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# Operation of a Controllable Force-sensing Industrial Pneumatic Parallel Gripper System

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# Operation of a Controllable Force-sensing Industrial Pneumatic Parallel Gripper System

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## Abstract

As part of the advanced programmable logic controllers (PLC) course at Michigan Tech, this class project was performed on a mechatronics system gifted by Donald Engineering, a Michigan-based supplier of industrial automation systems and components. This paper explores the functionality and application of a force-programmable and sensing pneumatic parallel gripper system. Force sensing is a critical part of many systems in modern automation systems. Applications such as prosthetics, robotic surgery, or basic manufacturing systems may rely on the ability to properly read and control forces applied to an object. This work evaluates the basic operation of the pneumatic force-sensing gripper system, through a human machine interface (HMI), and presents two demonstrations using programmable logic controllers to open the door for future customized developments. Different gripper force-time and pressure-time responses are presented to demonstrate the control and visualization of the grippers force.

## Introduction

Grippers are an essential component in industrial robots. They are used to interface the manipulated work pieces with the work tool. The precision of the robot cell is directly dependent on the precision of the gripper; if the precision of the system is low the performance of the whole system will be degraded. Programmable logic controllers are industry hardened computers that use integrated circuits instead of electromechanical devices to control an industrial process. They are very rugged, easy to use and their speed of operation is high. PLCs are being used in every industry because they are cost effective, reliable and flexible. This paper describes the components, operation and capabilities of a force measuring controllable pneumatic gripper system. Such grippers can be used to apply precise force profiles for handled work pieces. This system is designed to handle objects using a force sensing module and pneumatic gripper. The amount of force can be measured, set, monitored, and adjusted. The force is controlled using a closed-loop PI controller [1]. The system, shown in Fig. 1 and Fig. 2, consists of six main components: pressure regulator, directional valve, force measuring device, two-finger gripper, air prep system, and a power supply and signal conditioning module. The purpose of each component is shown in the figure below and described in further detail.

