Project Proposal

Robotic Operation of ICU Equipment in Contagious Environment

EN 601.456 Computer Integrated Surgery II

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1. Clinical Motivation

The COVID-19 pandemic has caused a tremendous global surge of ICU devices and staff demand. Since the virus is highly contagious, and directly impacts the respiratory system, it is believed that about ⅓ of the patients who have COVID-19 will require ICU admission at some point[1]. This poses great challenges towards the medical system as hospitals are overloading to take on COVID patients in ICU. As of February, the average national ICU occupation is still at 73 %[2], this is an almost 10 % raise compared to 2010 [3]. Most Significantly, given COVID's mode of transmittance, medical workers are at risk every time they enter an ICU room to do routine adjustments and check-ups for patients. Furthermore, entering the ICU requires consuming a full set of PPE. Not to mention the amount of time it would take to properly dress in PPE. Therefore, ICU teams need a novel way to remotely monitor and adjust settings on key ICU equipment in order to efficiently monitor and provide consistent healthcare service to all patients as we cope with ICU need surge due to COVID-19.

Our solution to their need is an integrated tele-operable robotics system that enters the ICU room on behalf of the ICU team member for the purpose of routine check-up and parameter adjusting. 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.

Our initial goal is to build a robot that, with its camera input, can recognize the machine it needs to control. After locating the panel, the robot with its specially designed arm would be able to control the panel following instructions given by a remote user.

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.

Figure 1. Nurses Dressing Up to Enter ICU (NYT)

2. Prior Work

Prior work done by Dr. Krieger and Dr. Valgvolgyi are remotely controlled 2D Cartesian robots. The robot is specially configured for a single machine with a touchscreen. The content on the screen would be lively captured by the camera mounted above the screen and shared with the user. The frame of the robot is located above the touchscreen. When a user touches a tablet remotely, his command would be transmitted to the robot and the robot is able to perform the touch activity accurately on the screen.

Figure 2. The 2D Cartesian robot designed for controlling touchscreen (JHTV)

There are also many prior designs of end effector that take on different forms and purposes when it comes to fitting in the last piece of puzzle between driving an robotic arm and completing physical operations. Here we focus on impactive end effectors such as grippers. Researchers have conducted prior research comparing the different ways of actuating a gripper as shown below. Furthermore, companies like On-Robot and Zimmer Group have also designed multiple industrial level tried-and-tested layouts of gribber that we can adapt when designing our own. Thus, based on these prior work, we can hope to integrate closely our design needs and the derived experience from academic and industry to arrive at the optimal design for our own purpose.
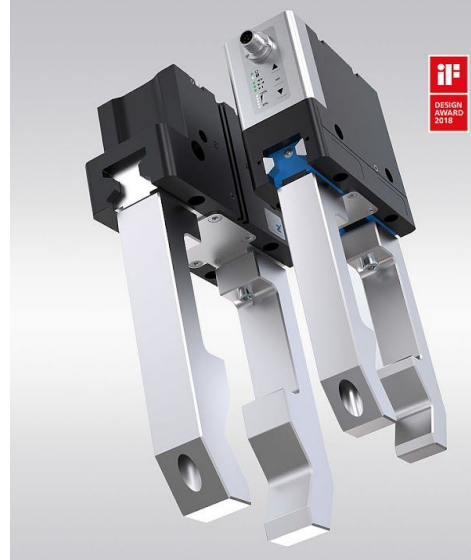
Figure 3. On Robot Sample[4], Zimmer Group Sample [5]

TABLE I.   COMPARISION OF DIFFERENT ACTUATION METHODS

Gripper type	Advantages	Disadvantages
Cable-driven	Optimal weight and space	Control Complexity
Vacuum	Highly flexible Clean	Some operational issue
Pneumatic	Small dimension Low weight Clean	Not precise enough High operating cost
Hydraulic	High force	Not clean enough high maintenance cost
Servo-Electric	Highly flexible Low maintenance cost Easily controllable Clean	Low force

Table 1: Comparison of Different Actuation Methods[6]

3. Goals

The ultimate goal of the project is to develop a 6 DOF robotic system that is able to recognize the target object, find its control panel and perform various interactions based on pre-programmed configuration with its actuator using remote command. In this way, one robot would be able to handle several different kinds of equipment in the ICU. We also expect the robot to be steady and quick-responding, so that it can handle emergency situations before medical workers get in place.

