Paper ID #27814

Non-Destructive, Remote Control of Industrial Robotic Arm

Prof. Aleksandr Sergeyev, Michigan Technological University

Aleksandr Sergeyev is currently a Professor in the Electrical Engineering Technology program in the School of Technology at Michigan Technological University. Dr. Aleksandr Sergeyev earned his bachelor degree in Electrical Engineering at Moscow University of Electronics and Automation in 1995. He obtained the Master degree in Physics from Michigan Technological University in 2004 and the PhD degree in Electrical Engineering from Michigan Technological University in 2007. Dr. Aleksandr Sergeyev's research interests include high energy laser propagation through the turbulent atmosphere, developing advanced control algorithms for wavefront sensing and mitigating effects of the turbulent atmosphere, digital inline holography, digital signal processing, and laser spectroscopy. Dr. Sergeyev is a member of ASEE, IEEE, SPIE and is actively involved in promoting engineering education.

Prince Mehandiratta, Michigan Technological University

Mr. Mehandiratta is currently pursuing a graduate degree in Mechanical Engineering at Michigan Tech. His professional interests include Industry 4.0, Robotics, Automation and Vegan Food Industry. He can be reached at pkmehand@mtu.edu

Prof. Scott A Kuhl, Michigan Technological University

Scott Kuhl is an Associate Professor of Computer Science and an Adjunct Associate Professor of Cognitive & Learning Sciences at Michigan Technological University. He received his Ph.D. in Computer Science from the University of Utah in 2009. He has been the faculty advisor for Husky Game Development Enterprise since Spring 2010. His research interests include immersive virtual environments, head-mounted displays, and spatial perception. A link to his web page can be found at https://pages.mtu.edu/˜kuhl/.

Non-Destructive, Remote Control of Industrial Robotic Arm

Abstract

Virtual robots are perplexing for a beginner-level robotics programmer. Since there are no commercially available remotely controlled robotic arms, and because robotic platforms are costly, students and researchers are often unable to learn the concepts of programming industrial robots. This project applies new concepts with available virtual robot technology to make a non-destructive, remotely-controlled robotic arm to better teach students and researchers about programming and control of robotic arms. By applying the remotely-controlled robotic arm concept, existing resources can be effectively shared with other universities to teach programming of industrial robots. Using this centralized developed system to allow remote access to the physical robot, students can test their programs with a real robotic arm instead of working in a robotic simulation environment which are commonly used across universities.

In order to provide remote access to the robot, a system is designed that connected the user, via a web interface of video feed, and external hardware controlling the proprietary robot teach pendant. The developed non-destructive system provides control over teach pendant without any modifications to proprietary Fanuc hardware. It enables remote access to the users wishing to learn, develop, or test robotic programming concepts. While robotic simulation software can be used to achieve this, the proposed solution provides an actual interactivity with the physical system. This allows the user to intermingle with the robotic arm and learn the programming skills used in industry.

Keywords

Remote Robot, Robotics, Control, PLC and Robotic Education

Remote Robot Introduction

The robotics market is growing rapidly and globally. The article recently published by the International Federation of Robotics[1] on World Robotics sales, shows a 30 percent increase in sales compared to 2016. This amounts to 381,000 more robots sold globally. With the apparent demand of Industrial Robots, there is a need for more trained robotic specialists. Even though, robotic simulation software is available online, virtual robots are hard to understand or control for many people. This project applies a new concept with the available virtual robot technology to make a non-destructive, remotely-controlled robotic arm to better teach students and researchers about programming and control of a robotic arm. Since there are no commercially available remotely controlled robotic arms, and because of the high cost of robotic arms, students and researchers are often unable to test their programs on real robots. By applying the following concept of a remotely-controlled robotic arm, the universities already equipped with industrial robots can share existing resources with other universities to teach programming of industrial robots. Using this developed system, to allow the remote access to the physical robot, interested parties can test their programs on a real robotic arm instead of simply working in robotic simulation environments.

To achieve this goal, a three-part system has been designed. First, a hardware to non-destructively control the teach pendant of a physical robot. Second, a system that captures and transmits video. Lastly, a website used by the client to remotely access, control, and program an industrial robotic arm. To gain remote access to the robot, the client requests a login token for the specific access time and access duration to the robot. Upon receiving approval from an administrator, the user is provided with a teach pendant control web link, which is limited to only the pre-approved time slot. The interface for the client consists of the virtual teach pendant, a display of the real teach pendant screen and two display screens showing the robot from different angles. The system layout in Figure 1 proposes three cameras in total for the system, where two cameras are placed in order to stream the live feed of the robot's movement and third camera shows the display of teach pendant on the website which will be further discussed.

