AC 2009-1400: A COST-EFFECTIVE ROBOT WORK CELL

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Cost Effective Robot Work cell

Abstract

This paper describes the design and construction of a cost effective robot work cell using an integrated software system. Surplus industrial cylindrical coordinate robots were updated with new electronics and software as well as tooling. A vision system was integrated using inexpensive USB cameras and a "shareware" vision software system was integrated into the robot operating system.

This system uses readily available tooling adapted from common appliances such as hand drills and hot melt glue guns to emulate common industrial processes. The work cell can be easily duplicated at low initial cost and ongoing maintenance. Undergraduate student teams were integrated with graduate students to design and build the system.

Introduction

This work was sponsored through the Graduate Fellowship Program of the Oregon NASA Space Grant Consortium. At the onset of this project the Mechanical and Manufacturing Engineering (MMET) department at the Oregon Institute of Technology had just a handful of functioning robots, even fewer robotic work cells, and none which were fully capable of simulating manufacturing assembly processes. This scenario left the MMET department with few real-world tools with which to educate undergraduate students on topics of current importance to manufacturing such as agile assembly systems, flexible work cells, virtual simulations, robotics and robot integration. The following project was thus commissioned in June 2007 to build a functioning robotic work cell to address this need.

A robot platform similar to the one we will build could easily cost tens of thousands of dollars for new equipment but with this project we would prove it could be done for considerably less money. To keep costs low we first located several obsolete but mechanically functional robots known to be available at OIT. We then planned to retrofit the robots with a modern PC-based control system and build tooling in-house to complete the project. The budget was initially $5,000 but in the end we only used about half that to fully complete the work cell.

Through a quick survey of the functioning robots in the MMET department we selected a pair of functional but electrically obsolete cylindrical coordinate SCARA robots that were donated to OIT. As we later learned these robots were manufactured by Seiko-Epson circa 1987 and used for discrete electronic component assembly processes in an industrial setting for several years before they were donated to OIT with their respective control systems and one complete work cell. The Epson robots were a perfect match for the project requirements as they were unused by the department, had a relatively small number of control axes, and were electrically and mechanically sound.

Although the two robots were identical only one of the robots was in a complete and functional work cell, see "Monica" in Figure I. The other robot 'Lisa' had been stored intact on a small platform, see figure II. As our project began we discovered that the work cell for Monica was still semi-functional using the original controllers. As part of the existing control system there were several saved programs on digital cassette tapes which could be run by this work cell. These programs consisted of simple point-to-point programs which literally picked up pennies from a parts feeder and dropped the coins in a bucket in another part of the work cell, see figure III. Although these programs and the work cell were functional, the equipment was not readily usable by undergraduate students due to lack of programming interface documentation and semi-functional control system. Additionally the end effectors of the robots, which consisted of simple pneumatic grippers with a rotational axis supplied by an additional servo, were in need of repair.

The idea of a functioning industrial work cell would have been somewhat incomplete without a system to direct parts into and out of the work cell. Although the original work cell had a simple conveyor system built underneath the main assembly robot it had several drawbacks including the fact it was missing several drive belts and had no positional feedback. We decided something better could be done to solve this problem and developed the idea to build a robot which could deliver bins of parts to and from the work cell. For this we enlisted a team of senior mechanical engineering students to develop the delivery platform as a senior project. Creating guidance system software in addition to the robot platform was simply beyond the scope of a mechanical engineering senior project so we enlisted an undergraduate student majoring in computer software engineering to help develop the needed software through a Microsoft Robotics Studio service and an overhead vision system. And so with these teams in place we proceeded forward on the project.

