


Fig. 5. Plot of joint angle trajectories

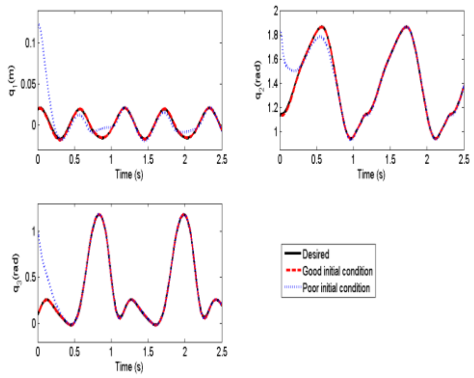


Fig. 6. Plot of control signals and vertical ground reaction force

Results show that the controller is able to drive the system to a desired state. Fig. 5 shows good tracking of the reference trajectories which is desired. However, Fig. 6 shows that the control signals u_2 and u_3 are too large to be implemented on the robotic system in real-time as it will lead to damage of equipment; additional research is needed to reduce the control signal magnitudes.

In conclusion, the simulation results show that the combination of two different robotic systems with different control schemes is possible, which is further verification of the stability proof. The simulation results help us investigate implementation of an environmental interaction controller to trade off tracking accuracy and reaction force magnitudes, hence reducing the control signal magnitudes.

The MATLAB code that was used to generate these results can be downloaded from http://embeddedlab.csuohio.edu/prosthetics/research/hybrid-fat.html [7].

System Identification and Control Optimization of a Prosthetic Knee. A Mauch SNS knee has been attached to an EMG-30 geared DC motor as our active leg prosthesis. The Mauch SNS knee is a widely-used passive prosthesis; we have modified it by removing the damper connection and driving it with our DC motor. Our work provides a conceptual approach for the system identification, control optimization, and implementation of an active prosthetic knee during swing phase.

To apply velocity control to the system, Proportional-Integral-Derivative control (PID) is used due its effectiveness in a wide range of operating conditions, its functional simplicity, and its ease of use with embedded systems technology. The goal is to investigate the behavior of PID parameters with respect to shank length. To achieve this goal we have to find a model for the prosthetic leg. We use heuristic algorithms and gradient algorithms to identify model parameters and tune the PID controller. Particle Swarm Optimization (PSO), BBO, and Sequential Quadratic Optimization (SQP) [16, 18, 29, 34] are used for identification and tuning.

Hardware setup includes a PC connected to a Quanser© DAQ card. MATLAB with Quanser Quarc software for real-time connectivity, and DAQ hardware; see Fig. 7. The DAQ system delivers an analog control signal to a servo amplifier to drive the EMG30 DC motor. The encoder sends signals through two digital channels. We use a quadrature encoder which has the ability to sense rotational direction.

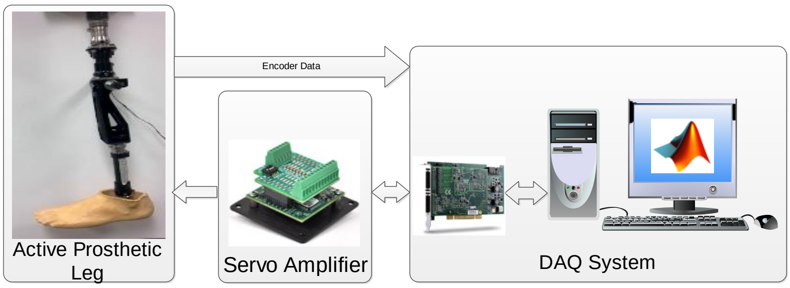


Fig. 7. Hardware Setup

Numerical differentiation is usually used to obtain angular velocity by differentiating the encoder signal [39]. This technique leads to a distorted signal due to encoder resolution. So a Kalman filter is instead designed to estimate the angular velocity.

The DC geared motor and the Mauch SNS joint are described mathematically [10]. Simulink is used to implement the models. In order to find model parameters, each optimization algorithm executes 20 times. The DC motor mode and Mauch knee joint model are combined to form the active prosthetic leg model. We also conducted a sensitivity analysis test for PSO and BBO.

The active prosthetic knee model and PID are used to build a closed-loop feedback system. To investigate PID controller parameter behavior with respect to shank length, we use optimization algorithms to tune controller parameters (K_p, K_i and K_d).