However, note that due to time and physical limitations, we make compromises and choose to do two of the major steps towards building the robot. The first goal is design and adapt a novel robotic end effector that can accurately perform various activities including pushing buttons, touching screens, turning knobs, etc. The second goal is to build a model that is able to recognize target equipment and find the distance and angle between the camera and the equipment using computer vision. Ideally, the robot would be able to do the registration and find its way to interact with the control panel.

4. General Experimental Setup

General experimental setup for Mechanical design will include a cartesian robot, a test field of different button, knob, touch screen, and a grid lined matrix overlay for quantification of accuracy.

General experimental setup for computer vision will include a computer vision model for oscilloscope recognition, an algorithm for image analysis that eventually finds the relative pose and distance between the camera and the desired position based on features in the image.

5. Technical Approach

5.1 ICU Equipment Real-Time Recognition Using Computer Vision

Figure 4. An example ICU setup (from Piezo™)

Figure 5. A typical ventilator used in ICU

The overall approach is to take pictures/videos of the desired equipment and use these data to train a neural network that would be able to discern the equipment using Tensorflow. Note that due to the restriction on medical appliances, we eventually choose to use an oscilloscope in replace of a real ventilator, given that the oscilloscope also contains buttons, switches, knobs and screens.

Figure 6. The oscilloscope I bought in replace of the ventilator

General steps of doing object recognition include:

a. Collecting and labelling the data;
b. Training model;
c. Testing model based on new data sets;

5.2 Pose Recognition Using Computer Vision/Image Analysis

To do the registration of the robot, we must know the current position of the robot as well as the desired position. The evaluation of the robot's current position is based on recognizing key features of the equipment. For instance, the position of corners/edges, shade, unique features, etc.

The basic idea would be doing edge/corner detection with a proper filter. The pose and the distance would then be decided based on these detected features.

5.3 User Interface Design

Develop a basic user interface that allows the user to see what is on the panel and make control accordingly.

5.4 Finding the optimum end effector geometry

To find the optimum end effector geometry, we would first conduct literature research to source current popular mechanical design based on our purpose.

Then, to compare selected mechanisms, we would develop Need Creterias and evaluation charts based on the proposed end goals. A preliminary need statement can be found below.

End Effector

○ Turning knob within precision requirement
○ Press button within precision requirement
○ Press screen within precision requirement
○ Leave enough viewing angle for camera
○ Mechanically stable and driven by motor

Cartesian robot

○ Move to given point on 2D plane within precision requirement
○ Remain steady while end effector operates
○ Cartesian robot is able to operate time efficiently

With selected mechanisms, we would conduct rapid prototypes and conduct preliminary manual tests to make sure that they pass the proof of concept. FEA will also be conducted while we wait for 3D manufacturers to print our model, this should provide valuable data for us to further quantify and optimize our mechanism choice.

5.5 Actuating end effector w/ motor

Since we need fast, accurate motions of small force, utilizing an electric stepper motor / servo would be our optimized form of actuating our end effector. This portion of the proposal thus focuses more on the manual assembly and testing of the end effector while being motorized.

This includes, sourcing and coming up with an plan to assemble a system to move and actuate the end effector. Current plan is to utilize an Arduino with servos attached to breadboards powered by triple A batteries. Detailed implementation can be sourced easily from online, an good example we would use is here:

5.6 Assemble and test with cartesian robot

To test the accuracy and efficacy of the end effector, we utilize a cartesian motor to conduct all the functionality and accuracy testing. The robot will be given tasks formed by a combination of : going to a specific point, interacting with the geometry of that point, monitoring how much the whole mount changed during operation to assess the accuracy, efficacy and repeatability of the robot. Cartesian robot will be built from T-slots and a stepper motor with 12 V DC battery powering it. The guide to such robots is generously provided by Dr.Kriger and can be located in our share folder. Based on the result and analysis of the testing, we will choose to compensate for the error physically or digitally.