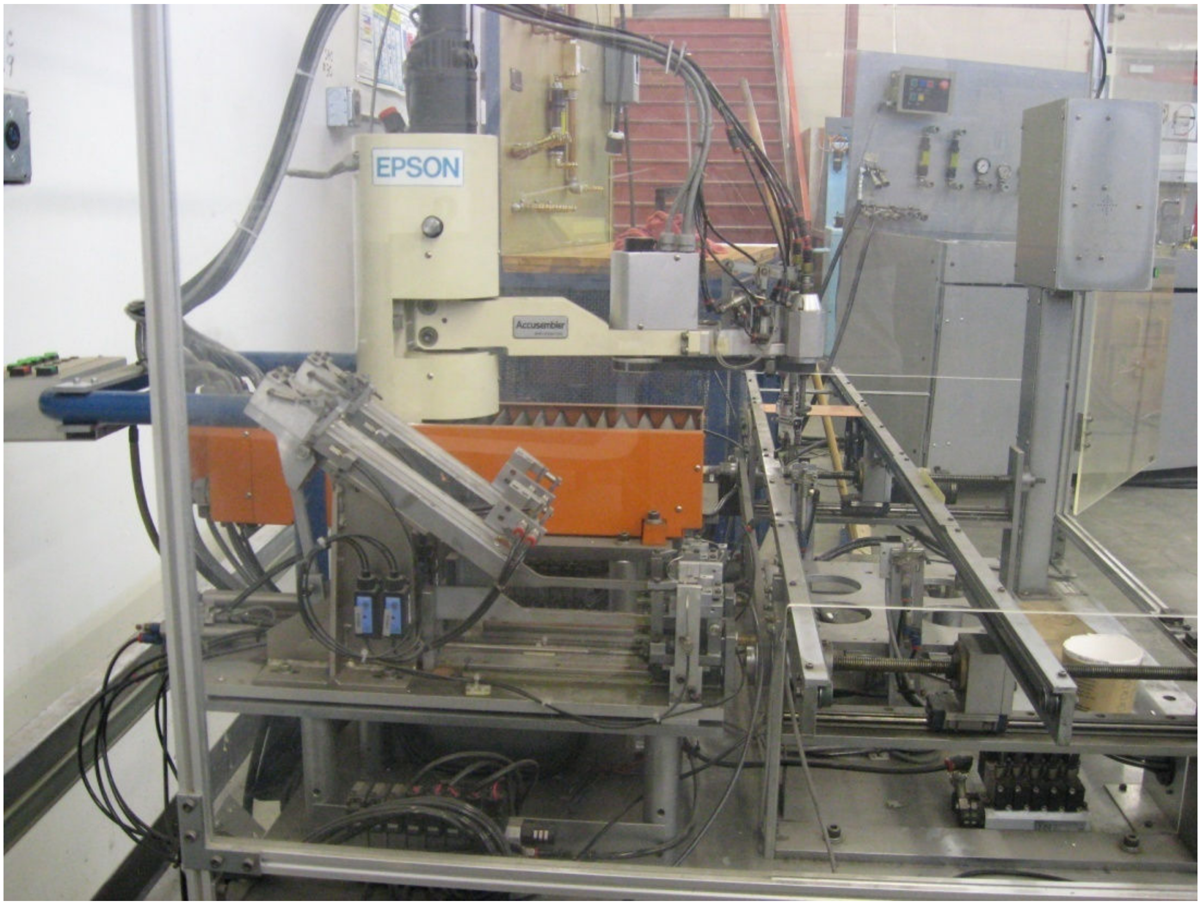

Figure I. ‘Monica’ Robot in Factory Original Work Cell

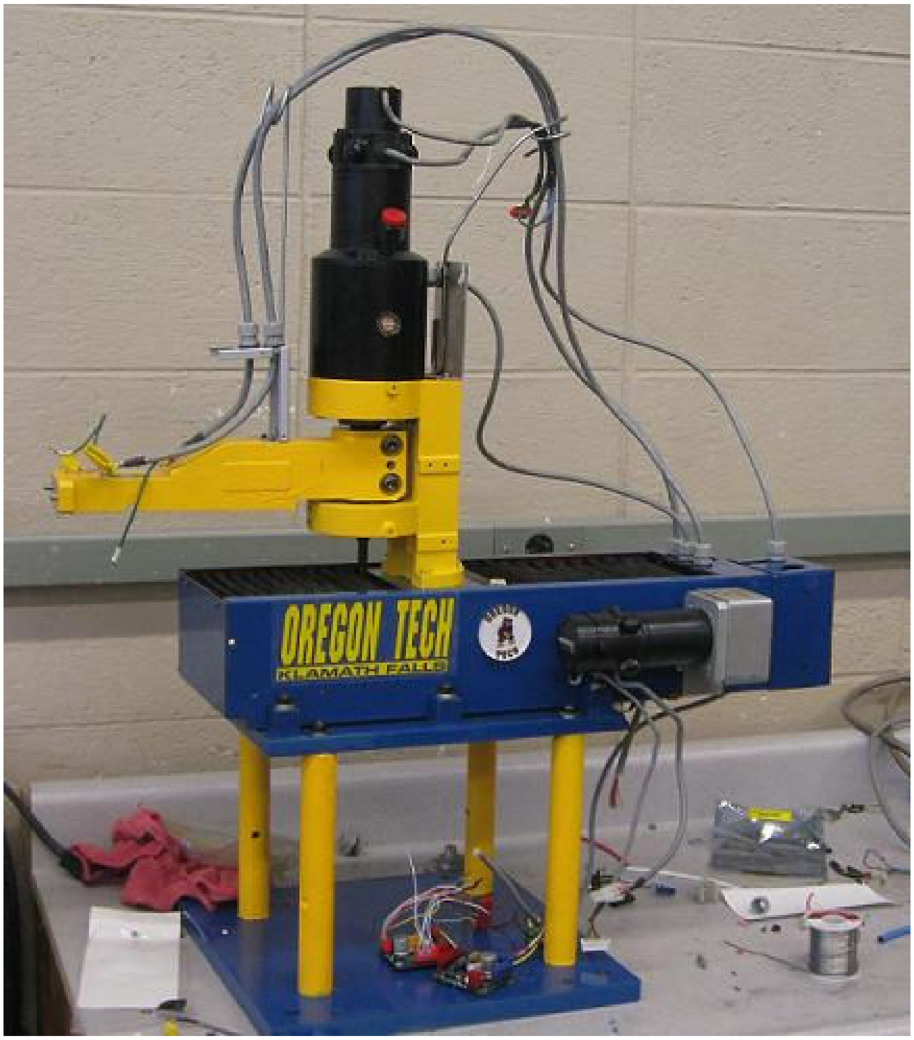

Figure II. Lisa with new paint.