Results show that for model parameter identification, PSO gives the best optimization results, and BBO gives better average overall performance than SQP. For PID tuning, BBO achieves the best average overall performance, but PSO shows the fastest average convergence. Finally, we see that increasing shank length results in an increase in the optimal proportional gain, and a decrease in the optimal differential and integral gains as shown in Fig. 8.

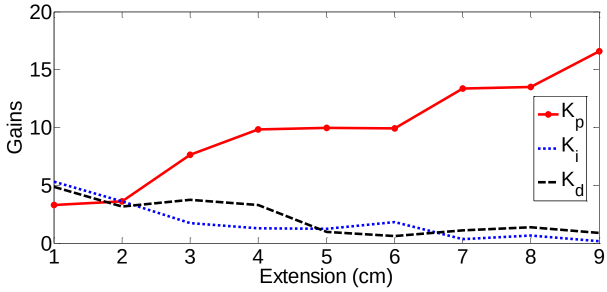


Fig. 8. PID parameter changes with respect to shank length

Ground Reaction Force Estimation with an Extended Kalman Filter. A method to estimate GRF in a robot/prosthesis system is presented. The system includes a robot that emulates human hip and thigh motion, and a powered prosthesis for transfemoral amputees, and includes four degrees of freedom: vertical hip displacement, thigh angle, knee angle, and ankle angle. A continuous-time extended Kalman filter (EKF) [35] estimates the states of the system and the GRFs that act on the prosthetic foot.

The system includes eight states: q_1 is vertical hip displacement, q_2 is thigh angle, q_3 is knee angle, q_4 is ankle angle, and their derivatives. Horizontal and vertical GRF is applied to the toe and heel of a triangular foot. The ground stiffness is modeled to calculate GRF. The initial state $x(0)$ is obtained from reference data, and we randomly initialize the estimated state $\hat{x}(0)$ to include estimation error. The diagonal covariance matrices of the continuous-time process noise and measurement noise are tuned to obtain good performance.

Results are shown in Fig. 9. Although significant initial estimation errors are present for displacements and velocities, the EKF converges to the true states quickly.

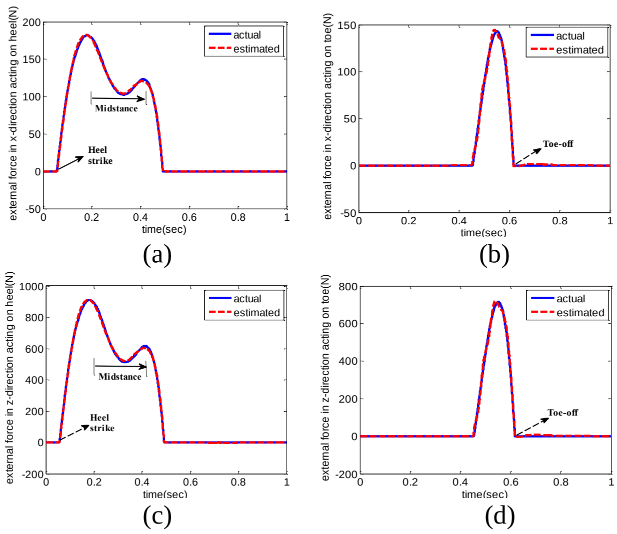


Fig. 9. Horizontal and vertical ground force (GRF) estimation

Electronic Energy Converter Design for a Regenerative Prosthetics. Prosthetic models use ideal electromechanical actuators for knee joints, which do not include energy regeneration. In order to focus on energy regeneration, a voltage source converter is designed to interface an electric motor to a supercapacitor.

A converter was designed to resemble a typical H-bridge motor driver. The voltage converter control system allows power to flow from the motor to the capacitor (motor mode) and from the capacitor to the motor (generator mode). During motor mode, the voltage converter's control system modulates the voltage applied to the motor using two circuits; one with the capacitor connected (powering the motor from the capacitor) and one with the capacitor disconnected (shorting the motor connection through the H-bridge). During generator mode, the voltage converter control system changes the impedance connected to the motor using two circuits; one with the capacitor connected (charging the capacitor) and one with the capacitor disconnected (allowing the motor to move with less resistance from the electronics). The circuit and motor were modeled with state space equations using MATLAB and Simulink software.