When the client presses any input on the virtual teach pendant, the data are transmitted via the internet to the arm server, which, using Modbus TCP/IP to communicate with a programmable logic controller (PLC), activates the hardware to control the real teach pendant. The vision system implements the digital camera, mounted above the real teach pendant's display to capture and feed real-time data. The video signals captured by the vision system from the real teach pendant, as well as from the physical robot, are transmitted to the vision system server. This sends the video stream to the client, enabling the user to observe in real-time teach pendant display activities and motion of the robotic arm. This enables remote access for the users wishing to learn robotic programming concepts. While robotic simulation software can be used to achieve this, the solution described here provides an actual interactivity with the physical system, allowing the user to interact with the robotic arm and learn the programming skills used in industrial robots.

Background on the Existing Platforms

The medical sector has applied similar concepts, for example, using, a remote robot-assisted laparoscopic cholecystectomy on a woman with a history of abdominal pain and cholelithiasis.[2] The surgery was done successfully across transoceanic distances with the surgeons being in New York and the patient located in Strasbourg, France. Therefore, a similar concept can be implemented in academia to provide students and researchers an opportunity to gain hands-on experience operating industrial robotic arms.

As manufacturers are moving towards automation-based production, industry and academia must join forces to prepare for the today's manufacturing demands. The developed complementary Robot Run, robotic simulation software at Michigan Tech[3] provides a free education simulation tool to the students to learn programming concepts. The developed simulation environment has been used by many institutions to teach students the concepts of industrial robotics.

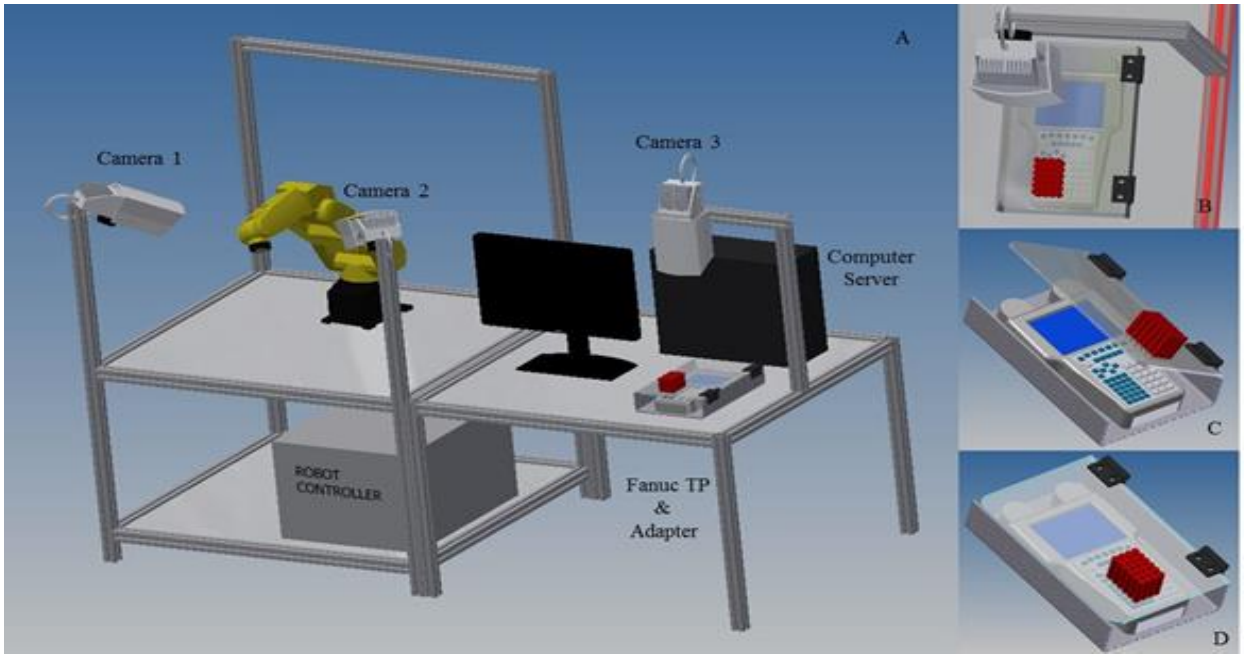

Figure 1: (A) Robot Remote System Proposed Model with two-live camera feed of the robot, (B)Top view of the teach pendant camera set up, (C) & (D) The initial testing phase of teach pendant with the push buttons.

To control the robot at the Industrial Automation lab of Michigan Tech, equipped with FANUC LR-Mate 200iC robots, the hardware is designed to non-destructively control the robot's motion. The push-type actuators, controlled by the programmable logic controller (PLC), enable activation of the individual keys on the teach pendant to generate the motion to enter programming instructions, while designing the robotic program.