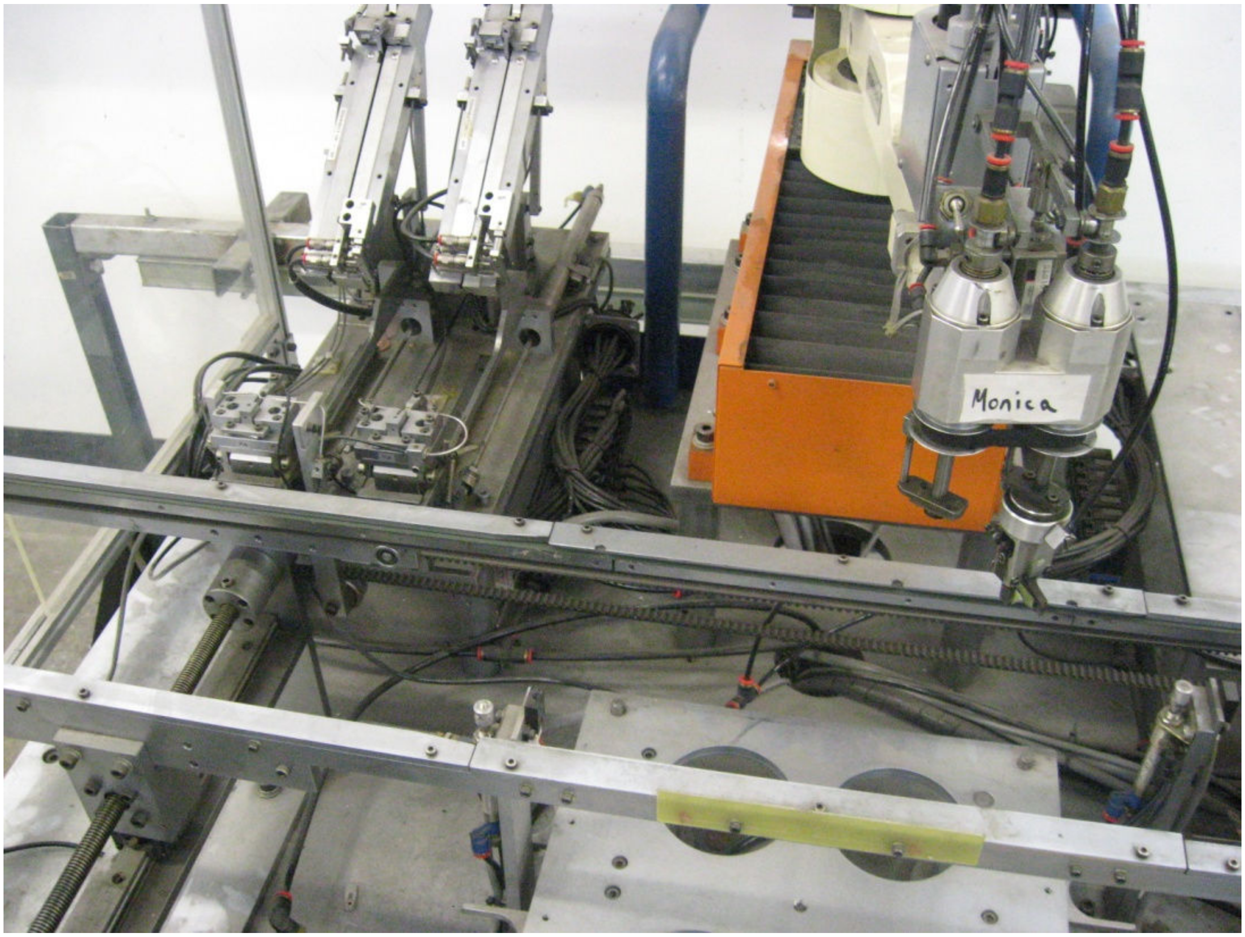

Figure III. Original Tooling and Parts Feeders.

Mechanical Design

We began the mechanical design portion of the project working with Lisa, the robot independent of the work cell. This way if the project went awry we would not lose a functional work cell and we could retain one robot in its original condition. As the robots and work cell were of considerable age and donated many years earlier we found very little in the way of documentation and information. With this in mind we began disassembling Lisa while simultaneously building a solid model of the robot using measurements taken on the robot. The servomotors installed on the robots were of particular interest due to the difficulty and cost of switching to modern motors. We wanted to use as much of the existing robot hardware as possible to keep total project cost at a minimum.

The solid models of the robots were created using Solidworks 2007 because there are simple tools in place to eventually import the models from Solidworks into Microsoft Robotics Studio 1.5 for later virtual simulations. We built complete solid models from the base of the robots to the blank end effectors on the robot arms to make mechanical design and virtual simulations easier as the project progressed. Once the solid models of the robots and work cell platform were completed we began to redesign the end effectors of the robots, see figure IV.

As noted earlier the original robot end effectors were simple pneumatic controlled grippers with a rotation axis supplied by a servo and belt drive system. The tooling needed for flexible assembly operations was unlikely to be served well by these existing end effectors and would need to be redesigned and replaced.

