Robotic Operation of ICU Equipment in Contagious Environments

Group 18:
Tianyu (David) Wang, Jiayin (Jaelyn) Qu

JOHNS HOPKINS
UNIVERSITY

Mentors:

Project Mentors:

Dr. Axel Krieger -- Mechanical Engineering Support

Dr. Balazs P. Vagvolgyi -- Computer Vision Support

Clinical Mentor:

Sajid H. Manzoor BS, RRT, RSPGT, MEd -- Clinical Testing Support

Our Project

Our solution to their need is an integrated tele-operable robotics system that enters the ICU room on behalf of the ICU team member. Much like an unmanned drone, this robot is designed to recognize key ICU equipment, operate them, and project key information from such equipment straight back to the operator. Thus reducing the time, protection gear, and exposure risk cost that an ICU team member faces when entering an ICU room during a COVID-19 pandemic.

Need Statement

ICU teams need a novel way to remotely monitor and adjust settings on key ICU equipments in order to efficiently monitor and provide consistent healthcare service to all patients as we cope with ICU need surge due to COVID-19.

More Specifically….

- ICUs are **overpopulated** and **understaffed** , National average ICU occupation rate: 73% .[1]
- Ventilators and infusion pumps are **critical equipment** in treating COVID-19
- **Routine** setting changes requires for staff to enter the room, which require PPE, time to put on PPE, and increases risk.
- Entering the ICU requires consuming a full set of PPE
- Entering the ICU also exposes staff to risk of infection by COVID-19
- Due to security concerns, equipment can not access network

Sputnik via AP

Medical workers put on personal protective equipment (PPE) before entering the Intensive Care Unit (ICU) of the United Memorial Medical Center in Houston, Texas, the United States.

"Monitoring these devices is exhausting, especially when you're dealing with lots of patients in large settings like a field hospital,"

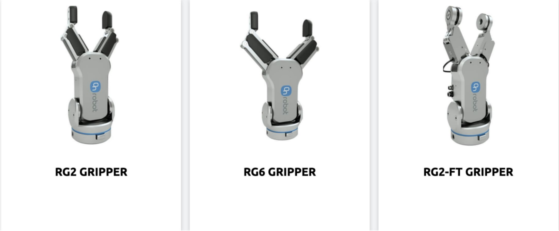
-- Lee, Controlling ventilators from a distance[2]

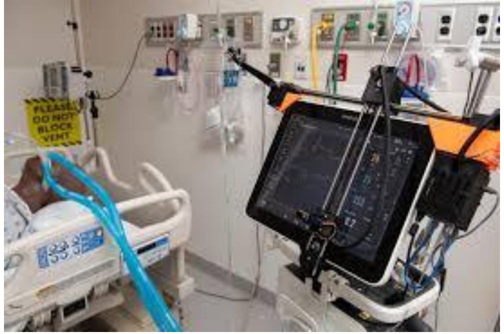
"We recommend minimizing the number of staff entering the rooms of patients with COVID-19, remote access to equipment controls and bundle care to minimize the number of exposures"

-- Aziz, Managing ICU Surge during the COVID-19 Crisis[3]

1. New York Times: https://www.nytimes.com/interactive/2020/us/covid-hospitals-near-you.html
2. Berkeley Engineering: https://engineering.berkeley.edu/news/2020/04/controlling-ventilators-from-a-distance/
3. Managing ICU surge during the COVID-19 crisis: rapid guidelines https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7276667

Prior Work

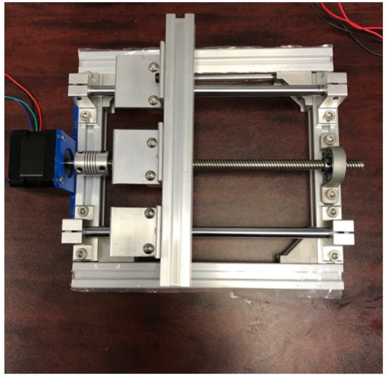




Established Cartesian Robot (Krieger)

Existing Remote ICU Touchscreen Robot (Krieger, Vagvolgyi)

Successive third party/ commercialized end effector design (EG. On Robot, Zimmer Group)



Current Challenge:

- Singular mode of interaction towards different interaction need.
- Lack of high degree of freedom

Source: Krieger, Vagvolgyi, On Robot, Zimmer Group

Our Goal

Mechanical design:

1. Adapt/ generate a multi-purpose mechanical end effector that performs operations including spinning knob, pressing touchscreens and buttons, etc. based on cartesian robot.
2. Adapted robot with 6 DOFs that performs the above tasks based on URs.