5.7 Adaptation to High DOFs with ROS

The ultimate goal of the robot is to operate on a robotic arm mobilized by a moving platform. To achieve such goal, we need to take the end effector - actuator combination out of the cartesian robot and adapt it to an robotic arm in high DOF such as UR. The will be facilitated by documentations in ROS converting cartesian coordinates to ROS commands, and calibration from 5.5 will be conducted again to ensure the efficacy and accuracy of the device.

6. Testing Plan

Testing plan for the computer vision part would mainly be testing
1) Accuracy of the model in recognizing the target machine
2) Accuracy of the algorithm in finding the relative pose and distance
3) A working user interface that would not corrupt easily\

Testing Plan for the mechanical design part will be designed and integrated into the design as we first select the optimum geometry. After that testing will be mainly focusing on accuracy and stability testing where we would ask the robot to perform random tasks drawn from the test bank to evaluate its mean accuracy and degradation of accuracy over time. More detail can be found in the design approach.

7. Key activities and deliverables

Shown as follows:

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

8. Dependencies

8.1 Material dependency
- Building blocks (T-slot), axels, screws etc
- Motors (stepper motor, servo etc)
- Cameras
- Basic tools
- 3D prototypes (outsourced)
- Oscilloscope

8.2 Testing dependency

- Measuring equipments

8.3 Time dependency

- Outsource printing
- Shipping
- Mentor availability

8.4 Budget

9. Timeline

Shown as follows:

	Event Num	Start Date	End Date	Event Name	# Days from Start	Event Duration
Mechanical	1	2/18/21	3/2/21	Literature Research On End Effector	0	13
	2	2/20/21	2/25/21	Plan Presentation, Plan Proposal	2	6
	3	2/26/21	3/3/21	Ordering Basic Parts that will be needed	8	6
	4	2/26/21	3/3/21	Generate Evaluation Chart	8	6
	5	3/1/21	3/4/21	Rapid Prototype (3D Design)	11	4
	6	3/4/21	3/11/21	Rapid Prototype (Printing)	14	8
	8	3/10/21	3/13/21	Proof of concept done	20	4
	7	3/4/21	3/9/21	FEA analysis	14	6
	9	3/13/21	3/15/21	Actuating Prototype with motor	23	3
	10	3/15/21	3/20/21	Work with Jaelyn on Osciloscope	25	6
	11	3/15/21	3/20/21	Assemble Test Bed	25	6
	12	3/20/21	4/4/21	Fine Tuning Robot with Test	30	16
	13	4/4/21	4/9/21	Documentation + Logistic fix up	45	6
	14	4/9/21	4/14/21	Attempt adaptation of Cartesian to ROS control	50	6
	15	4/14/21	4/21/21	Intergration with Jaelyn on testing and ROS adaptation	55	8
Computer Vision	1	2/26	3/3	Data preparation	0	5
	2	3/4	3/12	Constructing CV model for oscilloscope recognition	6	8
	3	3/13	3/16	Testing CV model for oscilloscope	15	3
	4	3/17	3/24	Constructing CV model for feature recognition	19	7
	5	3/25	3/28	Testing CV model for feature recognition	27	3
	6	3/29	4/5	elop algorithm for finding the distance based on camera i	31	7
	7	4/6	4/11	Documentation and logistic fix up	39	5
	8	4/12	4/14	Attempt for moving path algorithm design	45	2
	9	4/15	4/21	Integration with David on testing and ROS adaptation	48	6

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

10. Team Members

Tianyu (David) Wang (twang98@jh.edu)

Department of Biomedical Engineering, junior year

Jiayin (Jaelyn) Qu (jqu5@jh.edu)

Department of Applied Math and Statistics, junior year

11. Team Mentors

Dr. Axel Krieger -- Mechanical Engineering Support

Dr. Balazs P. Vagvolgyi -- Computer Vision Support

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

12. Management Plans

12.1 Meetings

Biweekly meeting with regular communication and update of progress through email.

12.2 Communications

Done with zoom when meeting bi-weekly and with email for instant communication;

12.3 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.

12.4 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.

12.5 Project Management

All project timeline will be kept in check using the Ganntt chart, updated weekly and each version will be separately stored on cloud bi-weekly.

12.6 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.

13. References

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