Using Robotics to Assemble Graphene Supercapacitor

Cameron Wu[1], John Kim[1], David Magluyan[1], Devin Kawamoto-Kindred[1], Yu Harrison Zhou[4], Nanyang Cao[1], Hanqing Zhao[1], Zijing Kuang[1], Timothy Kidd[1], Shu Wu[2], Steven Dobbs[3], Jenny Zhen Yu[1*]

[1]Department of Electrical & Computer Engineering

[2]Department of Chemistry & Biochemistry

[3]Department of Aerospace Engineering

California State Polytechnic University, Pomona, CA USA

[4]Irvine High School, Irvine, CA USA

ABSTRACT

Robotics is a field that seeks to use more precise and accurate mechanical manipulation to improve the speed, efficiency, and safety of certain tasks where human actions would be more of a liability than a benefit. The method is to take a currently existing robotic arm, which can successfully move and place objects for the goal of assembling a supercapacitor, and add implementations that would further automate and improve the efficiency of the process [1-2]. One desire is to have the robot run on a standalone computer (Jetson TX2) instead of utilizing one's personal computer of a group member. This would move the project approach towards full automation and separation from human operation. Another desire is to incorporate the OpenCR1.0 development board (from ROBOTIS Inc.) for the purpose of handling inverse kinematics calculations and controlling other pieces of hardware. Currently, the system still uses hardcoded forward kinematics for some aspects of the arm's movement, which adds additional complexity and difficulty in troubleshooting to the project. The final goal is to modify the arm's end-effector so that it can not only pick up and transport the supercapacitor components, but also dispense electrolyte gel in-between parts [3]. The overall goal is to increase separation from human operation of the project so that it can increase its efficiency and efficacy.

Keywords: Robotic arm, supercapacitor, graphene sheet, forward kinematics, inverse kinematics, machine learning

1 INTRODUCTION

The main objective of this project is to create a robotic arm that will be used for the purpose of assembling graphene supercapacitors that will be used for inflight power onboard a UAV. These supercapacitors will mainly serve as secondary power to effect changes in elevation. This will help save battery power in the UAV to allow it to run for an extended period of time.

This project is an on-going, multi-year project. We were able to build on the progress of last year's team, and we will leave it to future teams to continue our work. The biggest challenge for this year's team was organizing the work of previous teams. Because there are many different aspects involved in operating the arm (computer vision, arm motion, end effector operation, setup, etc.). This year's team was able to successfully gather all of the previous documentation and compile it into several comprehensive documents that will be given to next year's team to aid them in setting up this project. This will allow them to spend more time researching and testing to improve the functionality of the arm by implementing several features that this year's team was unable to implement.

Another difficulty this year's team faced was the changing design of the supercapacitor. This was able to be resolved due to communication between the supercapacitor design team and this robotics team. The team was able to successfully train the computer vision algorithm to recognize the new supercapacitor components.

Future teams will have three main challenges to overcome. Currently the motion of the arm relies on a combination of inverse kinematics and forward kinematics. Using inverse kinematics would greatly streamline the code for the arm motion. As such, one task for future teams will be to shift to using only inverse kinematics for controlling the arm motion. The arm is currently being run off of the personal computer of a group member. This led to scheduling conflicts, as that specific group member had to be available for the team to run any tests with the arm. Future teams should look to move the arm control and computer vision programs off of personal computers to a dedicated Nvidia Jetson TX2 that will remain in the lab. This will eliminate the scheduling conflicts faced by this year's team. Finally, the supercapacitor team requested that the robotics team design a gel dispensing system for the supercapacitor assembly. Due to early school shutdowns from Covid-19 in the spring of 2020, the team was unable to make much progress on this challenge, and the creation of this system is left to future teams.

2 The Arm

The physical design of the arm was provided by ROBOTIS. It is composed of 3D printed plastic pieces. The motors that control the motion of the arm were also provided by ROBOTIS. The end effector that is responsible for picking up the supercapacitor components is a suction cup powered by a 12 VDC motor, and controlled by an Arduino board with a transistor circuit. The arm as an integrated system has three main subsystems. The first is the computer vision system. This is responsible for recognizing the different supercapacitor components and sending the location of these components to the code that controls the motion of the arm. The control subsystem is responsible for determining what position to place the arm into so that it can pick up a desired component; it also is responsible for controlling the end effector. Finally, the gel dispensing system will be responsible for applying a gel separator to the supercapacitor components when needed.

Computer Vision

The computer vision side of the project is essentially the "eyes" of the robotic arm. This allows the robotic arm to identify and locate supercapacitor parts laid out on a white-board. The program that the team is using is called YOLO (You Only Look Once) and it is in conjunction with our webcam the Logitech C920. YOLO is a real-time object detection system that runs off Linux. This algorithm takes the entire image as an object and reconstructs object detection as a regression problem, from image pixels to bounding box coordinates and class probabilities. Figure 1 shows what the camera is seeing and how it identifies each component.