Two controllers were designed for the voltage converter. Both controllers use reference knee torque from control signals in the mechanical model with an ideal actuator at the knee. The first controller, a PD (proportional-derivative) controller, compares reference torque to the torque generated by the motor and voltage converter. The controller uses the comparison between reference and simulation data to determine switching between connecting and disconnecting the capacitor and motor. The switches use measured velocity to determine the direction of motor rotation. The controller uses direction, mode, and torque error to provide correct modulation. The second controller, an artificial neural network, follows the same logic as the PD controller. The controller gains were optimized with BBO. The optimized controller was able to track the reference torque with root mean square (RMS) error of 1.35 Amps as shown in Fig. 10. As can be seen in Fig. 11, the system was able to store 17.6 Joules in the capacitor bank. The results from the motor and voltage converter simulation show that it may be possible to gain energy through a normal stride. The energy gained would allow a prosthesis to operate longer than current powered prostheses.

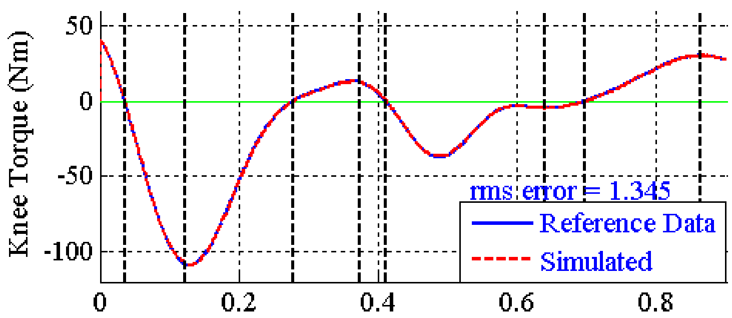


Fig. 10. Tracking a reference current for the knee joint with a motor and voltage converter

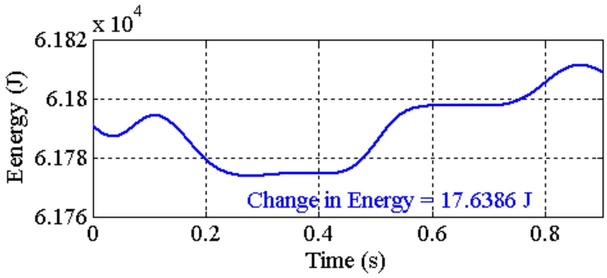


Fig. 11. The energy gained during one stride of gait with a motor and voltage converter

Fuzzy Logic for Robot Path Finding. This research deals with fuzzy logic to find a path for mobile robots that move in environments with obstacles, when the robot does not have prior information about the obstacles.

The radar of the robot returns a fuzzy set based on the distance L_i from obstacle i (see Fig. 12): $\mu_i^{\varphi}(\varphi_i) = \frac{L_i}{L_{max}}$. The robot finds the angle between its position and the target position, which we call α. If the robot moved in the α direction in an obstacle-free environment it would follow a direct line to the target. However, there are obstacles in the path. To find a safe path around the obstacles, we introduce a Gaussian fuzzy set [13, 14, 25, 40] which has a maximum value at α as follows:

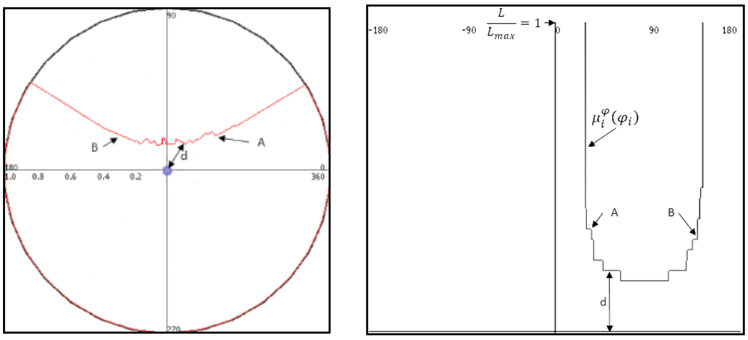
$$\mu_i^{\alpha}(\varphi_i) = e^{-(\frac{(\varphi_i-\alpha)^2}{2\sigma^2})}$$

We combine $\mu_i^{\varphi}(\varphi_i)$ and $\mu_i^{\alpha}(\varphi_i)$ to obtain a new fuzzy set, $\mu_i^{\psi}(\psi_i)$, shown in Fig. 13.

$$\mu_i^{\psi}(\varphi_i)=\min(\mu_i^{\alpha}(\varphi_i), \mu_i^{\varphi}(\varphi_i))$$

