Project Number: JS7-JS01

Remanufacturing of a Robotic Arm

An Interdisciplinary Project on Decision Making

Major Qualifying Project
Submitted to the Faculty
Of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for a
Degree of Bachelor of Science

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Abstract:

The PUMA 260 is a 1980s robot manufactured by RP Automation. The purpose of the project is to assess the feasibility of redesigning the manufacturing process and making recommendations to the company based on our findings. The goal is twofold: to apply new and different technology to the existing system in order to lower the cost for the end user to enter a new market for inexpensive robotics and provide recommendations to RP Automation. In our assessment of the product, we provided future students with a body of knowledge that will help them understand how decisions were made throughout the process. We have also built the foundation for a future project for prototyping the new robot. In completing these objectives we will have fulfilled the requirements of a Major Qualifying Project at Worcester Polytechnic Institute.

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Introduction

In this report, will convey to the reader steps we took to reach goals set for us by RP Automation, the company that we are consulting for. This project was designed to supply our client with recommendations regarding the use and production of their PUMA 260 robotic arm.

Robotics technology is a constantly changing and expanding science that requires companies involved to adapt quickly to new ideas. In technology based fields, due to incremental innovation, a company must adjust by choosing which products should be updated. In order to make this decision regarding the PUMA 260, we completed a robust market analysis for tabletop robotics. This study allows RP Automation to remain ahead of the technological curve and increase their market hold in this robotics field.

One of the most important aspects of gathering this information will be to plan ahead. Entering into data gathering with professional businesses without a strategy creates a high risk of failure. According to Professor Kasouf, a marketing professor at Worcester Polytechnic Institute, approaching any client that you wish to gain information from without a plan discredits your research and greatly reduces the possibility of obtaining useful data. Understanding this, we constructed a market analysis plan prior to beginning our study. This allowed us to maximize our output from our research.

Upon completion of the research done for RP Automation, we began the second phase of the project: adjusting the manufacturing process to fit the needs of the market determined in the first phase. We found that the pain that needed to be solved lay in affordable robotics for startup and smaller companies. This drove us to the conclusion that the robot needed an update in technology that would allow it to be manufactured and sold at an affordable price: between $5-10,000. In making suggestions to RP, we hoped to aid them in entering a new, previously unreachable market for robotics technology, as well as satisfy existing customers with a better product.

The Major Qualifying Project equates to a senior thesis for WPI students. This project is different than most because it is interdisciplinary; the criteria of the project satisfies the requirements of both the Management Engineering major as well as the Engineering Physics Major. Projects are designed to help the students participating gain a greater knowledge of their major while providing something of value to future generations of WPI students who will read them in the future. Besides fulfilling these criteria, the project fulfills two other needs:

1. We provided a service to RP Automation by completing market research for a product that the company wished to see upgraded as well as beginning the redesign process,
2. And beginning the redesign process allows future students in other departments to complete the project from the design phase.

Background

The Task

This project was one designed and sponsored by Benjamin J. Clark, CEO of RP Automation. In our first meeting, we were given a demonstration of the product we were to be dealing with, the PUMA 260, and introduced to the project sponsor. In this meeting we learned that the specialty field for the robot is constantly changing, but that it was currently being used mainly as a transfer device in fields such as semiconductor manufacturing.

Since it is an old robot, parts are no longer manufactured which means when it breaks, companies who use the product have to ship it back to RP to have it repaired.

During the time that the robot is being fixed, the company is losing effectiveness, which means it is losing money. In order to avoid this, it would be important to have a replacement robot for the line that it was working on, which would double the investment made by a company. On top of this, the control system used in the robot means that it is not a simple task to switch in and out robots. The user must teach every new robot what its job on the line will be, which can take a large amount of labor. Meanwhile, RP is running out of parts to repair the robot, and once the reserves dry out, business will stop for the PUMA 260.

Our sponsor requested that we look into potential solutions to the problem. Ideas brought up at this first session were to make the robot much cheaper by using plastic polymers while also considering the outgassing in a cleanroom environment, redesign the robot, borrow another control system to make it more user-friendly, and attempt to find new market applications for the robot that will allow RP to sell more products. After discussion, the project took on four distinct faces in a linear timeline:

1. Research the market value of a new product;
2. Determine what physical changes need to be made to the robot to meet and potentially exceed market value;
3. Calculate the costs of making those changes while attempting to significantly cut prices for the end-user;
4. Propose the final selling value and changes to the sponsor.