Software design:

1. With proper camera input, the software is able to use computer vision to recognize the target machine (ventilator, for instance) among all of the machines present;
2. Find the relative position between camera and the machine for future registration;
3. A working user interface that simulates the panel of the machine;

Deliverable

	David	Jaelyn
Minimum	Functional prototype within reasonable accuracy.	A model capable of recognizing the desired machine and an algorithm capable of calculating relative position and pose w/ unit tests;
Expected	Well tuned cartesian robot prototype with tested analysis and documentations.	A model capable of recognizing the desired machine and calculate relative position well tested with unit test.
Maximum	Preliminary adaptation for high DOFs ROS	A working user interface that allows the user to see and control the panel through the robot;

Software design process

1. Find an equipment with knobs,screens

   (Hard to get a real ventilator due to medical device restriction)

   Eventually replaced with an oscilloscope

Continued

2. Prepare for data sets: take images & videos of oscilloscope in several randomly set environments with random objects for future training and testing purposes;

3. Develop a computer vision model for recognizing the machine with openCV/Tensorflow + unit tests;

4. Develop an algorithm that is able to calculate the relative position between the camera and the oscilloscope based on detectable features in the images + unit tests;

5. (Maximum expectation) Develop a UI that simulates the panel so that users would be able to control;

Mechanical Design Approach

- Determine end effector geometry
  - Literature research on popular approach
  - Generate evaluation chart to narrow down selection
  - Rapid prototype of selected approach(Parameter: finger number, grabbing style etc)
  - Assemble approach and actuate manually for proof of concept
  - Run preliminary FEA
  - Consult with Dr.Krieger as needed
- Actuating end effector w/ motor
  - Preliminary assembling of actuator onto 3D printed prototype for motorized proof of concept.
  - Work with Jaelyn to try to operate on oscilloscope with actuator
- Assembling preliminary test bed
  - Build small cartesian robot, connect actuator and test

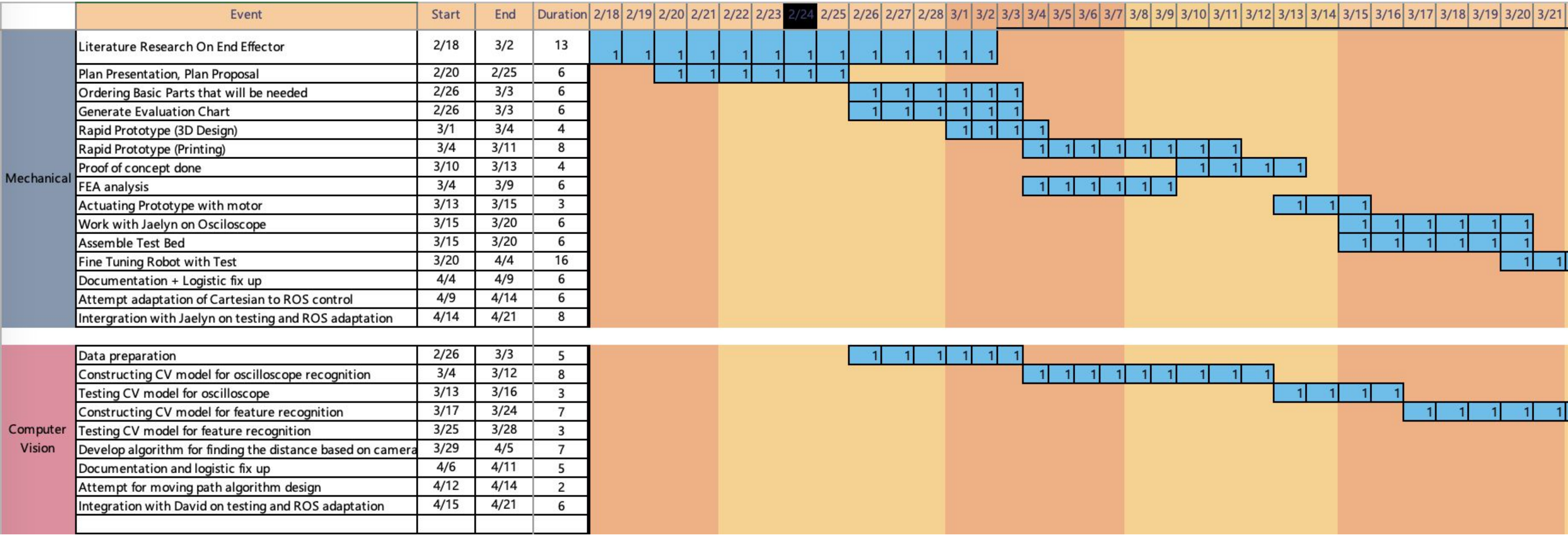
Continued...