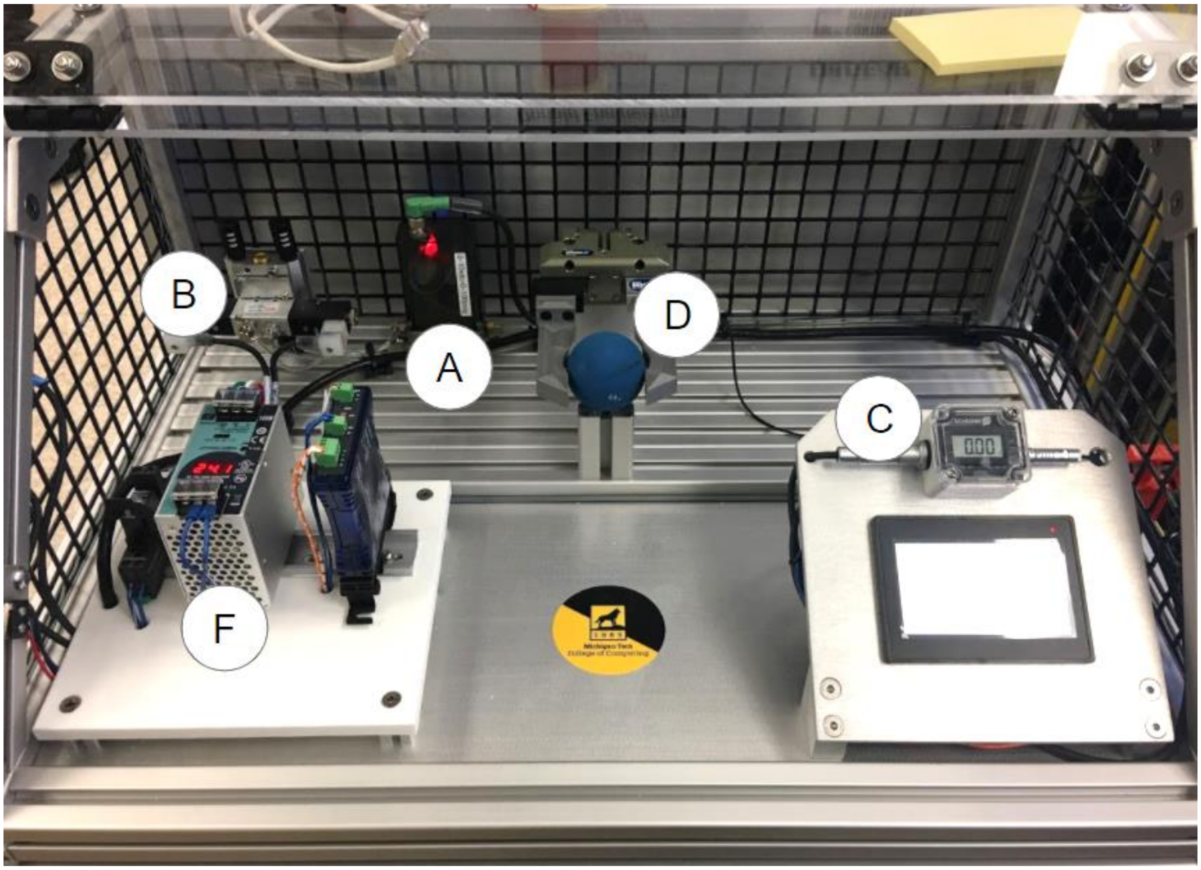



Figure 1. Front view of mechatronic station

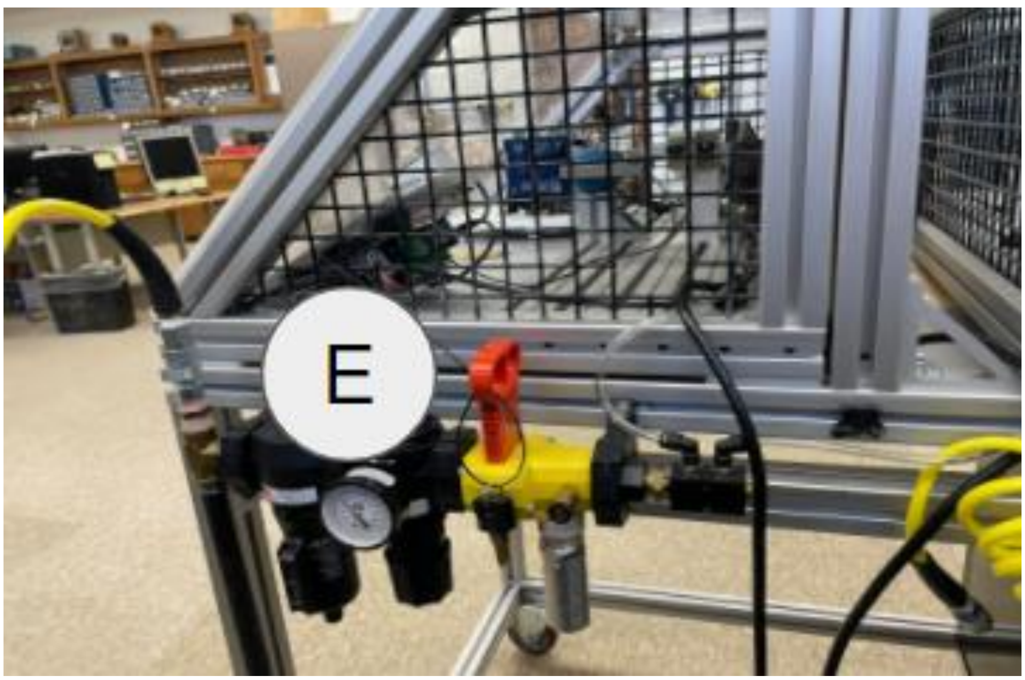



Figure 2. Air pressure valves on the side of the mechatronic station

### A. *Precision Pressure Regulator*

The high-resolution proportional pressure regulator produced by Clippard has the ability to linearly control pressure with a closed-loop system for high resolution. The system can be tuned to the desired application using an adjustable PI controller and multiple flow configurations [2].

### B. *Series Valve*

The Clippard Maximatic 4/2 Spring Return 4-way valve is a solenoid-controlled pilot operated valves for use in pneumatic systems. The body is constructed from aluminum to suit industrial applications [3].

### C. *Force Measuring System*

The Schunk force measuring system is used to directly measure the gripping force of the two-finger gripper. It gives a linear relationship between the gripping force and the output voltage. This can be used to adjust and control the gripping force of the two-finger gripper [4].

