Department of Electrical & Computer Engineering

ELEC 299 Winter 2019

Mechatronics Project: Queen’s Robotic Warehouse

Overview

Robotics and automation are rapidly expanding to new sectors in industry. A new paradigm known as *smart factories* is a concept of the fourth industrial revolution (industry 4.0) [1]. Automotive plants have used robotics for decades but other industries, including the health industry [2], are rapidly adopting automation, and the emerging Internet of Things (IoT) [3] have witnessed the evolution of robots [4] to include advancements in the robotic technologies and minimization of energy consumption that enables a direct safe interaction between human beings and robots in real time settings to accomplish more complex tasks [5-13]. Engineers from different disciplines play pivotal roles in the design and implementation of these robots using a wide range of evolving technologies in different disciplines. In 2015, the prototype of the first robotic kitchen was released which is designed to cook like an experienced chef [14].

Along these lines, the competition in ELEC 299 this year will emulate using autonomous robots in a working warehouse.

Goals

The main objective of this project to allow you to apply the hardware and software skills developed in the first half of the course to a team-based design challenge. This project builds on design and electrical and computer engineering knowledge developed over the last three terms. It will also highlight different aspects that engineers consider when they deal with robotic systems, such as hardware, software, hazards and compatibility, communication, and robustness.

You should be able to demonstrate:

- Effective use of a range of sensors and motors
- Effective Arduino programming.
- Analog and digital interfacing
- Working with others in a productive manner
- Effectively communicating engineering ideas in written and oral forms

Scenario

In this scenario your team has been asked to build a working prototype of a robotic system that will autonomously retrieve objects in a warehouse and deposit in a prescribed location. You will build a working prototype and work with two other teams to demonstrate them in a simulated warehouse during the ELEC 299 competition. You will also submit some reports about the prototypes and your recommendations for a real system.

Competition Playing Field and Rules

The playing field is a simulated robotic warehouse in which three robots autonomously pick up objects around the warehouse periphery and return them to their starting location. The goal is to retrieve all the objects as quickly as possible. Human navigation instructions may be provided via Bluetooth, but a time penalty of 10 seconds will be applied for every human intervention. Human intervention should be clearly recorded on the laptop screen in the Serial Monitor or equivalent. Teams can select to use any of the robotic sensors used in ELEC 299. Black lines will be provided on the bottom of the simulated warehouse for navigation. A stylized diagram of the playing field is provided below, and a more detailed handrawn version used for building the playfield is listed with this file in OnQ. The objectives are red dots, the walls are thick grey lines, the driving paths as black lines and the starting areas are bound by light gray lines. Design procedures and challenges encountered in the design will be presented in the project final report.

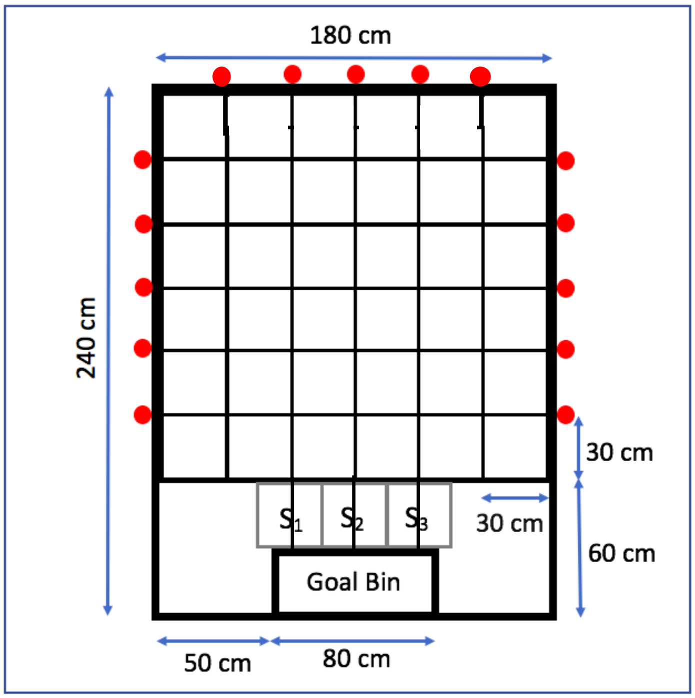

Figure 1:Diagram of the competition playfield.

Robots can only carry a single ball at a time. Teams can add new sensors if they have their own, but no other electrical components can be added, no permanent changes to the robot are allowed, and nothing can be removed from the bot. Teams should plan to have fully charged batteries for the start of the competition. Each triplet of teams will have approximately 10 minutes to complete the task.

