Senior Design Project: Conversion of FANUC Robotic Arm to 3-D Welding Robot

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Abstract

This paper describes a project wherein a team of students were tasked with converting a robot designed and integrated as a material handling robot, into a robot with welding functionality. Involved with the project was the complete installation and design of the robot, work cell, safety equipment, and safety programming parameters. Along with this installation, the change to a 3-D welding capable robot requires the use of a welding unit with advanced controls. The use of a Lincoln R450 wire feed welding unit was initially proposed as a part of the scope of the project, but due to outside circumstances it was not officially included in the requirements of the project.

This project incorporates a wide variety of skills required by the students as it is by nature a project involving interdisciplinary knowledge. As this is the case, it will provide a platform for students across Michigan Technological University campus to experience an industry-like robotic work cell that is performing tasks on the very cutting edge of current technology. This provides not only a great benefit to the Michigan Tech community at large in terms of research and development capability, but to the recruitment and involvement of a wider variety of potential students or industry partners.

Introduction

The industry today is relying more and more on the use of robotics as companies look to automate their processes further. One common use for robots has been for welding. This could entail spot welding or welding of longer joints. Robots are perfect for automating the welding process as they have a high degree of accuracy and precision, repeatability, and speed. Performing across multiple shifts, day in and day out, allows for the process to be routine and standardized as opposed to the higher variability of having human workers. Currently, the use of robots for welding has been taken a step further as the technology has been developed for welding 3 dimensional objects from nothing [1]. Industrial applications today are increasing in their use of robots for a variety of processes. Students graduating from University having completed courses covering robotic materials are quite valuable to potential employers. The senior design program at Michigan Technological University is designed to provide students with a real-world project that emulates the work that would potentially be done in the student's future career.

This senior design project revolves around the FANUC robotics platform and provides an excellent opportunity for hands-on learning of the controls and functions of the robot. Robots in use today are used for a wide variety of processes including material handling, machining, and welding, as well as many others [2]. The welding robots are typically used for welding parts together at specified joints in such a way that allows for fast turnover time and highly accurate results [2]. This project involves adapting a robot designed for material handling, into a robot that has welding capabilities. However, instead of welding parts together, this robot is meant to create metal structures through a 3-Dimensional printing, or welding, process. This project was designed to be completed in two phases. As the robot that is being utilized is from a previous installation, all the decisions around safety considerations, mounting locations, required ventilation, and expected functionality had to be developed by the students for this application as a part of Phase 1. Essentially, the robot was disassembled and shipped from the previous factory, and then reassembled in the lab 329 in the Minerals and Materials (M&M) building. With the actions taken during shipping, one of the cables containing 34 signal conductors was cut. This caused some confusion at the beginning of the project and was a major focal point for gaining understanding as the project was initially discussed and presented to the students.

Obtaining the Robot

The robot itself was a part of a tilt table that is used in a foundry. The department of Material Science at Michigan Technological University was able to procure the robot for the purposes of it replacing some rudimentary 3D metal printing equipment used in lab 329 in the M&M building. With the change of ownership to Michigan Tech, FANUC, the original equipment manufacturer, has agreed to license the robot under Michigan Tech and give us access to the required software. With the requirements for ventilation with the welding process, new ventilation ducting and a previously installed, but not in-use motor for that system was incorporated above the work cell. There is a dedicated control switch for the ventilation system located in the back of the lab.

Fig. 1. The original location of the robot in lab 329 of the M&M building, as it had been delivered from the Lyft factory.

The Robot

The robot is a FANUC R-1000ia/80F model, was initially set up for material handling. It was used along with a melt controller that, through a series of input and output signals shown in Figure 2, told the robot when it was appropriate to carry out certain actions, consisting of “Get Metal”, “OK to Pour” and “Ready to Extract.”