### D. *Two-Finger Gripper*

The two-finger parallel gripper produced by Schunk is able to provide high gripping force using pneumatic power. It is able to provide high maximum moments for versatile use with many different shapes and materials. [5].

### E. *Air Prep System*

The air preparation filters produced by Ross Controls filter the air for the pneumatic symptom of the two-finger gripper. It can remove oils**,** particulate and hydrocarbon vapors that could be harmful to the system over time and incorporates a Safety Lock out for System LOTO Procedures [6].

### F. *Power Supply and Signal Conditioning Module*

Power is run through this supply module and relayed to the varying components of the system. Signal conditioning is used to convert the incoming analog signal to digital.

## Literature Review

Some examples of published works related to gripper force control and sensing are presented here. Yu *et al.* [7] focuses on clamp force sensing and 2-D touch force sensing for a three-degrees-of-freedom cable-driven micromanipulator. They show that to properly control a surgical instrument, the manipulator, that must perform invasive surgery while controlling the force from the utensils gripper to avoid injuring the patient. The challenges faced in this application are a very compact construction and the disinfection method used on the tool. In this case, high precision is necessary to achieve an acceptable conclusion. This example shows the importance of force sensing in robotic surgery. Bogdan *et al.* [8] discuss control of force on a 3-finger gripper using a PLC program. The gripper is actuated by a stepper motor and they used an instruction list to write the program instead of ladder logic. Ottaviano *et al.* [9] explore two methods to control the force of a two-finger gripper with pneumatic actuation, continuous feedback and logic branching feedback motion. Maintaining a low cost and simple mechanical system is heavily considered when choosing a control scheme. After considering these factors, a closed-loop control scheme is implemented with a PI controller. The proportional and integral gains are experimentally evaluated for optimal response of the system. This paper is relevant for this project because it discusses the effects of the PI controller on the two-finger gripper which is the same controller at hand.

**System Programming**

Two programs were tested on the system. The default i. e. cold-start program and a custom program use to perform pressure-controlled force profile generation experiments.

*Cold-start Program*

The first program developed involves the cold-start process of the system, to ensure the system is fully connected and functional. This process consists of the following steps:

- Connect the station to an electrical power source.
- Connect the pressurized air supply.
- Extend the lockout shown in Fig. 2, upwards to allow airflow.
- Verify the air pressure gauge indicates 70-80 psi.
- Refer to the HMI screen, in Fig. 3, for the following sub steps:
    - Set starting values for target pressure and ramp time to 30 psi, and 5 seconds, respectively.
    - Click *Zero* to “zero” the system.
    - Click *Test*, then *Test Supply Pressure*


Figure 3. Gripper pressure profile HMI settings and calibration view.

- Close the station system cover to activate the safety signal.
- Press the *Close-Gripper* button.
- When the supply pressure value rises, press the *Open-Gripper* button
- Pressure on the screen should read approximately 70-80 psi. See Fig. 4.
- Click *Main* to complete cold start. See Fig. 4.

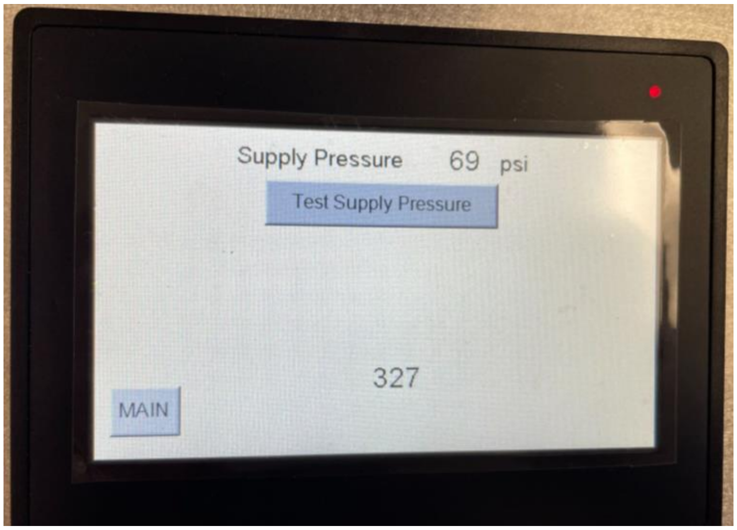



Figure 4. HMI closed-gripper pressure test panel.