- Fine tuning / testing with Cartesian Robot
  - Basic test construction, Data collection, Data analysis
  - Testing efficacy on different knob size, button size etc.
- Adaptation to high DOFs ROS
  - Conversion of control from cartesian to ROS
  - Calibration testing

Design Need Criteria

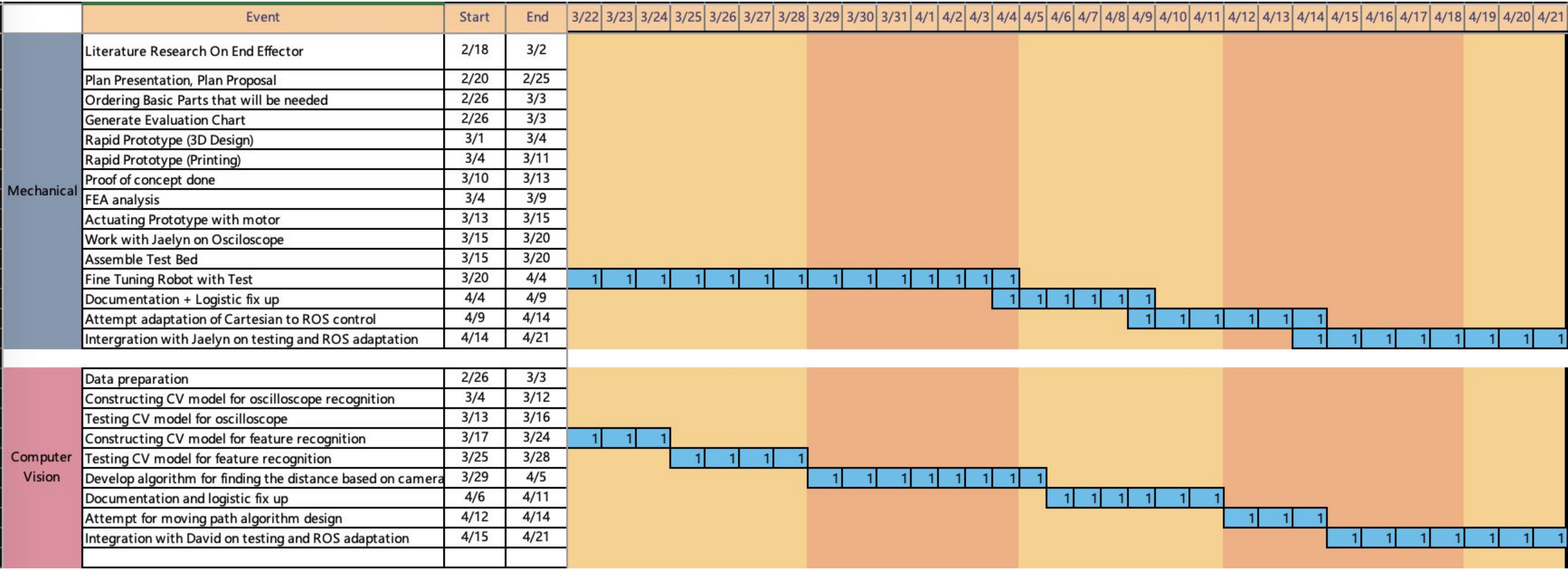
1. End Effector
    a. Turning knob within precision requirement
    b. Press button within precision requirement
    c. Press screen within precision requirement
    d. Leave enough viewing angle for camera
    e. Mechanically stable and driven by motor
2. Cartesian robot
    a. Move to given point on 2D plane within precision requirement
    b. Remain steady while end effector operates
    c. Cartesian robot is able to operate time efficiently

Time Table（Feb - Mar 21）



	Event	Start	End	Duration	2/18	2/19	2/20	2/21	2/22	2/23	2/24	2/25	2/26	2/27	2/28	3/1	3/2	3/3	3/4	3/5	3/6	3/7	3/8	3/9	3/10	3/11	3/12	3/13	3/14	3/15	3/16	3/17	3/18	3/19	3/20	3/21
Mechanical	Literature Research On End Effector	2/18	3/2	13	1	1	1	1	1	1	1	1	1	1	1	1	1																			
	Plan Presentation, Plan Proposal	2/20	2/25	6			1	1	1	1	1	1																								
	Ordering Basic Parts that will be needed	2/26	3/3	6									1	1	1	1	1	1																		
	Generate Evaluation Chart	2/26	3/3	6									1	1	1	1	1	1																		
	Rapid Prototype (3D Design)	3/1	3/4	4												1	1	1	1																	
	Rapid Prototype (Printing)	3/4	3/11	8															1	1	1	1	1	1	1	1										
	Proof of concept done	3/10	3/13	4																					1	1	1	1								
	FEA analysis	3/4	3/9	6															1	1	1	1	1	1												
	Actuating Prototype with motor	3/13	3/15	3																								1	1	1						
	Work with Jaelyn on Osciloscope	3/15	3/20	6																										1	1	1	1	1	1	
	Assemble Test Bed	3/15	3/20	6																										1	1	1	1	1	1	
	Fine Tuning Robot with Test	3/20	4/4	16																															1	1
	Documentation + Logistic fix up	4/4	4/9	6																																
	Attempt adaptation of Cartesian to ROS control	4/9	4/14	6																																
	Intergration with Jaelyn on testing and ROS adaptation	4/14	4/21	8																																
Computer Vision	Data preparation	2/26	3/3	5									1	1	1	1	1	1																		
	Constructing CV model for oscilloscope recognition	3/4	3/12	8															1	1	1	1	1	1	1	1	1									
	Testing CV model for oscilloscope	3/13	3/16	3																								1	1	1	1					
	Constructing CV model for feature recognition	3/17	3/24	7																												1	1	1	1	1
	Testing CV model for feature recognition	3/25	3/28	3																																
	Develop algorithm for finding the distance based on camera	3/29	4/5	7																																
	Documentation and logistic fix up	4/6	4/11	5																																
	Attempt for moving path algorithm design	4/12	4/14	2																																
	Integration with David on testing and ROS adaptation	4/15	4/21	6																																