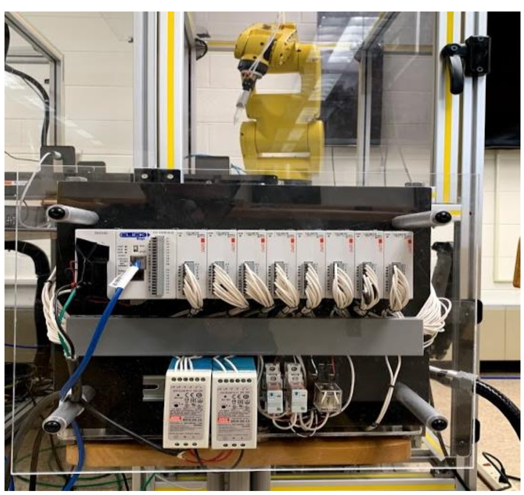

Figure 2: The final setup of remote robot system with FANUC LR-Mate 200iC robot and CLICK PLC

Figure 2 depicts the overall layout of the remote robot System. In order to ensure the safety of the Robot and teach pendant, the Robot's collision guard feature is used to stop the robot immediately in case of the emergency. The system developed follows all the security norms in order to provide the secured communication[4] between remote robot system and Operator using client's website. In case of communication loss at either of the sides or if arm server breaks, the PLC disconnects from the website immediately and neither of the actuators will operate until the secured and stable communication is achieved. The flow chart of the remote robot System's website development is shown in Figure 3 and the PLC and computer connected runs on MODBUS/TCP protocol. To explain web security, HTTPS requests two items: Certificate (Authority) or TLS (where Certificate does the IP address verification and then the client server requests for authentication), and TLS, which does the encryption data process to transmit the data between sender and receivers in an encrypted form. Since this is an encrypted process, the potential attacker doesn't have the access to comprehend the data, resulting in the data being transmitted securely as it utilizes public key cryptography (PKC) or asymmetric key algorithm (an encryption technique). Since, it uses a paired private and public key algorithm for secured communication.[4]

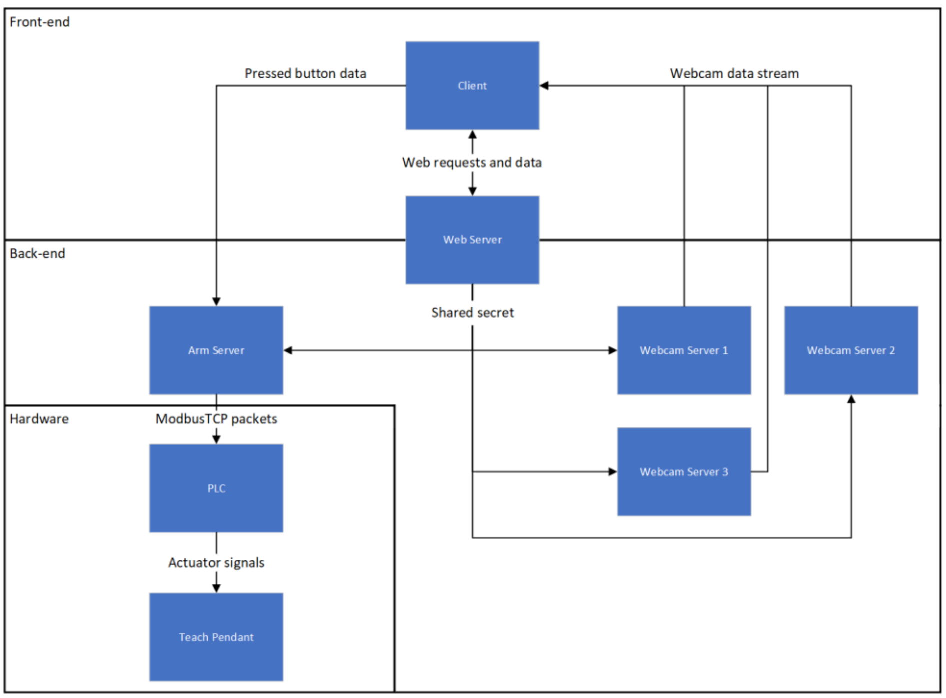

Figure 3: The flowchart of the backend programming for the remote robot system's web interface.

System Design and Solidwork Model

Designed in Solidwork, the remote robot system is dedicated to the teach pendant of FANUC LR Mate 200iC after analyzing the distance between each key and finding the suitable actuators available in the market. The middle plate is designed with circular openings to secure the actuators. To activate the robot motion, the special "Shift" key and "Deadman" three-way switch must be continuously pressed. To achieve this, the latching type actuators were selected. The designed model is shown from various angles in Figure 4.