*Custom Program*

The second program consists of a more detailed analysis of how the system conducts force sensing. By modifying the target pressure and ramp time, a relationship can be observed between the two variables. The control flow diagram shown in Fig. 5 indicates the working of the described system. Once the power is given to the system, the power supply module will power up each component of the equipment. A 24V DC power is supplied to these components. On the HMI panel, a target pressure is set. The *close* push button is pressed. The valve releases the pressure, and the pressure regulator controls the amount of pressure the gripper is receiving. Once the supply pressure reaches the target pressure the gripper closes on the soft foam work (ball) piece. If it does not, it goes to the pressure regulator. When the *open* push button is pressed, the gripper opens.

Two sets of values are programmed into the system. The first set involves adjusting the target pressure to 15, 30, and 50 psi while keeping the ramp time constant at 50 seconds. The second set adjusts the ramp time to 20, 35, and 50 seconds, while keeping the target pressure constant at 30 psi. Figure 6 shows the top of a MATLAB script used to enter and plot the recorded air pressure and gripper force profiles over time. Figure 7 shows the system performance in the case of variable steady state, i. e. target pressure values of 15, 30, and 50 psi while keeping the ramp, i. e. rise time constant at 50 seconds. Linear pressure and force profiles are observable without overshooting the target pressure or force. Clearly, there has been some human error in recording the value at times 5 and 20 seconds.

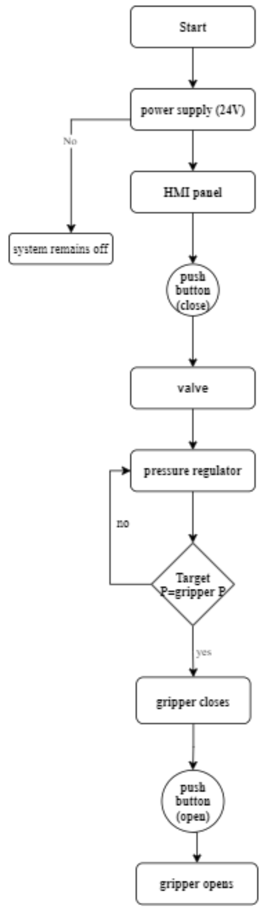
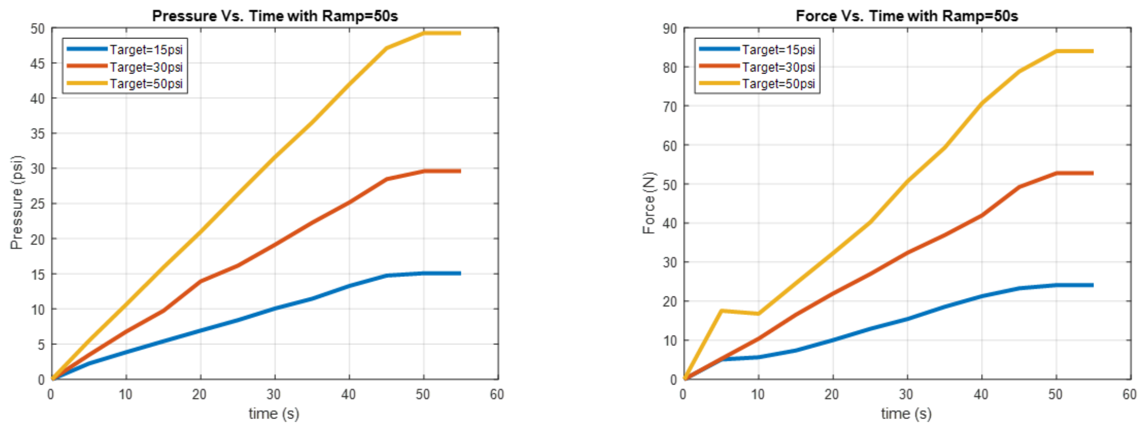