The movement direction then is φ, which is the maximum point in $\mu_i^{\psi}(\psi_i)$, which we call A. If the robot moves in φ_A, it will touch the obstacles. To solve this problem we introduce a new fuzzy set that has the value 1 in a range of 180 degrees around φ_A:

$$\mu_1^{\theta}(\varphi_i) = \begin{cases} 1 & \varphi_i < \varphi_{A+90}\ and \varphi_i > \varphi_{A-90} \\ 0 & otherwise \end{cases}$$



(a) (b)

Fig. 12. (a) A polar radar map in the presence of an obstacle, and (b) its transformation to Cartesian coordinates

In the next step we defuzzify $\mu^{\psi}(\varphi_i) * \mu_1^{\theta}(\varphi_i)$ using center of mass [28], which is shown in Fig. 13.

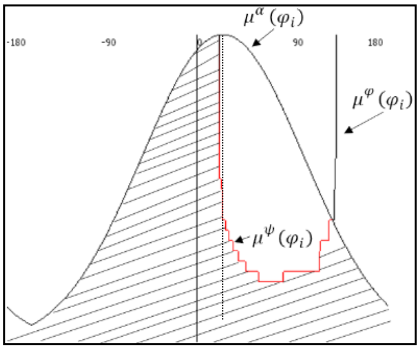


Fig. 13. Highlighted area is $\mu_i^{\psi}(\psi_i)$

Simulations confirm that the proposed approach provides reliable output. In different layouts and robot positions and target positions, the robot was able to find a path to the target point without touching any obstacles; see Fig. 14.

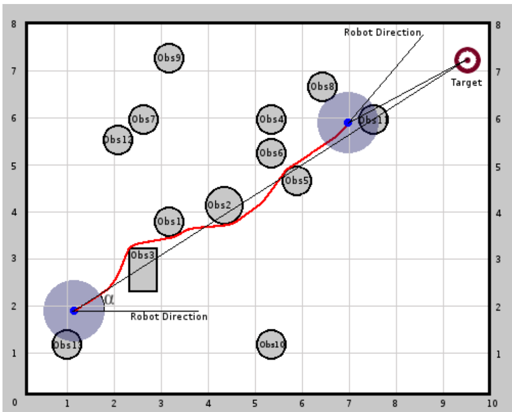


Fig. 14. Fuzzy path planning results: the red line is the robot path from start to target.

5 Conclusions

The authors have described university student training. The description has focused on student participation in the US NSF project “Optimal prosthesis design with energy regeneration” and the application of ICT and modelling technologies.

Several factors play an important role in the results of this paper. Student research requires skill in programming and software, and a broad theoretical knowledge in computer science, and mechanical, electrical, and control engineering. Students used MATLAB, Simulink, and toolboxes (Optimization, Fuzzy Logic, etc.), and programming in C and C++. The software used for robot trajectory planning research was designed and written by students in C++, and the GUI was designed using Qt and OpenGL. Standard libraries were used to make the software cross-platform.

The most important foundation for student research is theoretical knowledge in fundamental and elective disciplines such as Circuits, Linear Systems, Control Systems, Nonlinear Control, Machine Learning, Artificial Intelligence, Intelligent Controls, Optimal State Estimation, Optimal Control, Embedded Systems, Robot Modeling and Control, Probability and Stochastic Processes, Population-Based Optimization, and Prosthesis Design and Control, which provides a basic understanding of human biomechanics and lower-limb prosthesis design and control. These courses played a vital role in the proper grounding of basic and advanced ICT and control theory for robotic and prosthetic leg research. The facilities at CSU and funding from the NSF significantly helped in furthering student research-based education.

Finally, student participation in government-sponsored research, student exchanges of research experiences with each other, and publication of research results in high-caliber journals and conferences [1, 2, 7, 11, 16, 26], provide students with effective training and self-confidence in their higher education. Research-based education also allows students to obtain practical experience as research assistants, with corresponding responsibilities in the development and implementation of research projects.

Student participation in real-world research significantly influences their engineering and research qualifications by: (a) giving them a strong understanding of ICT and engineering concepts that are covered in corresponding courses; (b) giving them practical experience and the ability to apply theoretical knowledge; (c) giving them the opportunity to learn technical material independently; (d) helping them improve fundamental skills to apply in other research in their future; (e) providing them with a rich interdisciplinary research environment; and (f) providing them with an understanding of concepts both familiar and unfamiliar. Through extensive literature review and actively seeking ways to solve research problems, students are prepared to make meaningful future contributions to the field of ICT and control engineering.

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