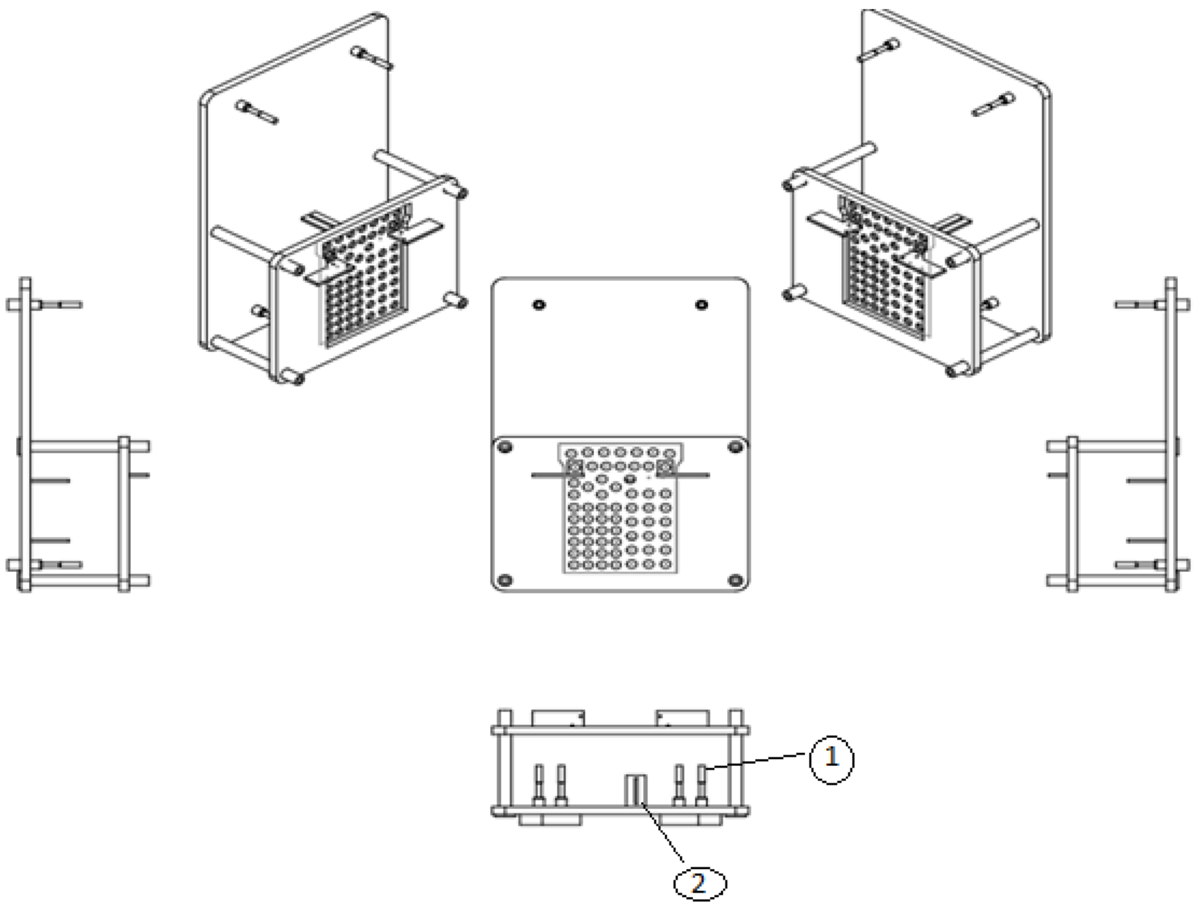

Figure 4: Solidwork model of the remote robot setup for the initial system without camera attached for the teach pendant display

The bottom plate holds the teach pendant, designed by using readily available screw holes on the back of the teach pendant. Four rods, shown by #1 in Figure 4 were attached to the plate to hold the teach pendant in place. Moreover, in order to press the "Deadman" switch using the latching actuator, the designed mounting plate, shown by #2 in Figure 4, is also added to the bottom plate.

The top plate is designed for the camera mounting, which shows the display of the teach pendant to the user. The top plate also acts as a protective cover for the teach pendant screen and reduces the amount of light falling on the screen of teach pendant to reduce glare and therefore provide better video quality to the client viewing the teach pendant screen. The outer layer of the top plate is used for mounting the DIN rails, "Click" PLC, relays, wiring cable duct, two power supplies and the inner layer for terminal blocks on DIN Rail. Moreover, in order to provide the protection to the operator, all the wiring is enclosed behind the glass sheet which is also mounted as a casing on the outside area of the top plate.

Components Description

The remote robot system components were selected after considering the size limitations, the force calculation on the keys in order to not harm the teach pendant keys or the "Deadman" switch but to still provide reliable operation over an extended period. The three latching type actuators were parallelly connected to drive enough current needed to apply necessary force through the relay mechanism to the "Shift" key and "Deadman" switch. It is calculated that 0.77A of current should be enough for the application considering the operating losses. The specifications of all the components used for the remote robot system are discussed in Table 1.

No.	Component	Description
1	Programmable Logic Controller (PLC)	The CLICK PLC C0-10DD1E-D with MODBUS/TCP capabilities from Automation Direct.
2	Power Supply for CLICK PLC	C0-01AC
3	8 Output Modules	C0-08TR with output current of 1A per channel.
4	2 Power Supply	MEAN WELL MDR-60-12 AC and MDR-60-24 AC
5	Push Type Actuator	Operates at DC 12V 0.77A to control teach pendant keys.
6	Latching Type Actuator	Operates at DC 24V 0.16A to control "Deadman" Switch and "Shift" key.
7	Din Rails	To mount the PLC, terminal blocks, and relays
8	Relays	1 OMRON Relay and 2 Automation Direct Relays
9	Terminal Block (TB)	Terminal blocks to connect the wires of the actuators with the PLC outputs
10	Wiring cable duct	To route wires wiring
11	Cable Tie	To wire all the actuators
12	TB Jumper	Shortening strips for the terminal blocks

Table 1. Description of components of the remote robot system

System Integration

The remote robot system setup is shown in Figure 5. Figure 5 (a) demonstrates front view of the hardware setup and consists of CLICK PLC, power supplies and relays. The inside view, provided in Figure 5 (b), shows all the solenoids controlling teach pendant keys and wiring approach with implementation of the terminal blocks. The description of all the PLC output connections with all the teach pendant keys via actuators on middle plate is shown in Table 2.