Figure 5. Flow control diagram of the system

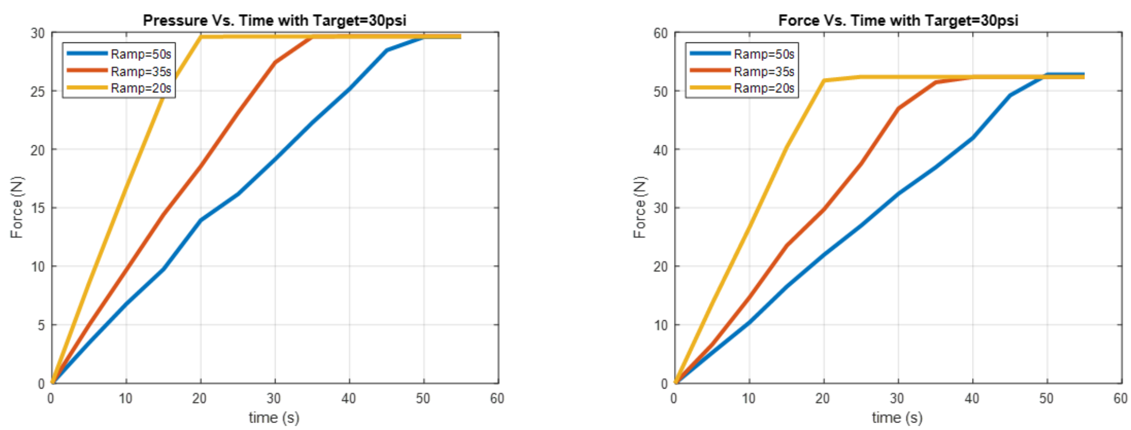
```
%% Data collected from machine

t=0:5:55; %Set time vector to 5 second intervals from 0 to 55 seconds

% Target Pressure = 15 psi, Ramp = 50s
Pressure15 = [0 2.25 3.86 5.41 6.93 8.41 10.07 11.46 13.28 14.75 15.08 15.08];
Force15 = [0 5.07 5.64 7.37 10.03 12.92 15.43 18.56 21.28 23.29 24.1 24.1];
Voltage15_Measured = [0 0.04 0.04 0.04 0.06 0.07 0.08 0.1 0.11 0.12 0.13 0.13];
Voltage15_Calc = Force15.*0.002244/2;


% Target Pressure = 30 psi, Ramp = 50s
Pressure30 = [0 3.47 6.79 9.75 13.93 16.16 19.15 22.28 25.16 28.46 29.59 29.59];
Force30 = [0 5.24 10.4 16.52 21.96 26.96 32.40 36.92 41.95 49.22 52.76 52.76];
Voltage30_Measured = [0 0.03 0.06 0.08 0.11 0.14 0.16 0.19 0.21 0.24 0.25 0.25];
Voltage30_Calc = Force30.*0.002244/2;


% Target Pressure = 50 psi, Ramp = 50s
Pressure50 =[0 5.5 10.65 15.92 20.97 26.34 31.62 36.54 41.97 47.1 49.24 49.24];
Force50 = [0 17.54 16.78 24.58 32.29 40.21 50.68 59.32 70.67 78.8 84.03 84.03];
Voltage50_Measured = [0 0.09 0.09 0.13 0.16 0.21 0.25 0.29 0.33 0.37 0.4 0.4];
Voltage50_Calc = Force50.*0.002244/2;


% Target Pressure = 30 psi, Ramp = 35s
Pressure30_35 = [0 5 9.69 14.42 18.54 23.11 27.42 29.62 29.65 29.65 29.65 29.65];
Force30_35 = [0 6.63 14.69 23.52 29.71 37.53 46.96 51.43 52.34 52.34 52.34 52.34];
Voltage30_35_Measured = [0 0.09 0.07 0.12 0.15 0.19 0.22 0.25 0.25 0.25 0.25 0.25];
Voltage30_35_Calc = Force30_35.*0.002244/2;


% Target Pressure = 30 psi, Ramp = 20s
Pressure30_20 = [0 8.59 16.73 24.57 29.60 29.63 29.63 29.63 29.63 29.63 29.63 29.63];
Force30_20 = [0 13.65 26.65 40.35 51.73 52.37 52.37 52.37 52.37 52.37 52.37 52.37];
Voltage30_20_Measured = [0 0.07 0.19 0.2 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25];
Voltage30_20_Calc = Force30_20.*0.002244/2;
```

Figure 6. Pressure and force profile data collection for plotting in MALTAB.




(a) (b)

Figure 7. Pressure and force profiles experiments. Variable steady state pressure and force with constant rise time.