It was also determined that throughout the process of completion we would record all of the decisions we made and provide reasons for each step in the process. This would allow us to provide future readers with a distinct understanding of the decision making process behind reviving an old technology.

RP Automation Inc.

RP Automation Inc. was established in 1984 by Benjamin J. Clark as a specialized robotics integration company. In the words of CEO Ben Clark, "I installed 250 [robotic] arms for Kawasaki and decided to start a company." Kawasaki sells performance vehicles such as motorcycles and ATVs, and their products are constructed on assembly lines using robotic arms. After working on a few more jobs Mr. Clark began specializing in Stäubli products and now integrates arms all over the world. Stäubli is a major robotics manufacturing company that builds six axis robots on a larger scale than the PUMA 260. Their products can be found in the WPI labs in Washburn Shops.

RP automation has grown from a small company into a recognizable integration business to people in the industry. "All of my new business comes from word of mouth" said Mr. Clark when asked about expanding the company. "I feel like providing a quality product and great service is the key to my business". Currently RP Automation works in many different industries including biomedical, semiconductor, and pharmaceutical. Each industry requires unique applications that RP is willing to solve.

The integration process is unique in the sense that one company is creating a specific solution by using the equipment provided by their client. In the case of RP Automation they are given a task to achieve and by using Stäubli products they form a solution that solves the task given by a client. One example is to use robotic arm to load and unload a manufacturing machine.

Stäubli Corporation

Stäubli robotics division was founded in 1982 with its collaboration with Unimation based out of Danbury, Connecticut. Two years later, Stäubli purchased Unimation and began production of the PUMA robot series. After moving the robotics division from the original home in Pittsburgh, Pennsylvania to Duncan South Carolina, Stäubli introduced the SCARA model robots to its lineup. These four axis machines are very fast at sorting and moving parts on an assembly line setting. Along with advances in the existing six axis arms, Stäubli continued to lead the industry in repeatability and speed with the new TX model arms and CS8C control systems. The current Stäubli robots are all based off of the old PUMA series with similar control systems and kinematics. Stäubli Corporation was an invaluable resource for the completion of our project, as they provided us with assistance in our research.

PUMA Robot Series

The first resemblance of the PUMA series robot was constructed in 1952 when George Devol started work on Unimation Robotics. Devol, who passed away in late 2011 at the age of 99, created the "first digitally operated programmable robotic arms" (Malone). He started a company called United Cinephone Corp. in 1932 in an attempt to break into the audible movie business, but he "ended up creating one of the technological marvels of the modern world: the automatic door" (ibid). In 1954, he applied to have a device patented that he

Figure 1: George Devol with a PUMA Arm

called the Programmed Article Transfer. In order to better pitch the idea, it eventually became called a robot. It was named the Unimate, the first sold robot from the new Unimation Corporation, and it was installed in a GM plant in Trenton, NJ (ibid).