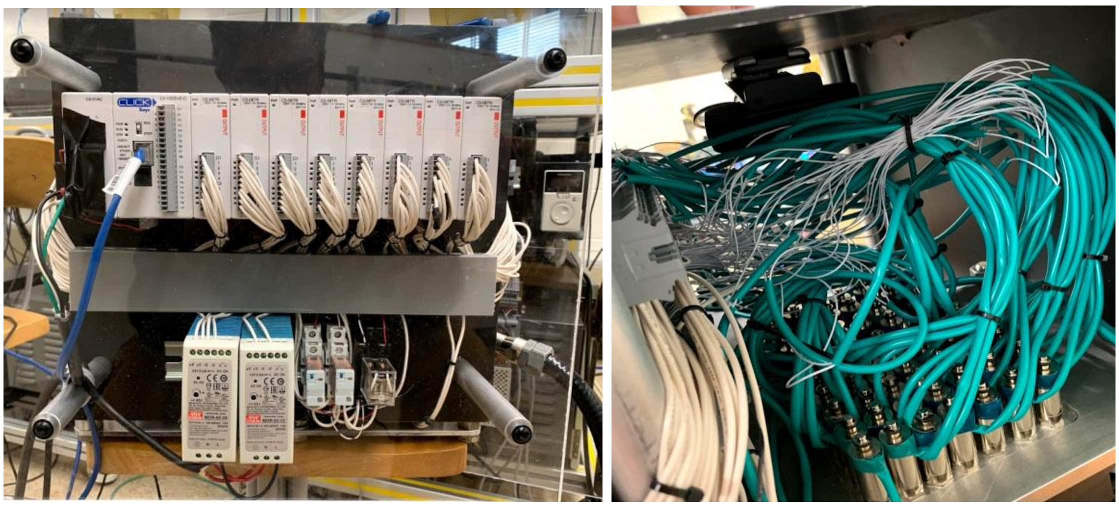

Figure 5: (a) The outer layer of remote robot which consists of CLICK PLC, Din Rail and its cover, 2 Power Supplies, 3 Relays and a sheet of glass to provide the protection, (b) The inner layer of the remote robot which shows all the actuators attached and wired up to the terminal blocks on the left which is connected to the PLC with white wires as shown and a camera attached on the ceiling

The PLC output modules[6] are the sinking type, which requires connecting the negative output of the power supply to the common of the PLC output modules, as shown in Figure 6. Therefore, for the push type actuators requiring 12V@ 0.77A supply, one end of each actuator is connected to the PLC outputs that were provided with the negatives of 12V, 0.77A supply and the other end directly to the positives of the power supply via terminal blocks that were used to connect the PLC output modules to the actuators with the wires routed through the protective duct. Table 2 provides the terminal block assignment with the respective actuators. To connect all the 'positive ends' of the actuators, the terminal block jumper is used to provide the 'positive ends' 12V, 0.77A to all those terminal blocks where 'positive ends' of the actuators were connected. Figure 7 shows an example of the wiring approach of one actuator used to control teach pendant key. An output of Y801 is connected to the negative terminal of the actuator with the positive terminal of the actuator is connected directly to the positive of the power supply #3. Similarly, all the other actuators were connected to the PLC except of output of Y101-104 being connected to 'negative ends' 24V, 0.77A, since Y101-103 were connected to relays A1, A2 and B. as shown in Figure 6.