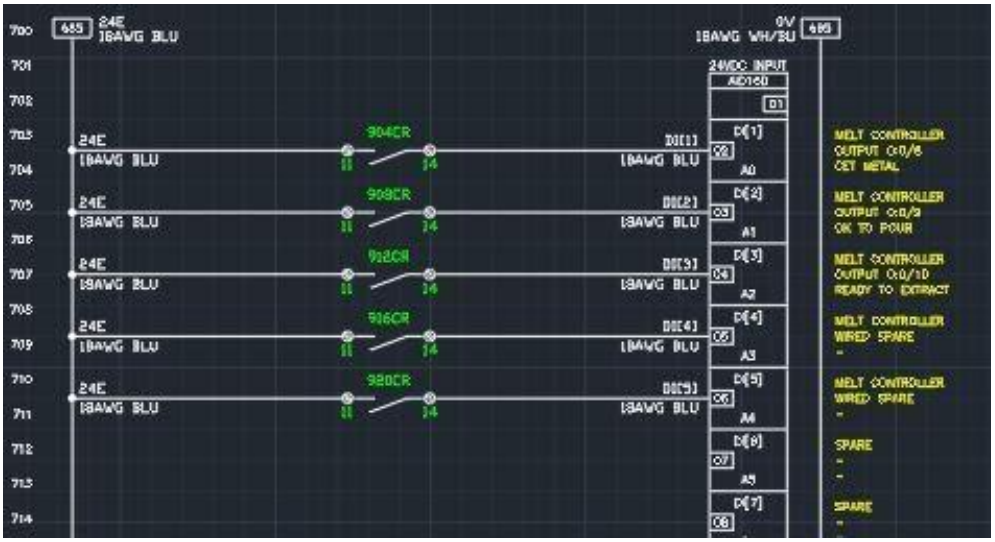

Fig. 2. The PLC input wiring diagram as provided by FANUC with the R1000-iA/80F robot. The inputs shown are used in conjunction with a melt controller for the previous application.

The melt controller was also tied in with the robot’s safety circuit as shown in the electrical diagrams in Figure 3. In the original setup, the melt controller had an emergency stop circuit as well which was connected into the External Emergency Stop (EES) circuit on the robot. The robot in turn sent out its safety circuit outputs to the melt controller through the External Emergency Stop Outputs (ESPB) circuit. Currently, the robot can be operated with only the contacts on the EES circuit being used. As these are the input contacts to the safety system, they need to be wired for the robot to function. The EES circuit is a dual-channel safety circuit. This requires the use of two separate contacts on each of the emergency stop push buttons. The dual channel requires that both sets of contacts be operated simultaneously. If the channels do not receive the signals within a specified time period, the circuit fails and causes the robot to enter a faulted state [3].

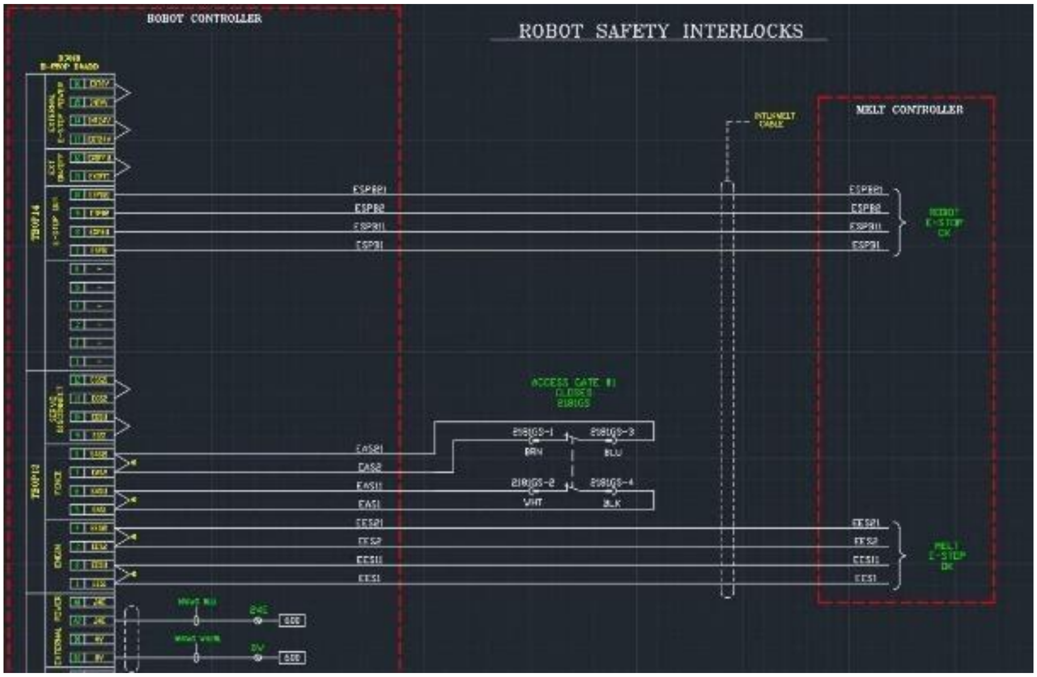

Fig. 3. The safety interlock wiring diagram as provided by FANUC. The previous application used a melt controller which had safety inputs and outputs tied together with the robot controller as shown. The gate interlock circuit is also shown.