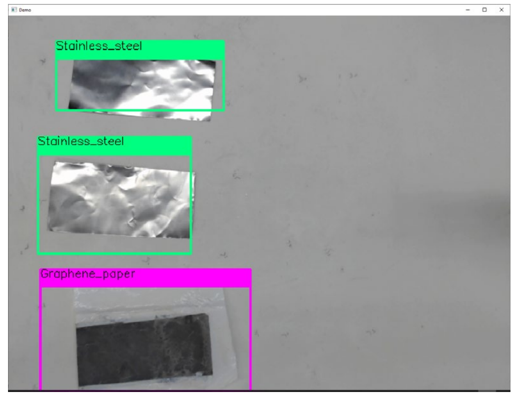

Figure 1: YOLO in action and what the camera is seeing.

There are a number of reasons why we would want to use YOLO instead of other computer vision software. The accuracy that the program provides and how fast it responds is necessary when operating the robotic arm. Being able to have quick feedback will give the arm a faster time moving to its desired location and build in a timely manner. In addition to recognizing the pieces clearly, it can clearly pinpoint the objects center location on the board. This will allow the robotic arm's end effector to be at the midpoint of the component so that it can activate its vacuum pump. Locating the midpoint of the component is necessary, so that the end effector doesn't go to the components edge making the piece flimsy or move differently than its original position. Since the arm cannot rotate at this given time, it is important that the pieces stay the same orientation.

Computer vision is a key component to the robotic arm because it is what identifies the unique components of the supercapacitor for assembly. By implementing YOLO, the assembly of the supercapacitor can be accomplished in a timely manner. If new supercapacitor components were to be introduced in the near future, it would not be difficult to train the new parts and have the camera recognize the new pieces.

Control System

The control system is the "brain" of the robotic arm. Its main task is controlling the hand of the robotic arm moving to a desired position and orientation, executing the planned sequence of motions in the presence of unforeseen errors, and making the current end effector hold the objects. Figure 2 shows the main elements of the robotic system.

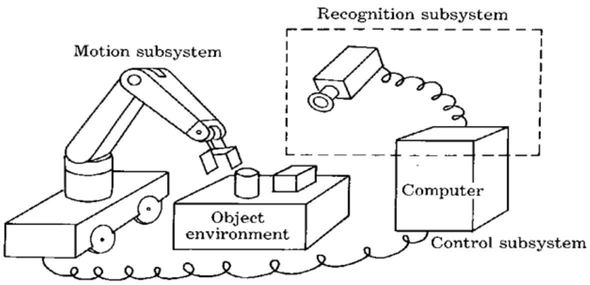

Figure 2: Main elements of the robotic system.

Currently, the robotic team is using a personal computer with an arduino board as a robotic control system. When the control system starts to work, the computer controller reads information from the camera of recognition subsystem, sends control signals to the motor of the motion subsystem by U2D2 communication converter and receives feedback information from it and then executes the planned sequence of motions according to the feedback information. In the meantime, the arduino board will accept a signal from the computer controller to get a command whether to activate the end effector - what the robotic team is using currently is an air pump.

The current process of how the arm functions is a combination of forward and inverse kinematics, where the rotation of the arm at the base is found via inverse kinematics, while the extension of the arm to reach towards the object is handled by forward kinematics. Transferring the motion of the arm to being fully inverse kinematics is one of the current and future goals of the project, since using inverse kinematics would give more freedom and finer control to the system, since the inverse kinematics would only depend on the desired end-point as an input. The fact that inverse kinematics can produce multiple possible solutions, limited by the length of the arms and the range that the joints can rotate along provide both a challenge and improvement, where being able to produce multiple solutions only dependent on the end-point of the end-effector allows for more freedom in the project. This means that it would become much easier to incorporate new designs of the supercapacitor, since the inverse kinematics allows the arm to act more flexibly. The fact that only one input is required (the end-point of the end-effector) this means that adding objects and positions to handle becomes much easier in the coding of the arm, especially since that information can be pulled from the computer vision aspect of the project dynamically. Using inverse kinematics, especially if it can be integrated with the open-CR board and libraries from ROBOTIS, would allow for the main code of the lab to be simplified and in turn allow for easier implementation of future coding improvements.

For the future works, in order to assemble the required supercapacitor, the control system would be able to collaborate with the gel system. Hence, the robotic team may replace current end effector with a new design. Also, the robotic team will use OpenCR1.0 to improve inverse kinematic algorithms to control the motion subsystem more accurately.