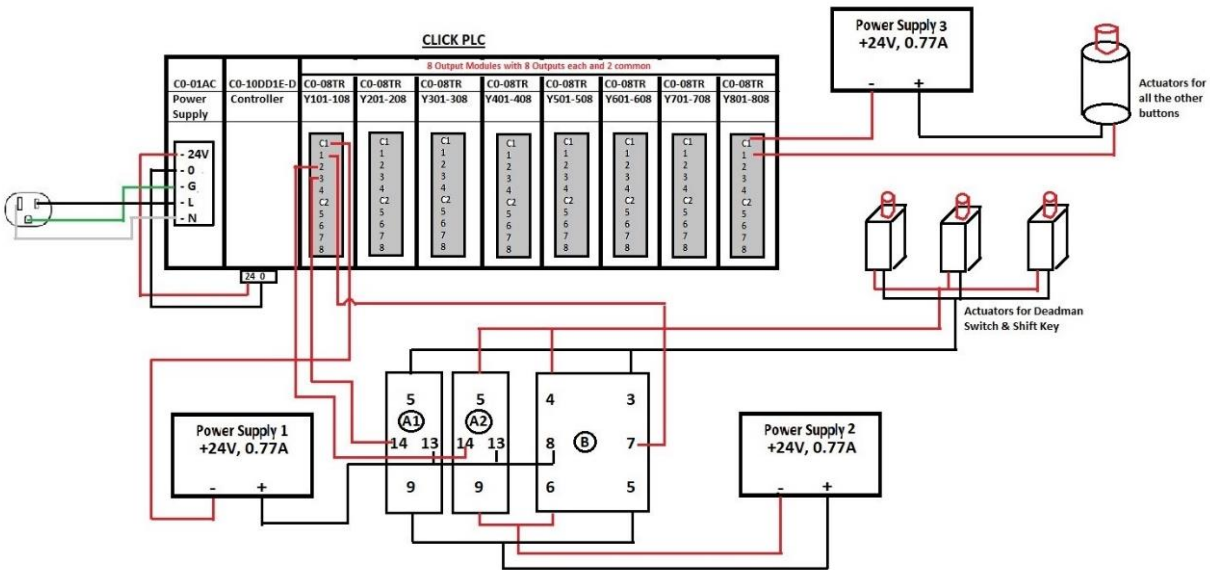

Figure 6: The wiring schematic for the entire system which shows the CLICK PLC, 3 latching type cuboid shaped actuators connected to 2 Power supplies and 1 cylindrical actuator, which represent all the push type actuators connected for all the buttons on teach pendant.

The latching type solenoids, connected to the relays A1, A2 & B, required actuation to simulate the operator pressing and holding the "Shift" key and "Deadman" Switch. Therefore, for jogging (movement of robot in the respective axis to which it is commanded to using the teach pendant keys) the Robot virtually, the operator needs to press the "Shift" key once on the simulated teach pendant, and the controller will actuate the latching mechanism. Similar operation actuates the Deadman" switch. Pressing again either "Shift" key or "Deadman" switch will release the latching mechanism and the physical components of the teach pendant will be disengaged.

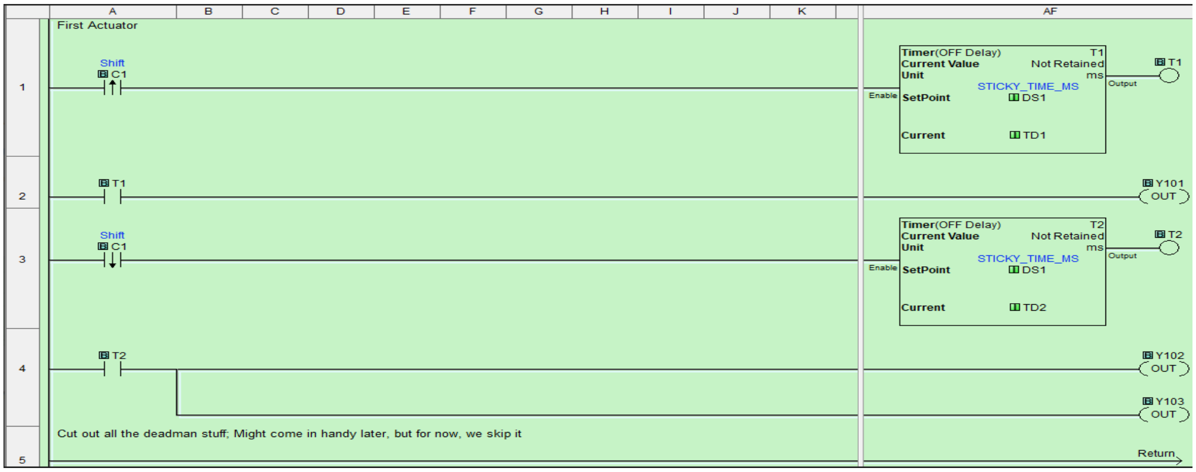

Figure 7: PLC code to press and release of "Shift" Key and "Deadman" Switch using rising and falling edge inputs of PLC program and Off Delay Timers

Additionally, latching type actuator extend in one direction, and even when power is removed, it remains in the extended position. To retract it, the pulse of reversed polarity is required. Relay B in Figure 6 provides main condition with the extended operation supply for the actuators, and to reverse the polarity of the actuators, the relays A1 and A2 were used. Three power supplies were required: two power supplies with 24V@ 0.77A and one with 12V@ 0.77A power supply, as shown in Figure 7.

The PLC program, shown in Figure 7, controls the "Deadman" switch. The "Shift" key uses "Timer off" instruction to delay the rung or that line of code. Moreover, if the signal breaks or the computer server gets disconnected, the actuators require a reset function. Figure 8 shows the PLC code, which ensures the reset capabilities of the actuators used for the "Deadman" switch and "Shift" key. To ensure the system's safety, the controlling program resets the signal after the signal has been absent for four seconds.