The field will include an IR beacon along the goal bin at each of the three starting positions S_1, S_2, and S_3, allowing robots to determine their locations (the IR beacons will be removed after the start of competition to avoid obstructing the goal bin). The three teams working together should coordinate the ASCII symbol transmitted by each beacon, and will be allowed to arrange their beacons in the three starting locations as desired. *The starting location of each robot will be assigned by the competition referees, so each robot must be able to start from any of the three locations.*

At the competition grades will be assigned to a team for completing each of the following tasks:

- Determine its location using the closest IR beacon
- Drive in a straight line following a black line
- Successfully turn 90º at an intersection of two black lines
- Pick up an object with the gripper
- Return an object to the home location
- Return at least one object from each of the three walls to the home location

Each team will have two opportunities to complete the course. After the first attempt teams will have about an hour to update their hardware and software before competing the final time. *The scoring rubric for the competition is shown at the end of this document.*

The top three teams in the competition will receive prizes.

Lab 4 Instructions

In Lab 4 there are five tasks that prepare you for the Proposal report deliverable. Before starting it make sure you have read the project instructions in this document and the grading rubrics in OnQ.

The fourth task below is to identify a strategy for working with the two other teams in your competition group. We suggest that you complete the first task in the list below and then designate one person on your team to be the liaison; the liaisons from each of the three teams can meet to discuss coordination strategy in parallel with the other team members who continue working on the hardware and software design. That will enable you to complete all tasks by the end of the lab.

Tasks

You should demonstrate that you have completed each of the tasks below to the teaching assistants. This should be described in point form text, hand-drawn schematics, pseudo code, etc., as appropriate.

1. Identify the functional requirements of your robot – what do you want it to be able to do.
2. Select the sensors and actuators and hardware to meet the functional requirements, and create a schematic including connections to the Arduino.
3. Identify the required software functions using a flowchat and pseudocode.
4. Identify how the three teams will work collaboratively to meet the project requirements and minimize collisions.
5. Create a brief project plan; who is assigned various tasks required to implement your plan, when each key milestone will be accomplished, and when the teams and groups are going to meet and make progress.

Lab 5 Instructions

In this lab you will have time to implement, test, and iterate on your robot. You should ensure that you have completed tasks required to submit your Progress Report, which is described below under Deliverables.

Deliverables

The deliverables are:

a) The project competition which will take place during the regular lab time in weeks 11-12. Instructions for the competition are above, and marks will be assigned for completing the tasks described there.
b) A proposal report, completed after Lab 4. Lab 4 will include a completion grade for providing a flowchart and schematic.
c) A progress report, completed after Lab 5 which will provide an opportunity for teams to test key functionality of their robots in the playing field.
d) A final report, completed at the end of term

Proposal report

This formal report should contain a description of how your team will implement the hardware and software for the competition, and how you will coordinate with the other teams. It should include:

- A description of the functional requirements and proposed specifications of the robot
- Schematic of hardware connections
- Flowchart showing the decision making proposed for the robot and associated pseudocode (in an appendix) of all key functions. An overview of building a simple flowchart and pseudocode is at: http://cdn.robotc.net/pdfs/nxt/reference/hp_pseudo_flow.pdf
- A description of how the three teams will work collaboratively and minimize collisions, and be able to start from any of the three locations. This may include any algorithms used.
- A project plan showing key tasks and milestones for the project, with names assigned to key tasks and descriptions of coordination with the other two teams

This report should follow the instructions shown below under **Report formats**, but it does not need to be long – it simply needs to address the requirements above. No table of contents is necessary. Ensure you review the Proposal Report rubric which is listed at the end of this document and linked to the Proposal Report Assignment in OnQ. The report is due by end of day a week after your Lab 4 (i.e. if your lab is on a Monday then it is due by end of day the next Monday).

Progress report

This formal report should contain the hardware and software to be used for the competition. It should include:

- Schematic of hardware connections including a photograph
- Description of work to date, deviations from the project plan and updated project plan, and a description of robot function in tested Lab 5.
- Description of strategy for collaborating with the other team
- Description of any literature or algorithms used
- Updated flowchart showing the decision making proposed for the robot with code attached in an appendix.

Note that the full functionality is not required at this stage, but teams should be able to show substantial progress.

This report should follow the instructions shown below under **Report formats**, but it does not need to be long – it simply needs to address the requirements above. No table of contents is necessary. A rubric will be posted for the Progress report closer to the deadline.