For the purpose of building a manufacturing assembly cell we would need one robot which could grip or lift parts onto fixtures while a second robot performed machining and assembly functions. The machining and assembly tooling would be based around a hot-melt glue gun and inexpensive dremel-style tool for deburring operations, see figures V and VI, while the pick-and-place robot would be served by more standard robot tooling.

Multiple tooling on the robot end effectors was decidedly more effective if the tooling could be independently utilized and controlled, thus we would need a mechanism to enable each of the robots to hold and select multiple tools. Fortunately a turreted tool holder was discovered on another robot after a quick search through a pile of 'scrap' robot hardware. New tooling and controls were designed and fabricated around this turret to mount the hot-melt glue gun and dremel. Finally, the hot melt glue gun was fitted with a pneumatic cylinder to feed sticks of glue through the gun.

The tooling for the second robot, 'Monica' would then need to lift and manipulate parts. We decided to keep costs low by utilizing off-the-shelf robot parts, electing to use an SMC robot gripper and generic vacuum cups, see Figure VII. To enable selection of multiple tooling we designed a simple swing-arm to raise and lower the vacuum cups out of the way of the pneumatic gripper. With this simple and effective tooling we could manipulate items ranging from cylinders to rectangular blocks to thin sheets of material.

It was obvious at this point that the robots would be difficult to use with tooling simply bolted onto the robot 'elbows' as the robots had two axes: a linear slide and vertically rotating shoulder joint. In short we would need to further develop the end effectors of the robots to have at least one additional axis of movement. To do this we used four linear bearings and a pair of acme threaded shafts from salvaged and obsolete printing equipment. These linear bearings and shafts were easily re-used to provide a third axis enabling the end effectors to move vertically, see figure IV. As we had a pair of extra servos from removing the previous robot end effectors we also re-used these motors for the new end effectors as well.

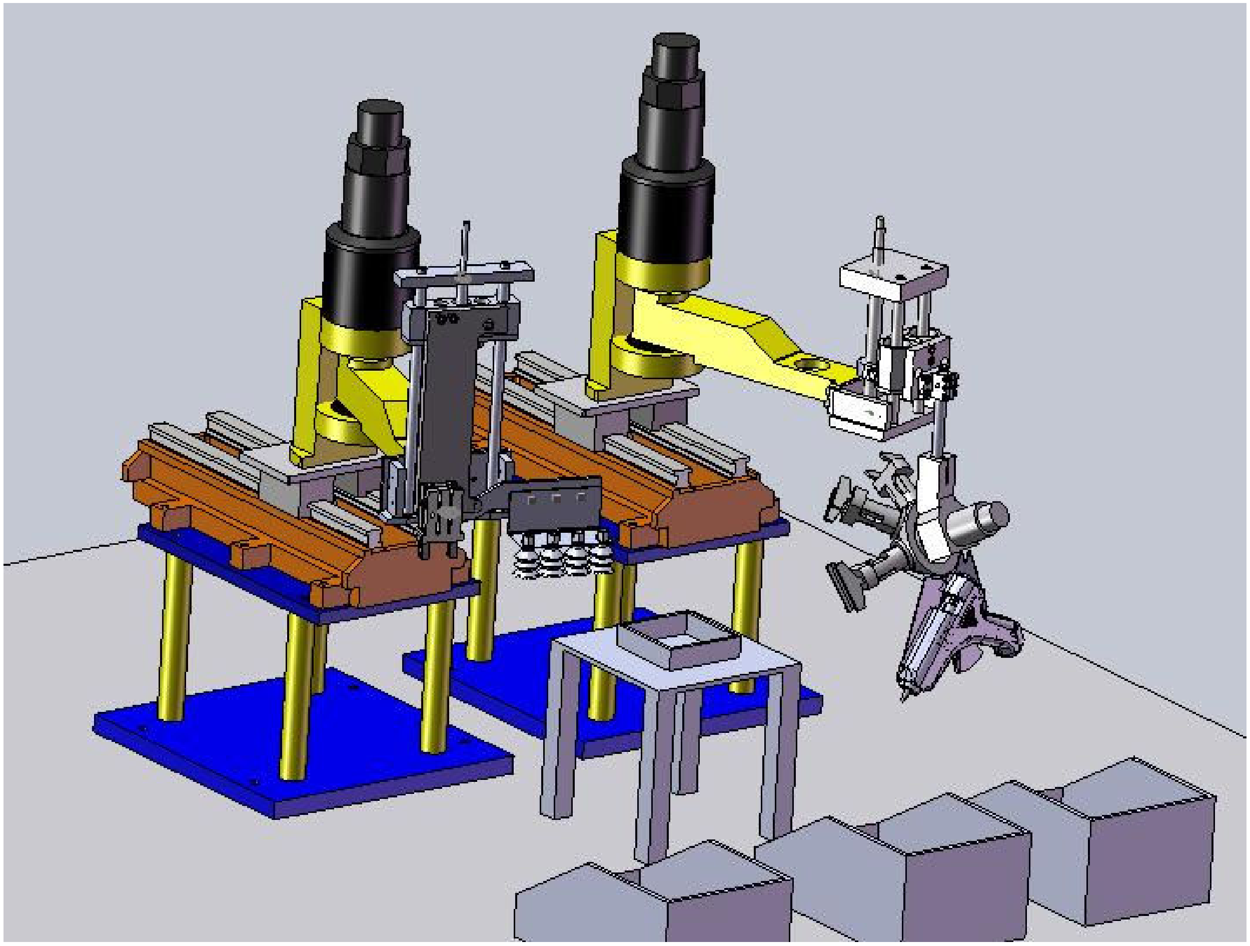

Figure IV. Robots in Virtual Work Cell.