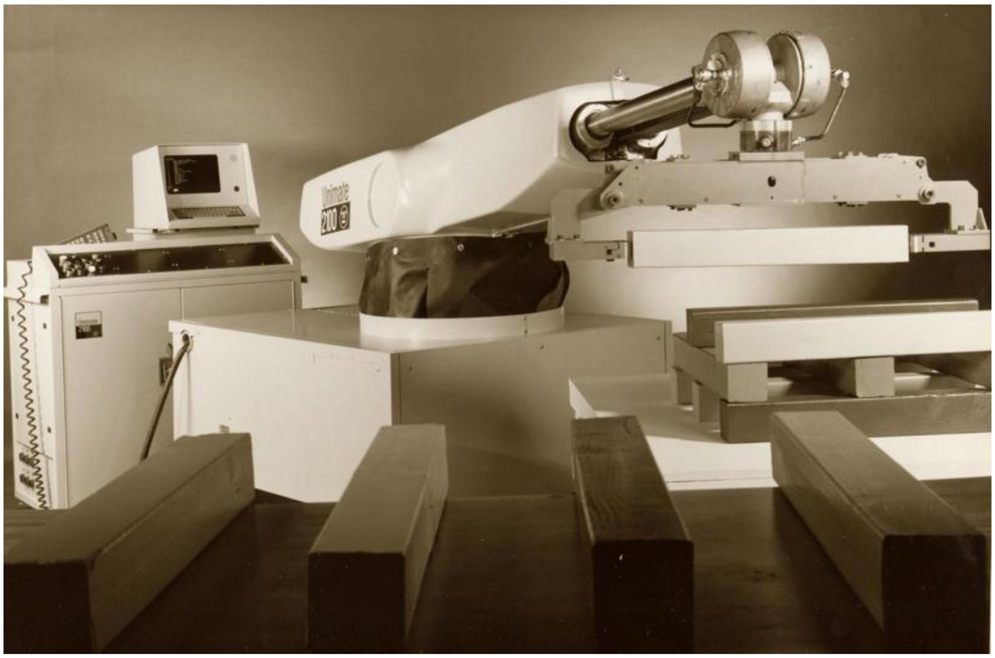


Figure 2: Programmed Article Transfer

From there, a few different robots were introduced to the Unimation product line until 1979 when the PUMA series was released. PUMA stands for Programmable Universal Machine for Assembly. These robots were unique in the way that they were able to handle materials and carry out tasks with great precision, speed and repeatability. In robotic terms repeatability is a measurement of how accurately a robotic system can perform the same movement. Around 1983 Westinghouse

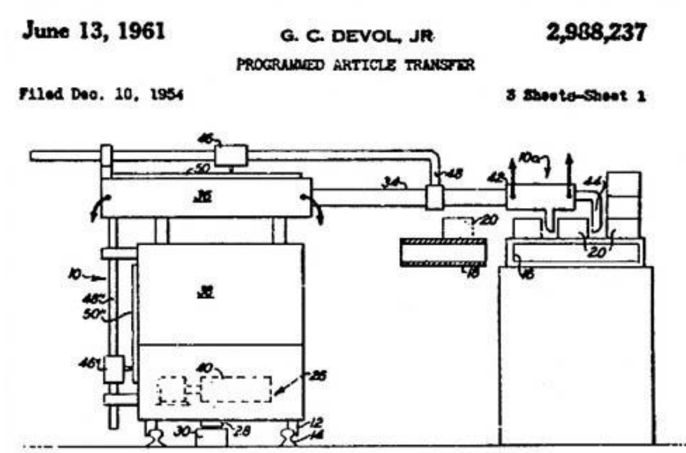


Figure 3: Patent Design

bought Unimation and continued work on the existing robot series as well as introducing a few new products. In the early 90s, Stäubli purchased the rights to the PUMA series and ten years later sold the rights to RP Automation Inc. This is where the PUMA series has been left until today. After the sale to RP Automation, the PUMA series was not advanced any further due to focus on other products. To date, the arms are maintained until complete failure or the older arms are switched out for new equipment.

PUMA 260

The PUMA 260 robotics system is a six-degree of freedom robotic arm that is used for industrial applications. A degree of freedom is defined as a range of motion that the machine can operate. Each degree of freedom is acquired by the motion of one of the six axes on the robotic arm. The 260 has one joint or axis slightly above the base which allows the robot to swivel around the stationary base. Continuing along the frame of the robot, joint two moves the shoulder of the arm in an up and down motion. Joint three works as an elbow to the arm, extending and retracting the outer link from the base. Joints four, five, and six are located in the wrist of the robot and give the robot rotation and pivot at a much tighter tolerance level. Moving any combination of these joints gives the robot freedom of motion in the x, y, and z planes as well as rotation about each of these axes.

Figure 4: PUMA 260B

Each axis is driven by a small electric motor and gear system controlled by an external system and encoders. Encoders are a glass disk attached directly to the motor drive shaft, which are marked by a specific number of black lines. The encoders used in the 260 series are 250 count encoders, which means that there are 250 sections around the circumference of the disk. As the motor turns the controller is able to count the spaces that pass by a light beam and calculate the position of each joint of the robot. By calculating the positions of each joint the controller can determine the position of the robot on space and move the robot according to the locations it is attempting to reach.

The current robot frame is constructed of cast aluminum. Each piece is molded and cast into the shell that is used as the framework and covers for the exterior of the arm. Inside the frame and covers are the gear assemblies and wiring that make the robot move along its motion paths. Gears and assembles are made from more durable materials that withstand a long lifetime of use without failure.