Gel Dispensing System Design

By considering various factors such as the characteristics of the electrolyte gel required by the supercapacitor, the operability of the whole system, and the budget, the team have proposed the following designs:

The first design is simple and low cost. A heating plate is used to keep the gel's temperature at a fixed value, and the temperature is monitored by a thermocouple thermometer. Then the gel will be applied to the supercapacitor parts manually using a glass eye dropper.

Another design is to purchase a commercial off-the-shelf robot which is generally designed for gel dispensing. The robot can accomplish the task accurately and efficiently. However, the disadvantage is the extreme high cost of thousands of dollars which is over the budget. Therefore, the team would not make this design their first choice.

Through automatizing the manual part of the first design, the team proposed the following design:

The final design will use a glass beaker to hold the gel dispenser, and a heating plate which has a time function and a warm-keeping function to accurately make the gel stay at the best temperature. In addition, using a pump and a rubber hose to transfer the gel from beaker to dispenser is necessary. For the dispenser, a commercial touchless automatic liquid dispensing machine with some simple modifications allows the sensor to recognize the supercapacitor parts when the parts are at the right location in order to trigger the dispenser. There is another option. Building an easy robotic arm with a motor, a torque, and a wooden bar as the arm instead of using the sensor of the dispenser machine is more operable. After hard-coding, the motor will be able to make the arm which connected to the dispenser rotate to the correct direction and make the dispenser dispense the gel onto other components of the supercapacitor.

Nvidia Jetson TX2

One of the future goals of the project is to implement the Nvidia Jetson TX2 as show in figure 3. The Jetson is a developer board that runs Ubuntu Linux, similar to a Raspberry Pi, but much more powerful. This will replace the laptop currently used to run the robotic arm. It also removes the hassle of setting up a laptop, belonging to one of the new members, with all the required programs, files, and setup, each year, just to run the robotic arm. On top of that, the Jetson is also capable of machine learning, meaning that, once set up, the next team will have everything setup at the beginning of the school year.

Figure 3: Nvidia Jetson TX2.

3 RESULTS

Our results show that the arm can in fact do it's designed task in a timely manner. The camera can pick up the location and identify the current supercapacitor components using YOLO. In addition, the arm is able to move to the location where the parts are located and stack the pieces accordingly. The arm is still using forward kinematics for the extension of the arm, but have since added code to make the arm move smoother to each piece. The process takes around 45seconds on average, but with the inclusion of a gel dispenser the process will most likely take longer.

4 CONCLUSION

The goal that we have set since the beginning of the project has been met. Being able to identify, locate, and assemble supercapacitor components is a huge accomplishment that we have set out for ourselves. The combined effort of joining computer vision and control systems is an accomplishment in itself and the team could not be happier the way it turned out. Future works that the team wishes to accomplish is add a gel dispenser and improve code for the robotic arm. We believe that this can be accomplished next year and make the arm even better than before.

5 ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Mr. & Mrs. Joe and Grace Ye Endowment, Mr. Brandon Antillon, Mr. Aaron Park, ROBOTIS Inc., Cal Poly Pomona IDEA Lab directed by Dr. Olukemi Sawyerr (iLab.cpp.edu) through a VentureWell grant (venturewell.org), Boeing Phantom Works, the Achieve Scholars Program, Mr. Alan Arslan, Creative Aero Engineering Solutions Inc., Prof. Martin Mason, Mt. San Antonio College, Ms. Lindsey Sayers, Southern California Edison, Dr. Todd Coburn, and Dr. Laila Jallo, Cal Poly Pomona. We thank Dr. Yadong Yin, Dr. Yaocai Bai and Dr. Quanbin Liu (University of California, Riverside) for assistance with the device testing.

REFERENCES

[1] Z. Yu, S. Dobbs, K. Anderson, P. Sun, B. Zhu, A. Nair and S. Wu, “Fabrication of a Lower Weight, All 3D Printed Graphene Supercapacitor”, TechConnect World Innovation Conference in Boston, MA, June (2019), TechConnect Briefs 2019

[2] S. Dobbs, Z. Yu, K. Anderson, J, Franco, A. Deravanessian, A. Lin and A. Ahn, “Design of an Inflight Power Generation and Storage System for Use in UAVs”, IEEE Conference on Technologies for Sustainability (SusTech) in Long Beach, CA, November (2018), ISBN 978-1-5386-7791-9/18/

[3] J. R. Amend, E. Brown, N. Rodenberg, H. M. Jaeger and H. Lipson, "A Positive Pressure Universal Gripper Based on the Jamming of Granular Material," in IEEE Transactions on Robotics, vol. 28, no. 2, pp. 341-350, April 2012.