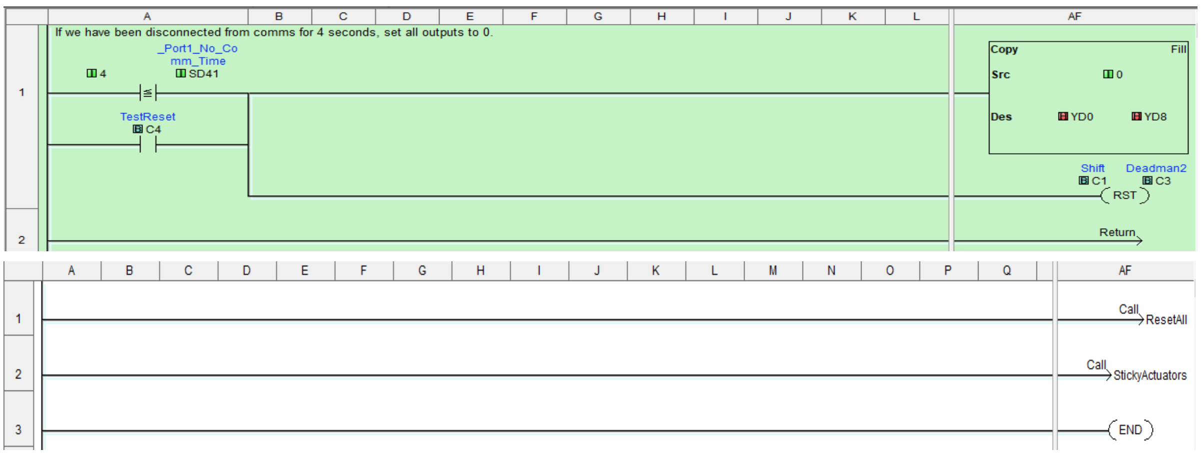

Figure 8: Security of SHIFT and Deadman Switch by using Reset All block for resetting the system if servers are disconnected for 4 seconds.

Remote Robot Control Panel

The user friendly website, designed to control the Robot, contains all the information needed for the Robot Operator. To maintain a secure system, access to the control panel is only provided to one computer/user at a time. If the controller is to open on any additional device, the program generates an error in loading the control panel page, as this could signal a security breach, posing a risk for the robot operation or for the operator's work.

The website is currently operated through a web link assigned to Michigan Tech's specific http address, which can be loaded only when the computer is connected to the PLC and the computer has access to the internet. The client needs to access the designated project website, select the time slot, and receive an approval from the administrator. The robot is tested out for proper operation before giving full access to the client. Once the full access is granted, the user has full control of the robotic arm that can be controlled using the teach pendant displayed on the screen. The two cameras provide real-time feed streaming the video of the robot and displaying the screen of the actual teach pendant, as shown in Figure 9.

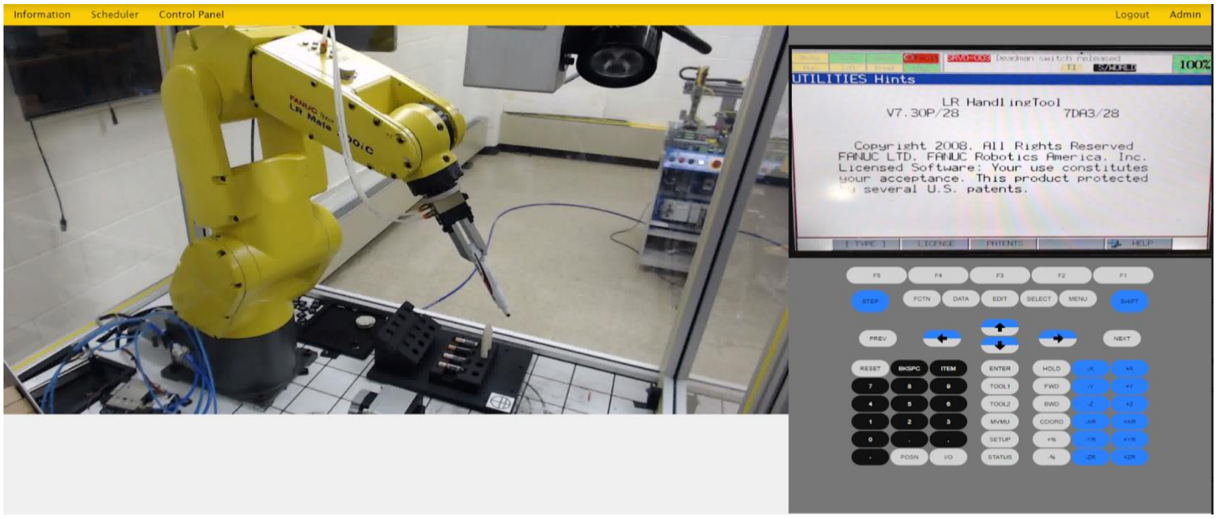

Figure 9: Client's view screenshot of the Control Panel, of a FANUC robot in the left via 1st camera and 2nd camera for teach pendant display as shown above the buttons on the right.