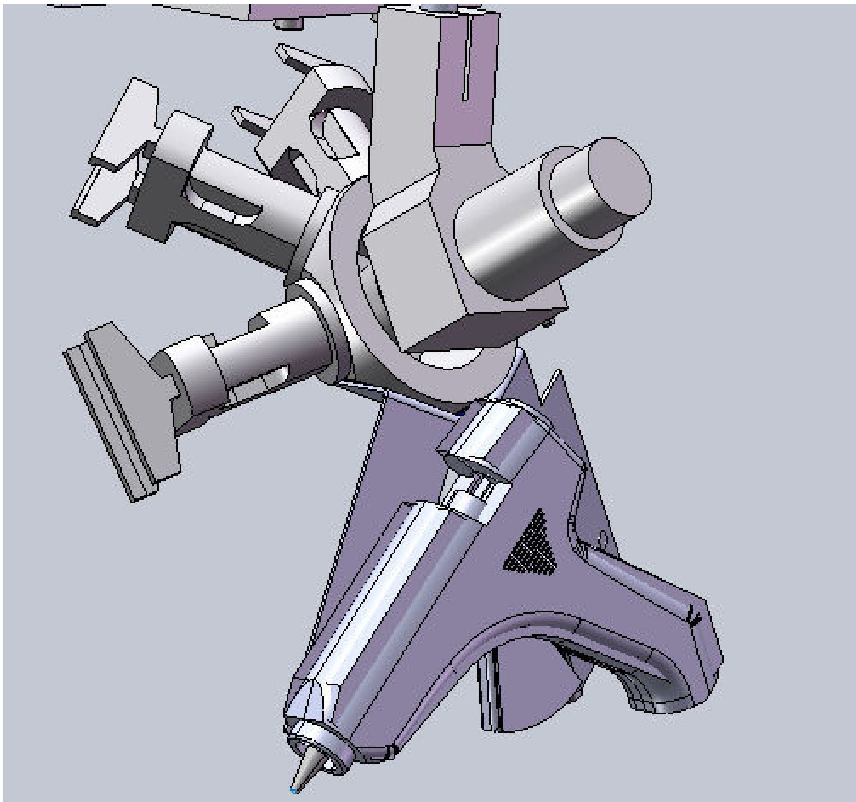

Figure V. Hot-melt glue gun on tooling turret.

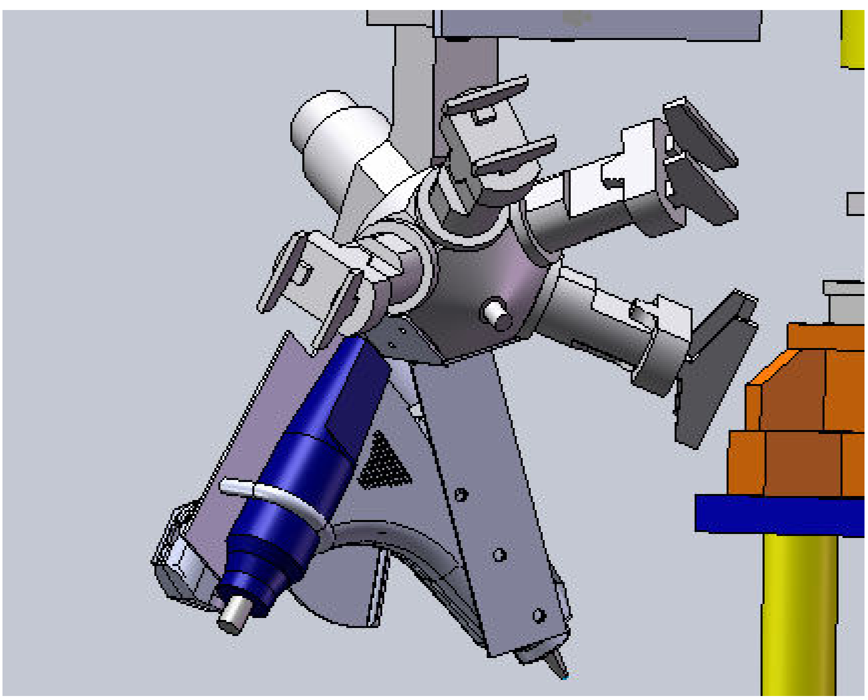

Figure VI. Dremel on tooling turret.