The robot moves by driving the digital motor that turns a drive shaft that runs to a specific joint. The drive shaft is connected to a gear assembly, which can be a combination of many different gears that work together to create the desired direction of motion without compromising the overall path of the robot.

Controller

The current control system of the robot is the Unimation controller, which is the main interface between the robot and the user. Stäubli has integrated the software needed to control the robot into the system and allows for the user to program and move the robot from a remote video display. To date the system runs in a DOS setting and can be accessed with a communication port on modern computers. The control system uses the feedback it gets from the encoders in the robot arm to calculate the specific position of the robot arm in space. The controller allows for arm to make accurate and rapid movements that can be repeated to within .02 mm after each movement. Repeatability is the ability of the robot to move within a determined distance of the originally programmed point. This ability is very crucial to the quality of the robot as that the lower the repeatability number, the better the machine works under tight tolerances.

Experience with the Product

One of our team members has worked an internship for RP Automation for the past five years on various different types of projects. The experience he has learned includes programming and a complete knowledge of the PUMA 260 system. We were able to use his experience with the robot to aid us in minor engineering tasks in the robot arm as well as fix the arm if it was broken. This work experience also included knowledge of different robotics markets that the PUMA system could potentially move towards. His knowledge in these areas was helpful in guiding the planning of the robot and catering any new improvements we would make to have the greatest benefit in a multitude of different market sectors.

Relevant Coursework – Physics

Working with robotics technology was a new venture, but understanding circuitry from Electricity and Magnetism courses helped ease the technology gap that came with working with a new idea. Also, my experiences in Introduction to Thermodynamics and Heat Transfer, as well as Math Modeling with Ordinary Differential Equations conveyed the knowledge necessary to study the thermal properties of aluminum, the current construction material for the robot, as well as other materials we studied as potential replacements in construction.

My minor in Entrepreneurship also played an integral part in assisting with the market analysis part of the project. These courses were Engineering Entrepreneurship, Entrepreneurial Selling, and Growing and Managing New Ventures. These case driven courses provided examples of real life situations that assisted us in honing in our market research strategy, specifically in regards to determining whether or not we could sell the product after evaluation.

Related Coursework – Manufacturing Engineering

This project required a good understanding of manufacturing processes and the economics that go with it. Classes such as materials handling and intro to mechanical engineering were a great foundation that helped us to make manufacturing decisions. Having the knowledge of the costs that are associated with different manufacturing processes allowed us to make educated decisions on which processes would benefit the product more. Other classes such as entrepreneurship helped our team with the understanding of product life cycles, and business plans.

The Handbook

We determined that the first task we needed to complete in order to successfully redesign the PUMA robot was to determine the market for the product. If there was no market or market extender for this product, the resources that would be put into redesigning the system would outweigh the potential gain, putting a stop to the project post market analysis. As this was our first foray into market analysis, it was important to find a guideline that would help us evaluate the current situation the product was in. To do this, we researched to find a useful summary on proper techniques to understanding and solving a problem.

Eventually, we decided to use a bulletin published by The Ohio State University on proper evaluation techniques when dealing with water quality evaluations in a particular area (Ricker, Brown, and et al). While this was not exactly the situation we were dealing with, the step-by-step guideline could easily be applied to any type of study. Though it may seem to be an obscure reference for a robotics project, the handbook clearly breaks down the steps to tackling a project without too much specification on which type of project is being conducted. This allowed us to take the suggested steps and apply them to our market analysis for the PUMA 260.

Understanding that the guide was meant for water quality evaluation, some of the points needed to be tweaked, but on the whole, the six-step process provided a stable structure for constructing an evaluation. Step one is to focus the study, and mainly, to determine what problem is being focused on. Opportunity arose to identify the people who have a vested interest in the project and call to question the critical ideas that the evaluation must address, which will be mentioned in the methodology.

The second step of the process was to create measurable objectives for the evaluation. According to the brochure, a measureable objective contains four pieces of information: Audience, Behavior, Conditions, and Degree (The "ABCD" Rule). Unless an evaluation has measurable objectives, then there can be no conclusion made at the end of the project. There must be an explicitly described target audience for the project; expected behavior of the audience needs to be established; the conditions needed for the audience to behave as needed must be listed. Once measureable objectives have been established, the project has a direction.