The website and the user interface for the website is designed after considering the FANUC proprietary and copyrights of the teach pendant. Neither the remote robot or Robot Run were designed to copy any of FANUC HandlingPro software. The project's motive is simply to help people learn more about the FANUC Robotics so they can visualize and practice, even if they lack enough expensive software or physical access to a robot.

Conclusion and Future Work

The Remote Robot hardware and software have been tested to ensure its full functionality. It has also been pilot tested by few undergraduate students at Michigan Tech. The students found the project very interesting and easy to learn by jogging and programming the real robot instead of performing it virtually. Most importantly, the users receive instant feedback from the real robot based on the input on the virtual Teach Pendant allowing users to learn firsthand FANUC robot programming skills. The full utilization of the Remote Robot is underway, and it is ready to be disseminated to a wide spectrum of users including students and researchers. With the help of the developed system, the users will be able to control the robot and develop their own scenarios through Robot programs.

For future work, the remote robot project will be extended to operation via tablet by developing the website and software options compatible for tablets and smart phones. Additionally, the visual feedback to the user can be enhanced by installing more cameras to provide multi-viewing angles of the robot.

Configuration of all the PLC outputs with Modbus Address

PLC Output	Teach Pendant Key	MODBUS Address	PLC Output	Teach Pendant Key	MODBUS Address
Y101	PRESS(SHIFT+DEADMAN)	16384	**Y501**	9	8352
Y102	RELEASE(SHIFT+DEADMAN)	16384	**Y502**	6	8353
Y103	RELEASE(SHIFT+DEADMAN)	16384	**Y503**	ITEM	8354
Y104	N/A	N/A	**Y504**	, -	8355
Y105	GROUP	8288	**Y505**	POSN	8356
Y106	F5	8229	**Y506**	3	8357
Y107	NEXT	8230	**Y507**	PREV	8358
Y108	DISP	8231	**Y508**	.	8359
Y201	+Y(J2)	8256	**Y601**	5	8384
Y202	-ZR(J6)	8257	**Y602**	2	8385
Y203	+XR(J4)	8258	**Y603**	7	8386
Y204	+Z(J3)	8259	**Y604**	4	8387
Y205	+ZR(J6)	8260	**Y605**	8	8388
Y206	+YR(J5)	8261	**Y606**	BACKSPACE	8389
Y207	+X(J1)	8262	**Y607**	1	8390
Y208	-YR(J5)	8263	**Y608**	0	8391
Y301	-X(J1)	8288	**Y701**	MENU	8416
Y302	-XR(J4)	8289	**Y702**	UP ARROW	8417
Y303	-%	8290	**Y703**	SELECT	8418
Y304	+%	8291	**Y704**	LEFT ARROW	8419
Y305	COORD	8292	**Y705**	RIGHT ARROW	8420
Y306	-Y(J2)	8293	**Y706**	DOWN ARROW	8421
Y307	-Z(J3)	8294	**Y707**	STEP	4822
Y308	BWD	8295	**Y708**	RESET	8423
Y401	HOLD	8320	**Y801**	F2	8448
Y402	STATUS	8321	**Y802**	DATA	8449
Y403	SETUP	8322	**Y803**	FCTN	8450
Y404	FWD	8323	**Y804**	F3	8451
Y405	TOOL 2	8324	**Y805**	F4	8452
Y406	MOVE MENU	8325	**Y806**	EDIT	8453
Y407	ENTER	8326	**Y807**	I/O	8454
Y408	TOOL 1	8327	**Y808**	F1	8455

Table 2: Addresses of the PLC Outputs with the teach pendant Key and MODBUS addresses

Bibliography

1. Global industrial robot sales prediction data, https://ifr.org/ifr-press-releases/news/global-industrial-robot-sales-doubled-over-the-past-five-years
2. Jacques Marescaux, MD, Joel Leroy, MD, Francesco Rubino, MD, Michelle Smith, MD, Michel Vix, MD, Michele Simone, MD, and Didier Mutter, MD (2002). "Transcontinental Robot-Assisted Remote Telesurgery: Feasibility and Potential Applications", https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1422462/
3. RobotRun Simulation software, https://pages.mtu.edu/~kuhl/robotics/
4. S.L.Garfinkel (1996). "Public key cryptography" *Computer (Volume: 29 , Issue: 6 , Jun 1996)*
5. Digi-Key solenoid manual, https://www.digikey.com/products/en/motors-solenoids-driver-boards-modules/solenoids-actuators/180?k=Pulse+Duty+Solenoid+Open+Frame+Latching+%28Push&k=&pkeyword=Pulse+Duty+Solenoid+Open+Frame+Latching+%28Push&pv14=127&quantity=0&ColumnSort=0&page=1&pageSize=25
6. Sinking and Sourcing Concept, https://library.automationdirect.com/sinking-sourcing-concepts/