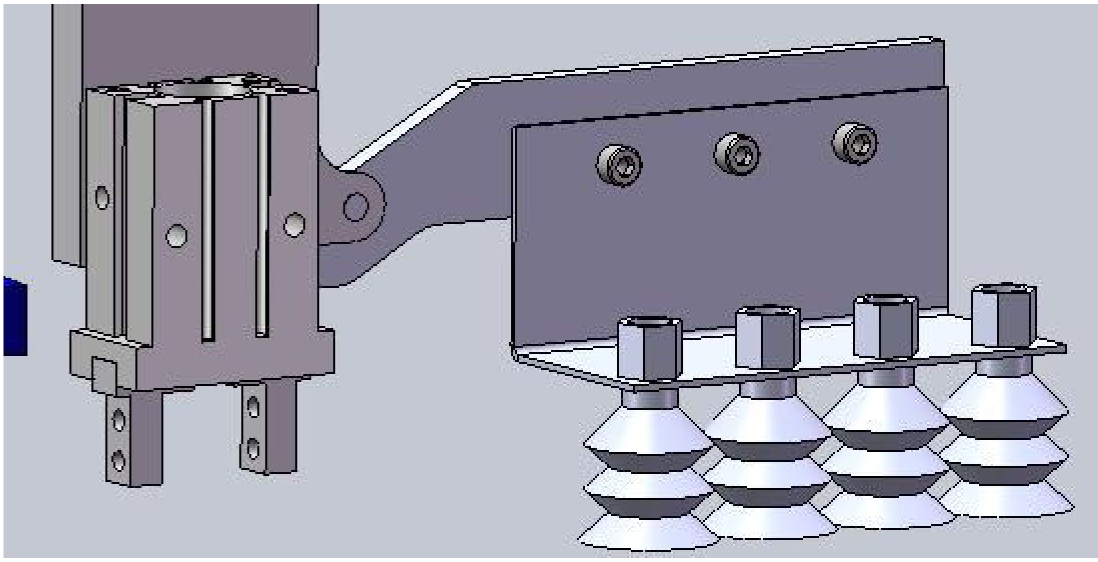

Figure VII. New vacuum cups and pneumatic gripper.

Electrical Controls

The original control system for the work cell consisted of five large rack mount cabinets located underneath the robot platform. The cabinets, weighing in at ~50 pounds each, contained all the necessary processors and electronics to drive the servos, pneumatic actuators, and conveyor system of the work cell. As mentioned earlier the original control system also relied upon audio cassette tapes for storage and recall of robot programs through a teach pendant. All of these control systems needed to be replaced to meet the project requirement that the work cell be controlled via software running on a modern PC.

The most fundamental system needed for a functioning robot is the control system of the robots servos and actuators. In the case of our work cell these systems were based upon older 24VDC servos manufactured by OEM's Yaskawa Electric Manufacturing Company and Harmonic Drive LLC. All other automation in the work cell contained pneumatic cylinders and pneumatic motors controlled by 24VDC solenoids. With a little research we obtained product manuals from the servo manufacturers with wiring diagrams and motor specifications for the servos.
At this point the decision was made to base the control system of the work cell on a 24VDC bus for two main reasons: the stock robot servos ran most efficiently at 24VDC and 24 volt automation systems could be easily obtained. We therefore purchased a single large power supply for the work cell, an Automation Direct PSM24-600S. This power supply gave us 25A of working current, which according to the power budget, see figure VIII, is almost enough current for four large servos and three small servos to operate at maximum current concurrently.
Next we located servo motor controllers. As it turned out these were fairly expensive and we found limited selection due to the prevalence of newer AC servos and scarcity of DC servos. We eventually selected EZSV23 controllers from Allmotion.com, see figure IX. These controllers could handle 5A of current at up to 40VDC and were compatible with the existing servo encoders. As an added bonus the EZSV23 controllers also had two auxiliary programmable 1A outputs and inputs which enabled us to host a variety of instrumentation and other controls that

we would need for our work cell. After the controllers arrived we discovered through experimentation that the EZSV23 controllers worked great with the smaller servos but were overloaded while powering the largest servos. Even with power resistors in line with the motor coils to reduce current demand it was not feasible to use the EZSV23 controllers for the larger servos. Thus we had to select a secondary set of controllers which could handle larger current demands, eventually deciding to use Syren25A controllers, see figure X. The Syren25A is designed to handle up to 25A of current at 24VDC, which is sufficient for the larger servos we had. In total we purchased four Syren25A controllers in conjunction with four Phidget 1057 servo encoder interface boards as the Syren25A had no interface for servo encoders. The 'Syren25A + Phidget 1057' is a less expensive combination but is a less elegant solution and provides fewer options for work cell control. The combination of three EZSV23 boards, four Syren25A and four Phidget 1057 boards in summary provided the best work cell control at the lowest price for our project.

Robot	Servo	Servo Model	Operating Current (Amps)
Lisa	Shoulder	UGRMEM-04MA	8.4
Lisa	Slide	UGRMEM-02MA	4.2
Lisa	Vertical	RH8-6006	0.8
Monica	Shoulder	UGRMEM-04MA	8.4
Monica	Slide	UGRMEM-02MA	4.2
Monica	Turret	RH8-3006	0.8
Monica	Vertical	RH8-3006	0.8
			Total = 27.6

Figure VIII. Power Budget.