Third, a project team must determine what barriers they could face while trying to complete the evaluation. The brochure describes several categories that could cause problems, and understanding what problems could arise before they happen is one of the most important steps before facing a project. If a project hits an unexpected roadblock, it is monumentally harder to deal with the roadblock than if a team had already come up with a solution. As the evaluation plan begins to develop, the team needs to recognize potential problems.

In order to determine these problems, it was pertinent to list possible reasons why the project could not be completed. This could be for a number of reasons including but not limited to lack of funding, lack of support, incapability of the team to handle the evaluation, and surprise changes in the structure of the project. These obstacles may not be foreseeable until after the project starts, notably when discussing the direction of the project with the stakeholders.

Even as thoughts of potential barriers arose, it was important to note all opportunities that amassed as well. These provided a direction for the evaluation to continue. One of the most important decisions that can be made in terms of an evaluation is to stop progressing the minute the project is doomed a failure. If a group can come to the conclusion that a company should not move forward with their intended project, the operation should be ceased immediately to save the stakeholder time and resources.

Once the barriers and opportunities are determined, the evaluation team needs to come up with the type of information needed in order to complete the evaluation. According to the brochure, for step four, there are two general types of information that can be gathered: descriptive and judgmental. Descriptive information is all of those things that are hard truths about the subject under question while judgmental information is based on opinion, preference, beliefs, and personal perceptions. Listed on page 17 (Ricker, Brown, and et al) of the brochure, which can be found in the appendix, are many strategies for gathering information, some of which were chosen later for the purposes of the PUMA 260 evaluation.

Before collecting information, it is important to complete the fifth step of the evaluation process, organizing where results will go. Data means nothing unless it is given a purpose, which makes it important to assign value to different amounts of information in order to differentiate what applies to which part of the evaluation. Results can be varied based on the scope of a project, so it is important that each bit of information finds its own place.

Once the project has been organized, tasks must be delegated with deadlines such that there are no miscommunications between team members over what needs to be done. One of the most effective tools for this is a Gantt chart, which sets a timetable for due dates and checkpoints on project deadlines. This is something that can change over time, but it often provides a good outline for the direction of a project and helps to keep it on track.

Methodology

After discussion, we concluded that the evaluation would focus on two major tasks: determining the market capacity for a tabletop six-axis robot and establish what changes needed to be made in order to make it market relevant. Once it was understood what was being evaluated, the group determined why this was being looked into; what was the purpose of the evaluation? Without knowing the reason for reaching the goal, the evaluation has significantly less meaning. This project had four main purposes:

1. To clarify the role that the PUMA 260 will play on the market;
2. To modernize the technology in the robot to increase ease of use and accessibility to spare parts for broken machines;
3. To inject the market with a new presence should it be deemed viable;
4. And to determine whether the project is worth the resources it will consume based on the cost and feasibility of implementation.

The most important purpose is the last one; for a company to understand that undergoing a project will cost them resources they should not waste is better than putting out a finished product that will end up counting as a loss for the company.

One of the measurable objectives for this project was that this was being completed for RP Automation, and we needed RP to help us research what the current market was for their product. In order to reach this goal, we needed to be given the necessary support and funding to reach out to companies and sources that could help us understand where the product is going. We needed to be given enough freedom to learn what we needed to in order to finish this project.

The two major sponsors for the project, RP Automation Inc. and Stäubli Corporation, were both essential to completing the project. Upon completion, Stäubli had sponsored our attendance at a large lab automation conference and RP Automation had provided us with a sample robot unit to test and study. RP also sponsored our trip to the conference, which allowed us to complete a market analysis. One potential problem we faced by working with incorporations was that some of the information we received was considered to be trade secrets of the company. For example, the bill of materials used to construct parts of the SolidWorks design cannot be divulged as part of this report due to the sensitive nature of the information. Also, the analysis of the material later recommended for manufacturing is also withheld from this report.

RP requested that we provide counsel on how to move forward with the PUMA 260 product line. In addition to the work towards a completed product, we were tasked with understanding how we came to the conclusions we made. It can be difficult at times to materialize the way an idea forms in a team, so it was important that we kept detailed logs of our meetings.