Final report

The final report should be a formal report that includes:

1. A description of the original functional requirements and proposed specifications of the robot
2. Final schematic of hardware connections, including any changes from the original plan.
3. Flowchart showing the decision making for the robot, including changes from the original plan.
4. A description of the robot's performance and comparison with the functional requirements and specifications described in the proposal report.
5. An analysis of the team's performance against the original project plan, and description of how well the team worked together.

The main body of your report (i.e. excluding title page, executive summary, table of contents, references page and appendices) should be no more than 10 pages long.

Report formats

All reports should be formal engineering documents. Specific expectations are outlined below and in the rubric – ensure you read both!

The document should be written in an easily readable font (e.g. Times New Roman 11 pt.), following principles for effective technical communication, including section headings, figure captions, citations, cross-references, numbered equations, etc.

The title page should include a listing team members, student numbers, and a statement that all work in the report is by the listed authors, with the exception of properly cited material.

Submission Instructions

Save and submit **ONE** electronic file in DOCX format to OnQ under the appropriate report name (**Proposal report, Progress report, or Final report)** under Contents | Project; name this file using the style "**Teamnumber-XReport.docx",** where you replace "Teamnumber" with your actual team number and "XReport" is either ProposalReport, ProgressReport, or FinalReport**.** Only one team member needs to submit.

References

1. M. Indri, A. Grau and M. Ruderman, "Guest Editorial Special Section on Recent Trends and Developments in Industry 4.0 Motivated Robotic Solutions," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1677-1680, April 2018.doi: 10.1109/TII.2018.2809000
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8331177&isnumber=8331183
2. S. Martelli *et al*., "Deep Endoscope: Intelligent Duct Inspection for the Avionic Industry," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1701-1711, April 2018. doi: 10.1109/TII.2018.2807797
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8295126&isnumber=8331183
3. B. Huang, M. Ye, Y. Hu, A. Vandini, S. Lee and G. Yang, "A Multirobot Cooperation Framework for Sewing Personalized Stent Grafts," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1776-1785, April 2018. doi: 10.1109/TII.2017.2773479
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8113497&isnumber=8331183
4. A. Grau, M. Indri, L. L. Bello and T. Sauter, "Industrial robotics in factory automation: From the early stage to the Internet of Things," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing, 2017, pp. 6159-6164. doi: 10.1109/IECON.2017.8217070
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8217070&isnumber=8216002
5. E. Dean-Leon, K. Ramirez-Amaro, F. Bergner, I. Dianov and G. Cheng, "Integration of Robotic Technologies for Rapidly Deployable Robots," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1691-1700, April 2018. doi: 10.1109/TII.2017.2766096
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8081844&isnumber=8331183
6. L. Roveda, G. Pallucca, N. Pedrocchi, F. Braghin and L. M. Tosatti, "Iterative Learning Procedure With Reinforcement for High-Accuracy Force Tracking in Robotized Tasks," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1753-1763, April 2018. doi: 10.1109/TII.2017.2748236
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8024058&isnumber=8331183
7. Hernandez, C., Bharatheesha, M., van Egmond, J., Ju, J., & Wisse, M. (2018). Integrating Different Levels of Automation: Lessons from Winning the Amazon Robotics Challenge 2016. IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, 1-11.
8. R. Wang *et al*., "From Offline Towards Real-Time Verification for Robot Systems," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1712-1721, April 2018. doi: 10.1109/TII.2017.2788901
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8245858&isnumber=8331183
9. González, A.G., Alves, M.V., Viana, G.S., Carvalho, L.K., & Basilio, J.C. (2018). Supervisory Control-Based Navigation Architecture: A New Framework for Autonomous Robots in Industry 4.0 Environments. *IEEE Transactions on Industrial Informatics, 14,* 1732-1743.
10. Y. Zhang, Z. Zhu and J. Lv, "CPS-Based Smart Control Model for Shopfloor Material Handling," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1764-1775, April 2018.
doi: 10.1109/TII.2017.2759319
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8059835&isnumber=8331183

11. G. Demesure, M. Defoort, A. Bekrar, D. Trentesaux and M. Djemaï, "Decentralized Motion Planning and Scheduling of AGVs in an FMS," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1744-1752, April 2018.
doi: 10.1109/TII.2017.2749520
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8046073&isnumber=8331183
12. H. Liu *et al*., "Dynamic Wireless Charging for Inspection Robots Based on Decentralized Energy Pickup Structure," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1786-1797, April 2018.doi: 10.1109/TII.2017.2781370
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8170258&isnumber=8331183
13. M. Schluse, M. Priggemeyer, L. Atorf and J. Rossmann, "Experimentable Digital Twins—Streamlining Simulation-Based Systems Engineering for Industry 4.0," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1722-1731, April 2018. doi: 10.1109/TII.2018.2804917
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8289327&isnumber=8331183
14. http://www.moley.com/