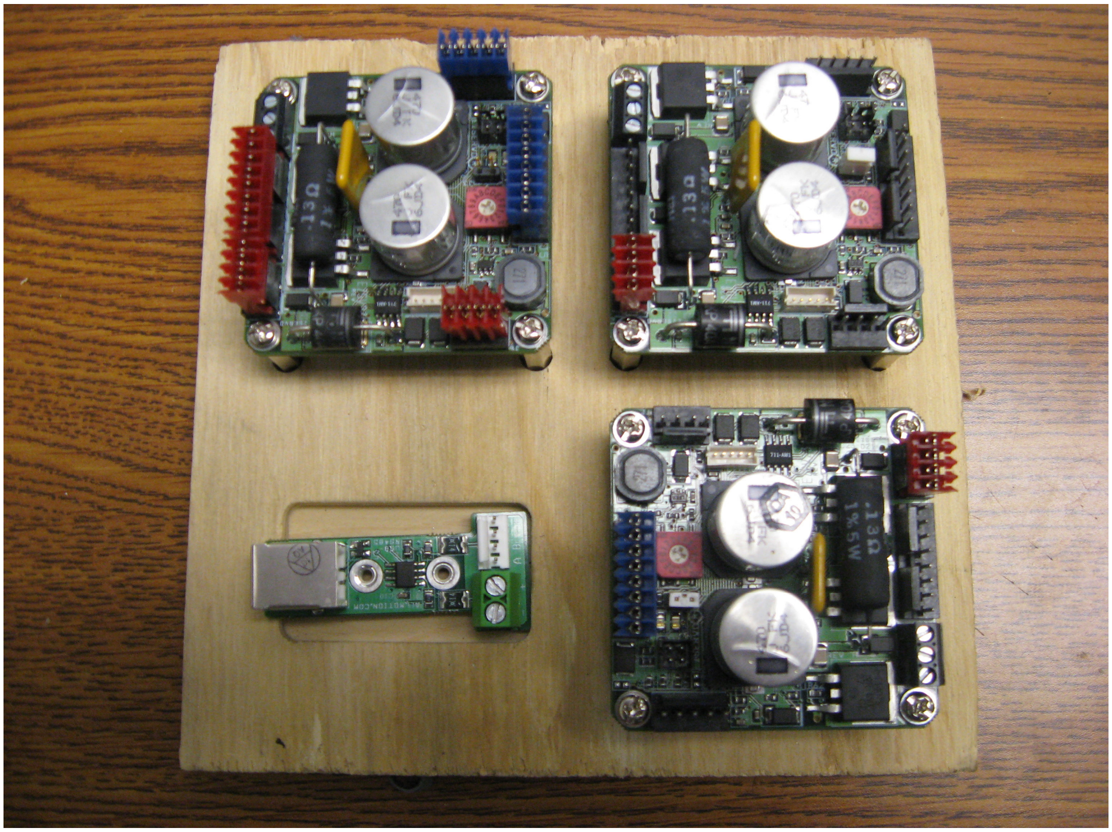

Figure IX. EZSV23 controllers.

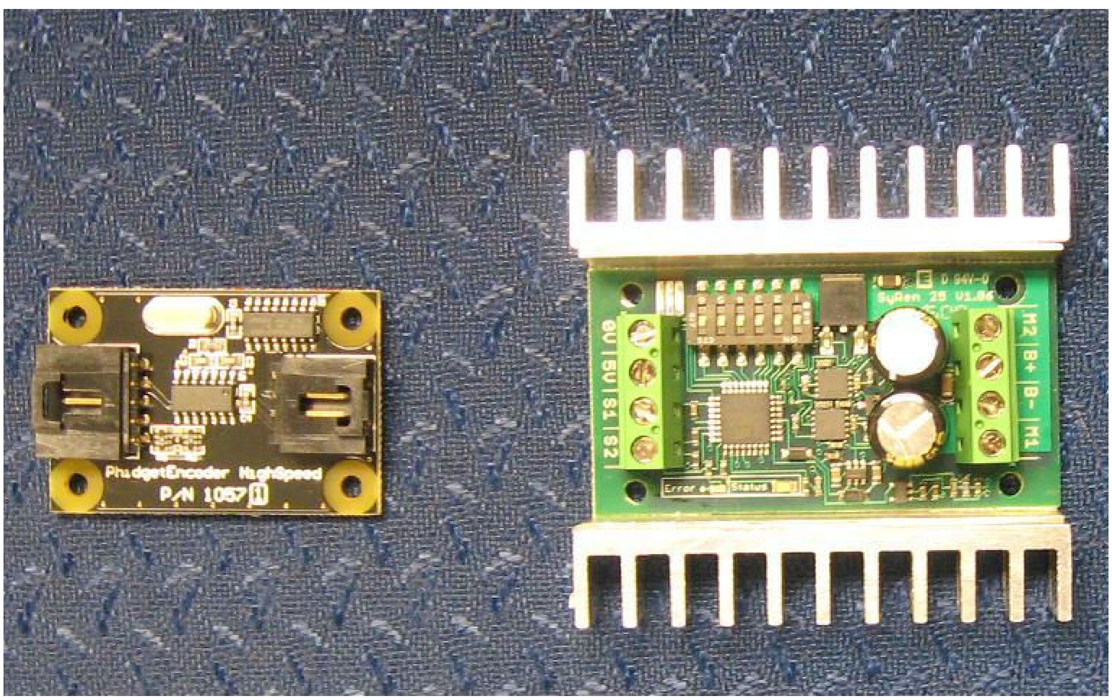

Figure X. Syren25A and Phidget 1057.