This type of robot is used for procedures such as palletizing materials or moving materials from one location to another [2]. Fanuc has other similar robots in the R-1000ia family that are commonly used for welding applications in the automobile and aerospace industries [2]. That type of welding is mainly for connecting parts at specified joints in which the robot can continuously repeat the same action with a high degree of precision and accuracy [2]. The objective is then, to convert or adapt the current robot set up for material handling, to be able to carry out welding processes instead. Through reconfiguring the required software and adding new software programs, as well as some mechanical changes, that goal is attainable.

The capabilities of the robot's servo motor in terms of the accuracy and precision of movement, in conjunction with the ease of programming has made this robot a great choice for conversion to a 3-D welding process [2]. The use of robots for 3-dimensional welding is an extremely new process that is still under development. However, the advancements in robotics have allowed for user-friendly programming interfaces that control the robot with a great deal of precision, accuracy, and repeatability [2]. In comparison with the more primitive technologies currently in lab 329, the upgraded robotic platform presents much more flexibility in the movement patterns, programming options, and available functions. This, along with an advanced welding control unit from Lincoln Welding has made it possible to manufacture 3-D welded parts that are then able to be machined down to the exact specifications. The advanced controls on the welding unit help to create parts that are solid and durable, without defects in the overall integrity of the structure. This is what allows for the machining process to occur to bring the parts to within specification.

College of Computing Collaboration with Materials Science Department

The Materials Science department currently has equipment capable of the 3D welding process. However, in terms of what the equipment can process and output, it is very rudimentary in comparison to what is currently being developed using robotic platforms. The current equipment runs off a CNC 3 axis platform. The equipment is not capable of controlling weld temperature and has limitations in its precision and accuracy due to the mechanics of the mechanical system used to move it. The robot provides a major upgrade in its speed, precision, and accuracy with the high resolution of the servo motors as well as the added movement through the addition of more axes when compared to the existing equipment [2]. The FANUC robotics platform is designed as a user-friendly, adaptable solution [2].

The Electrical Engineering Technology (EET) Department currently has a strong curriculum in robotics training, specifically on the FANUC platform. Due to the greater push for robotics in industry and automation processes, the department has increased its focus on these areas. The project required by the Material Science Department provides an excellent opportunity for students in the Senior Design program to implement their skills in a highly relatable way. Required with the project calls for making an analysis of the physical dimensions of the laboratory to decide where the best location to place the robot would be. Correct machine guarding and safety measures needed to be studied, decided on, acquired, and installed. Approval from the Department of Health and Safety on the layout and design of the safety equipment, protocols, and lab overall, was also required.

The scope of this project mirrors the way many projects in industry are developed, planned, and executed. Allowing the student to experience a real-world application of their skills is a vital part of not only instilling confidence in the student, but also as a proof for the department in the validity of their curriculum. Incorporating the EET department into a project for the Materials Science Department allows for multiple projects, across future semesters by the interdisciplinary nature of the 3D welding process and the use of the robotic platform. The initial configuration and installation being handled by the EET students made it possible for future students to utilize the robot for learning to operate the robot and incorporate skills from other disciplines to accomplish the 3D welding process. Projects in the future can be aimed at accomplishing the tasks laid out in the Progress and Preparation for Future Students sections.

Safety

As safety is of the utmost importance, the number one priority was to design the work cell to be as safe as possible. The Department of Health and Safety (D.H.S.) on campus was contacted to tour the lab and verify the safety of the work cell and laboratory layout. Currently there are only general lab safety training courses available and developing the safety protocols was outside of the overall scope of the project. In the current form, the lab safety training provided by D.HS. is adequate to be in the lab to learn about the robot. The specific protocols and procedures relating explicitly to the robot need to be created.

There is a six-foot-tall fence that encompasses the entirety of the robot, controller cabinet, welding controller and equipment, as well as a worktable, see figure 4. The fenced area is 9’x10’ and has an access door centered towards the front of the lab. The access door has a magnetic safety switch that will indicate when the door is shut or open [5]. Next to the door is a space for the controller cabinet. On the cabinet is the first of four emergencies stop switches that are located around the perimeter of the work cell. The emergency stop switches are wired into a dual channel safety system located on a printed circuit board on the inside of the controller cabinet (see figure 3 for wiring diagram). The dual channel requires two separate contacts to close simultaneously, meaning redundancies in the emergency stop button contact arrangement. This arrangement provides for maximally safe conditions in that if one of the two circuits fails for any reason, the robot will fault and will not be able to move until that fault is cleared from the teach pendant and the emergency stop system is reset.