(a) (b)

Figure 8. Force-Pressure experiments. Variable pressure and force rise time with constant steady state.

When the ramp, or rise time is made constant and the rise times are varied, complementary profiles are produces. As can be seen from the plots in Fig. 7, of the force and pressure vs. time, the ramp time is at 50 seconds, and the final pressure is close to the target pressure. The force is more non-linear than the pressure with some spikes and curves in the plot that are not present in the pressure vs. time plot. When the target pressure is set to lower values, the final target pressure has a positive steady-state error. The opposite is also true; when the target pressure is set to higher values, the final target pressure has a negative steady-state error.

From Fig 8, some observations can be made. With the higher ramp times, the pressure and force seem to decrease in slope 5 seconds before the defined ramp time; however, this does not happen with the lowest ramp time of 20s. The ramp time does not affect the steady-state value of the pressure. Nonetheless, in this second scenario, the pressure and force profiles are also largely linear and controlled to not overshoot the target end pressure of 30 psi.

## Conclusions

In conclusion, the force sensing gripper system is part of the mechatronics playground gifted by Donald Engineering. Advanced PLC students utilize these systems to develop creative projects for class credit. The project described in this paper uses the gripper force system to set and visualize the force applied to a gripped object. The system shows how the impact of force ramp time affects the accuracy of the internal controller. The user must be aware that the system may not always meet the intended target pressure (i.e., Steady state error), which can have consequences in real-world applications. Next steps include utilizing the station's ability to change the finger length of the grippers. In addition to the length, potential relationships can be observed by changing the grippers overall dimensions, material type, or the object being used. This project has a companion video on YouTube.

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## Biographies

BRIAN PIECHOCKI is a Project Engineer at KYYBA Inc., where he performs design releases for FCA's air induction systems. He earned a graduate certificate in mechatronics, robotics and automation engineering from Michigan Tech in 2021, and a bachelor's degree in mechanical engineering in 2018.

CHELSEY SPITZNER is an intern at JLC Industries. She earned a bachelors degree in electrical engineering from Michigan Tech in 2021. She currently pursuing a master of science in electrical engineering at Michigan Tech.

NAMRATHA KARANAM is a graduate student at the department of Mechatronics at Michigan Technological University since spring 2020. She is currently working as Teaching assistant for PLCs, Robotics and Electrical Machinery courses at the University. Prior to this, she did her Bachelor's in Mechatronics at Mahatma Gandhi Institute of Technology located in India. She has done many projects during her course of time at Tech and currently seeking for jobs.

TRAVIS WINTER is the engineering manager at Donald Engineering. He was instrumental in building and commissioning the advanced programmable logic controller systems installed at Michigan Technological University's Mechatronics Playground.

ALEKSANDR SERGEYEV is a Professor of Mechatronics, Electrical, and Robotics Engineering Technology program in the Department of Applied Computing at Michigan Tech. He is a Director of FANUC Authorized Certified Robotic Training Center, and a Director for Master of Science in Mechatronics degree program at Michigan Tech. Dr. Sergeyev is a member of SPIE, ATMAE, IEEE, and ASEE professional organizations, and has mentored numerous undergraduate senior design projects and student publications.

MARK GAUTHIER is the President and Owner of Donald Engineering Co., Inc (DE). located in Western Michigan. After Graduating from Michigan Technological University in 1985, he worked as a technical designer at SDRC in Farmington Hills, Michigan in statistical analysis and assembly review for the automotive industry. In 1988, he joined the family business at Donald Engineering and became power specialist and automation designer. He became president of DE in 1996. In 2019, he consulted and assisted with starting up the Mechatronics program at Michigan Technological University to further education in Automation, Fluid Power, Motion Control, PLCs and Machine safety.

NATHIR RAWASHDEH is an assistant professor at the department of applied computing at Michigan Tech. since August 2019. He instructs introductory and advanced programmable logic controller courses. Prior to this appointment, he was an associate professor in the Mechatronics Engineering Department at the German Jordanian University, where he spent 10 years. His industrial experience includes 5 years with Lexmark International, Inc. Lexington-Kentucky and MathWorks, Inc. in Natick-Massachusetts. Dr. Rawashdeh is a Senior Member of the IEEE and has experience with European-funded research capacity building projects. His research interests include mobile robots, autonomous driving, image processing and sensor fusion.