Time Table（ Mar 22 - End)



	Event	Start	End	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16	4/17	4/18	4/19	4/20	4/21
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	Integration with David on testing and ROS adaptation	4/15	4/21																									1	1	1	1	1	1	1

Dependencies

1. Material dependency
    a. Building blocks (T-slot), axels, screws etc
    b. Motors (stepper motor, servo etc)
    c. Cameras
    d. Basic tools
    e. 3D prototypes (outsourced)
    f. Oscilloscope
2. Testing dependency
    a. Measuring equipments
3. Time dependency
    a. Outsource printing
    b. Shipping
    c. Mentor availability
4. Budget

Management Plan（Meeting）

- Daily communication between Jaelyn and David
- Weekly meeting with Dr.Krieger and Dr.Vagvolgyi
  - Biweekly Hour Long Meeting. Thursday 10 am.
- Meet with clinical sponsor as needed
- Individual Scheduled Meeting based on request

Management Plan

- Communications:
  - Done with zoom when meeting bi-weekly and with email for instant communication;
- Code:
  - Codes for the computer vision part will be mainly written in python utilizing Anaconda locally, and codes for mechanical design will be written locally in Arduino and stored in a shared cloud drive.
- Mechanical File:
  - All CAD will be designed using AutoDesk Fusion 360 and stored in the cloud. An additional set of STL files for different stages of the project will be stored separately on a shared cloud drive.
- Project Management:
  - All project timeline will be kept in check using the Gantt chart, updated weekly and each version will be separately stored on cloud bi-weekly.
- File Sharing:
  - All files will be shared and stored from Hopkins OneDrive where a separate SharePoint has been created with an indexed folder to store all related material of the project.

Reference / Reading List

End Effector Design:

- A Double Claw Robotic End-Effector Design [1]

[1] R. Alqasemi, S. Mahler, and R. Dubey, "A Double Claw Robotic End-Effector Design," p. 6, 2007.

- Design, development and experimental assessment of a robotic end-effector for non-standard concrete applications [2]

[2] N. Kumar et al., "Design, development and experimental assessment of a robotic end-effector for non-standard concrete applications," in 2017 IEEE International Conference on Robotics and Automation (ICRA), May 2017, pp. 1707–1713, doi: 10.1109/ICRA.2017.7989201.

ROS:

- Documentation - ROS Wiki [3]

[3] "Documentation - ROS Wiki." http://wiki.ros.org/Documentation (accessed Feb. 24, 2021).

- CartesI/O: A ROS Based Real-Time Capable Cartesian Control Framework [4]

[4] A. Laurenzi, E. M. Hoffman, L. Muratore, and N. Tsagarakis, "CartesI/O: A ROS Based Real-Time Capable Cartesian Control Framework," Montreal, Canada, May 2019, Accessed: Feb. 24, 2021. [Online]. Available: https://hal.archives-ouvertes.fr/hal-02017773.

- Getting Started With ROS (Robotic Operating System) [5]

[5] ZRob314Follow, "Getting Started With ROS (Robotic Operating System).," Instructables. https://www.instructables.com/Getting-Started-with-ROS-Robotic-Operating-Syste/ (accessed Feb. 24, 2021).

Cartesian Robot:

- Design and Implementation of a Cartesian Robot [6]

[6] A. Gasparetto and G. Rosati, "Design and Implementation of a Cartesian Robot," in AMST'02 Advanced Manufacturing Systems and Technology, Vienna, 2002, pp. 539–544, doi: 10.1007/978-3-7091-2555-7_61.

Thanks!

Questions?