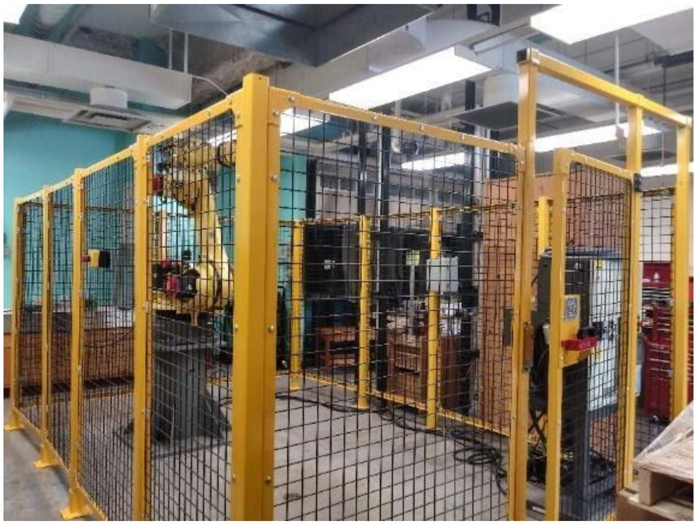

Fig. 4. The final layout of the work cell. On the left of the image is an example of the emergency stop push buttons

The robot has many safety features that can be utilized by the user. During the teaching process, in which the movements and tool locations are taught to the robot, the controller must be switched into T1 mode with a key switch on the face of the controller cabinet. When the robot is in this mode, the door interlock circuit is disabled, which allows the operator to go into the work cell [3]. It also limits the speed of the robot to 50% of its capabilities to ensure operator safety. The robot has full speed capabilities when the key switch is placed in the AUTO mode [3]. The AUTO mode also enables the circuit for the emergency gate switch used to monitor if the work cell door is open or closed while the robot is in operation [3]. The movements and locations are programmed through the teach pendant, on which are two dead-man switches. One of the switches always needs to be pressed while programming and moving the robot. This ensures operator safety by forcing the operator to have a grip on the teach pendant. If for some reason the switch is let go of, it immediately stops power to the robot servo motors and places the robot in a faulted state.

System Description and Main Objective

The overarching purpose of this robot is to aid students research and development capabilities in the Material Sciences department, as well as the rest of the campus. The main objective is for the robot to be used to create 3-dimensional metal structures in which the robot will "print" them out through a series of sophisticated programming interfaces. The robot will be used in conjunction with a Lincoln wire feed welding unit that has advanced controls to monitor and control the various parameters including temperature of the weld. Creating machinable 3-D parts requires control over the temperature of the weld so that it can continue to build upon the previous layers. Below, is an example of a robot designed for and integrated with the Lincoln welding equipment as a 3D welding robot, see figure 5. The Lincoln welding equipment can utilize pulse control to manipulate the current needed to produce the weld [4]. This speeds up cooling time, allowing the robot to continue printing without pausing, or creating catastrophic failures in the integrity of the structure it is printing.

Fig. 5. A FANUC robot designed for an integrated with a Lincoln welding unit for 3-D welding projects.

Aside from its main objective, the robot will help students learn interdisciplinary skills by incorporating robotics as well as material sciences. As the ability to understand the materials being printed, the software used to program the part, the software to interface with the robot, as well as the controls and software that is operating the robot itself. This variety of skills is not only useful to the student, but also makes them much more valuable to the industries they work in.

The robot alone is also an interesting technology that not many people are able to see in action. By incorporating the robot into school or department tours, it will inevitably spark interest from the public and those who see it, which will help the overall community of Michigan Tech to continue to thrive. The work cell looks very similar to what would be seen in an industrial environment, allowing students and others to get a real, first-hand look at what this technology is capable of and how it is being used in industry today.

Progress

The first goal was learning about FANUC robots in general, how they function, what they do, and what industries are using them. The robots come from Fanuc, basically ready to operate. Once a location for the robot and the work cell was determined and installed, only a few cables are required to be able to power up the robot and look through the various menus and settings on the teach pendant.

The major faults, as shown in figure 6, show that the backup batteries on the robot, which store the servo-motor location information, had died, and needed to be replaced. The necessary steps to replace the batteries and reconfigure the home or reference locations of the servo motors through a "Mastering" process were completed. The robot has indicator marks for each of its axes. When the robot was able to function, the Mastering process involves jogging each joint the location specified by the indicators and going through a few steps with the teach pendant to re-teach the reference locations.