Software Design

In planning the project expenses we knew the software control system for the work cell needed to be either inexpensive or free. This meant there are but a few options. Microsoft Robotics Studio (MSRS) stands out as a simple 'one-stop' solution for this need. The software package and development environment can be freely downloaded and programmed in a variety of languages including MSRS Visual Programming Language, Visual Basic, and C#. MSRS software even includes a virtual simulation package with physics rendering. Additionally MSRS natively supports most USB cameras and vision analysis, through services which are installed with the software package.

The challenge with controlling robots in MSRS is that the programming environment requires specific drivers for each piece of hardware, similar to the way Microsoft Windows requires drivers for PC hardware. Although many MSRS services for robot hardware can be downloaded from robot manufacturers' websites, these drivers are limited to mostly hobby-style robot hardware. The EZSV23 controllers we used for smaller servos included these services. Unfortunately the Syren25A controllers we used for larger servos didn't have MSRS services readily available. This was also the case for our Phidget 1057 encoder hardware.

It was easy to see we would need to build a lot of software in order to create a functional work cell. As we needed software programming experience to keep the project moving we pitched the idea of writing the services and virtual simulation software to a CSET (Computer Software Engineering Technology) professor as an idea for a student project. One of the selling points for this type of project is that rather than develop interesting but trivial engineering solutions the students can develop software to solve a real-world program and provide an invaluable tool for undergraduate education.

For the project a group of students committed to the project as CSET curriculum requires a yearlong junior project. The team project will be to create user-friendly services and a GUI (Graphical User Interface) which will be able to control the entire work cell through MSRS.

In keeping our work within MSRS and Solidworks we are able to utilize the projects from all three teams of undergraduate students in building a complete and functional work cell with integrated parts delivery system. The central programming interface through MSRS will also leave a shorter learning curve for undergraduate students who utilize this work cell in later robotics courses.

Line Item	Part Number	Item Description	Vendor	# purchased	Price each	Subtotal
1	EZSV23	Allmotion 5A servo controller starter kit	Allmotion.com	3	425	1275
2	Syren25A	Syren 25A DC motor controller	Lynxmotion.com	4	74.99	299.96
3	Phidget1057	Phidget model 1057 USB encoder	Industrial Component	4	65	260
4	N/A	36" x 36" x 1/2" 6061 Aluminum plate	Klamath Metals	1	80	80
5	276-1539	D-Sub 9 Connector hood, plastic	RadioShack	9	1.99	17.91
6	279-1538	D-Sub 9 Connector female, solder style	RadioShack	5	2.19	10.95
7	276-1428	D-Sub 9 Connector female, crimp style	RadioShack	3	1.99	5.97
8	276-1537	D-Sub 9 Connector male, solder style	RadioShack	8	1.99	15.92
9	N/A	Shrink Wrap, various items	RadioShack	1	30	30
10	A9982-ND	T-Handle MTA-100 Tool	Digi-Key	1	18.29	18.29
11	A31111-ND	8 position, 22AWG connector receptacle	Digi-Key	3	0.42	1.26
12	A31108-ND	4 position, 22AWG connector receptacle	Digi-Key	3	0.23	0.69
13	MCU-036-472	USB to TTL 72in converter cable	Superdroid Robots	2	34	68
14	PSM24-600S	Rhino 24V switching power supply, 600W	AutomationDirect	1	276.5	276.5
15	6408K912	Flexible spider shaft coupling, 3/16 bore x 5/8 OD	McMaster-Carr	1	2.54	2.54
16	6408K914	Flexible spider shaft coupling, 5/16 bore x 5/8 OD	McMaster-Carr	1	2.54	2.54
17	6408K61	Buna-N spider for 5/8" OD flexible coupling	McMaster-Carr	1	1.16	1.16
18	6408K112	Flexible spider shaft coupling, 5/16 bore x 1-5/64 OD	McMaster-Carr	1	2.33	2.33
19	6408K113	Flexible spider shaft coupling, 3/8 bore x 1-5/64 OD	McMaster-Carr	1	2.33	2.33
20	6408K84	Buna-N spider for 1-5/64" OD flexible coupling	McMaster-Carr	1	1.52	1.52
21	7806K590	Ball Bearing, 6 mm Shaft Diameter	McMaster-Carr	2	9.47	18.94
22	6681k120	Ball Bearing for 12 mm Shaft Diameter	McMaster-Carr	2	18.41	36.82
					Grand Total	2428.63

Table I. Budget.

Conclusion

Keeping expenditures low and fulfilling the project requirements is a difficult balancing act but it was definitely made easier by utilizing robots which were mechanically sound and near-functional at the outset. This simplified the project considerably and the only major modifications needed were in the areas of end-effector tooling and controls. In total the project cost was just $2428, see Table I.

The most prominent difficulty during the project was coordinating the various team efforts to complete shared areas of the project. We succeeded through this lengthy effort largely by maintaining a central project coordinator and keeping communications open through meetings and online workspaces for sharing information, files and project progress.

Recommendations for improvements on future projects of a similar nature would include the use of complete work cell hardware, AC servos where possible, selecting robots with four of five useful axes, and selecting controllers with native MSRS services.