Proposal report rubric

Categories	Outstanding (8) 8 points	Outstanding (7) 7 points	Meet Expectations (6) 6 points	Marginal (5) 5 points	Marginal (4) 4 points	Not demonstrated (3) 3 points	Not demonstrated (2) 2 points	Not demonstrated (1) 1 point	
Requirements and specifications	Clearly describes problem requirements and constraints, and team's desired specifications and priorities supported by concepts and processes from other sources.	Clearly describes problem requirements and constraints, and team's desired specifications and priorities supported by concepts and processes from other sources.	Clearly describes problem requirements and constraints, and team's desired specifications and priorities.	Presents requirements, specifications, and constraints though somewhat incomplete, unclear, or non-specific.	Presents some requirements, specifications, and/or constraints with significant gaps or issues.	Problem description, requirements, specifications, and constraints are not clear and not sufficient to work on the project.	Problem description, requirements, specifications, and constraints are not clear and not sufficient to work on the project.	Problem description, requirements, specifications, and constraints are not clear and not sufficient to work on the project.	/ 8
Hardware and software design	Detailed flowchart, schematic, and pseudocode appear able to meet all project requirements using creative approaches.	Detailed flowchart, schematic, and pseudocode appear able to meet all project requirements using creative approaches.	Detailed flowchart, schematic, and pseudocode appear able to meet all project requirements.	Flowchart, schematic, and pseudocode may be able to meet all project requirements, though uncertain.	Problems with proposals in flowchart, schematic, and/or pseudocode will prevent robot from meeting some project requirements.	Some of the flowchart, schematic, and pseudocode are missing or fundamentally incorrect.	Some of the flowchart, schematic, and pseudocode are missing or fundamentally incorrect.	Some of the flowchart, schematic, and pseudocode are missing or fundamentally incorrect.	/ 8
Project plan	Detailed layout with clear timeline and resource plan that considers how tasks depend on others.	Detailed layout with clear timeline and resource plan that considers how tasks depend on others.	Project is appropriately deconstructed with clear milestones and delegation.	Plan is feasible but not well supported or exclude some critical tasks.	Plan is not feasible and/or does not recognize critical tasks.	Project plan not provided or inadequate to assess project.	Project plan not provided or inadequate to assess project.	Project plan not provided or inadequate to assess project.	/ 8
Written communication	Concise and clearly formatted following guidelines with no grammatical errors, varied transitions and attractively formatted.	Concise and clearly formatted following guidelines with no grammatical errors, varied transitions and attractively formatted.	Concise and clearly formatted following guidelines with few grammatical errors.	Clearly formatted following guidelines, with minor grammatical errors (more careful proofreading is required).	Not formatted following guidelines; many grammatical errors, however report is understandable.	Not formatted following guidelines; spelling or grammatical errors take away from the effectiveness of the report.	Not formatted following guidelines; spelling or grammatical errors take away from the effectiveness of the report.	Not formatted following guidelines; spelling or grammatical errors take away from the effectiveness of the report.	/ 8

Competition rubric

Categories	Outstanding 85-100%	Meet Expectations 67-84%	Marginal 50-66%	Not Demonstrated <50%	
Objectives Collection Within 10 min. (40 marks)	40 points Robot collects all 15 objects	30 points Robot collects one object from each wall.	20 points Robot collects 1 object	0 points Robots collects 0 objects	/ 40
Robots Operate Autonomously (24 Marks)	24 points Provide evidence of no operator control.	18 points Minimum operator control.	12 points Significant operator control.	0 points Fully controlled by the operator.	/ 24
Robots Collisions (24 Marks)	24 points None	18 points 1-2 Collisions	12 points 3-4 Collisions	0 points 5 or more Collisions	/ 24
Identifying Starting Location (12 Marks)	12 points Accomplished using IR from a specified platform	9 points Accomplished using IR from any location	6 points Accomplished using Bluetooth	0 points Not Accomplished	/ 12
Driving	24 points Able to drive autonomously navigate between locations.	18 points Able to drive straight along a black line and turn 90 degrees at an intersection.	12 points Able to drive straight along a black line.	0 points Not able to navigate.	/ 24