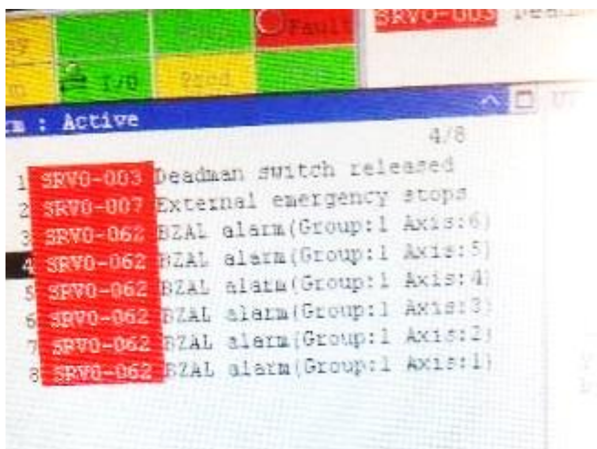

Fig. 6. The errors shown relate to the Deadman switch being released, the external emergency stop circuit, and the servo positioning information, respectively

The work cell has been put together and the emergency stop buttons have been mounted around the perimeter. A junction box that will be used for wiring the emergency stop circuits was also installed. The cable that has the PLC input and output wires, PLC spare wires, and safety circuit wires, has a total of 34 individual conductors in it. As most of them are not needed for this application, incorporating a small junction box, shown in Figure 7, that the conductors can be terminated on the terminal strip. It will help for any future changes as the wires are all connected into terminal blocks that can be easily wired to any new equipment.

Fig. 7. The junction box and terminal block strip inside it meant for the 34 conductors from the cut cable coming from the controller cabinet.

A worktable was designed that was to be built by the machine shop located on the first floor of the M&M building, shown in figure 8. Once completed, it will be set in the work cell to be used by the robot. It is 4’x4’ and 30” tall. It should provide a stable work area for the robot to use. This work completes Phase 1 of this project.

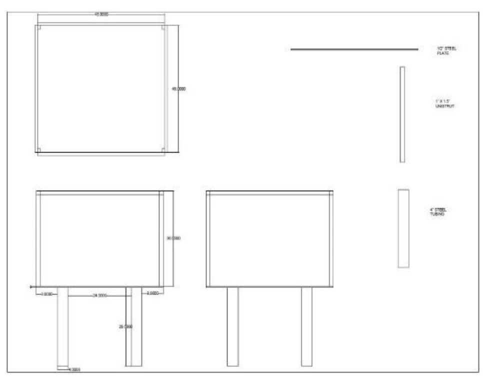

Fig. 8. Design of the robot worktable with mounting strut for the welding light curtain.

Phase 2 Preparation and Future Work

As it stands, the items left to complete are

1. Running a conduit from the junction box to the 3-emergency stop push buttons.
2. Ordering and adding the Normally Closed contacts and wiring the stop switches.
3. Wiring the remaining cable into the junction box.
4. Mounting and connecting the magnetic door switch to the door.
5. Installing a separate 480-Volt outlet for the welding equipment.
6. Installing the software from the flash drive from FANUC. Setting up the necessary DCS parameters.
7. Creating the safety training procedure for the robot.
8. Unpacking, installing, and connecting the Lincoln welding equipment.
9. Teaching User-Frame and incorporating tooling with the robot.

Moving forward with the project would involve future students completing the work where it left off in Phase 1. This would include completing the wiring of the emergency stop push buttons. As well as completing the software upgrades and inputting the required DCS parameters. The DCS parameters are potentially very involved to set up in that each axis has a variety of limits that can be placed on the position and the speed. These parameters can also be setup in the World or User frames in such a way that it limits the robots speed and positioning as a whole according to the X-Y-Z plane. Direct supervision by the lab director or supervisor of the input parameters to the required functions is suggested.

Conclusions

The Senior Design program at Michigan Technological University for the Electrical Engineering Department is designed to give students an opportunity to be exposed to industry experience while in school. This Senior Design project revolved around the installation and configuration of a Fanuc robot in lab 329 of the M&M building for the Materials Science Department. Although this project was not centered on a specific industry partner, it provided the same experience in working with industrial equipment and creating an industrial environment within a laboratory setting. The scope of the project was such that the students needed to adequately research the FANUC robotics platform as well as the safety equipment and procedures required for an industrial robot work cell. This adequately mimicked the industry experience.

The knowledge of robotic platforms is extremely valuable in industry today. Not only operating but having installed and configured a robot is an experience that will be helpful moving forward into other, larger projects in future careers. This project will help the community at Michigan Technological University in multiple ways by incorporating more interdisciplinary skills, bringing the research of students to the cutting edge of technology, and peaking interest in a rapidly expanding industry.

References

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