A new PUMA robot could draw interest from a new market as well as current users. Our goal was to have all of the companies who currently use the 260 model upgrade to the new system but also make it unique enough that other companies will want to enter the market for this product. If the project was deemed non-profitable or non-feasible, then the decision would be made not to move forward with the remanufacturing. If this is the case, RP loses no money on research and development and can continue servicing PUMA robots until the parts run out.

We completed this project for a major company in this field, but we did not have extensive knowledge of the inner workings of this company. It was extremely important that we worked closely with RP to receive everything we needed to move forward with the evaluation in the manner we deemed most important for the success of the project. Our original goal was to compile a questionnaire for existing users of the PUMA 260 to answer. This questionnaire would target specific uses the PUMA served as well as services the user would like to see the PUMA offer. If any of the current users had specific issues with the way the 260 operated or built, the form would have been a great opportunity to understand this. Unfortunately, communication issues did occur, and we were unable to reach any of the existing users of the robot, as most of them were located in Japan. A copy of the original questionnaire can be found in the appendix.

While brainstorming possible problems we could encounter during our project, communication issues were considered, and our back-up plan was to use data gathered from the conference and from secondary contacts and research to make our decisions. We had more than enough resources to move forward, and there was no resistance from the companies helping support the project to see it completed.

In order to move forward with our market evaluation, we asked representatives at Stäubli Corporation how they gathered their data. It was suggested that we travel to a major conference, where many companies in the field would be in attendance. This allowed us to meet potential buyers and competitors for our project. The Stäubli representative suggested that the SLAS conference in San Diego was the most appropriate event that was being held in the time frame of our project. SLAS stands for the Society of Laboratory Automation and Screening, and this particular conference would have multiple companies at it that could be interested in the technology we would be offering, which would, in turn, draw competition to the showcase.

Since we were working closely with Stäubli, we requested that we be allowed to join them as students under their company's name, already an established one in the automation industry. This would help us gain the respect of the people we would be talking to, as well as allow us to talk to the Stäubli salesmen who were there to sell a similar product.

Results

Our major result that we determined from our research was that if changes are not made to the PUMA 260 robot, the customers that currently use it now will be lost. The PUMA 260 is a unique robot in that it is the only one of that size that RP offers, which means that those current customers would have to search elsewhere for a replacement. The market for the robot will fall by the wayside as other companies in the field had come up with equivalent technology that can be purchased for a cheaper price. The results section will be divided into the following sections: the conference, the questionnaire, and the final conclusion.

The Conference

Sunday February 5th, 2012

After arriving in San Diego, California, we prepared our plan of action for the conference. We decided to use the preparation day for the conference to walk through and determine which companies would have interest in the product we were looking to sell. Having Stäubli name tags afforded us the luxury of being associated with a market leader in the product which got us respect from the companies that were there. We determined that there were definitely companies in attendance who used similar technology to what we were attempting to redevelop. We wanted to determine what made the product these companies were using better than the PUMA and understand why they were using it.

Monday February 6th

The conference officially began on Monday, and we quickly realized that we had ample time to visit every booth. We started by questioning the Stäubli people about their TX 60 robotic arm, the one being used as their display model. The model itself was a six axis robotic arm, similar in shape to the PUMA 260, but it had a larger reach. It was showcasing three abilities during the show:

1. It would grab vials with a pincer wrist attachment and stir them slowly, showcasing its ability to move over all of its axes in one smooth motion,
2. It used a needle to show how it could pinpoint multiple locations with a high repeatability by poking the tops of numerous vials positioned around the case,

3. And, it used a grabbing end affecter to lift and place pipetting plates that would hold sample materials for lab work, showcasing its ability to grab lab materials in both landscape and portrait planes.

This robot had many of the same features as the PUMA 260 arm, which means that the PUMA could be used in similar market settings. At the time of the conference, Stäubli was just getting into the photovoltaic market, working in solar panel construction.

Soon after this, a man who was working in collaboration with Stäubli at the event visited the booth. His name was Terry Rutledge, and he ran a company that assisted small companies in marketing their product. He showed interest in helping us take a finished product to market and find integrators and fabricators that would use it. After exchanging cards, we decided that he would be a strong resource for later in the project, but for now, there was not much use for his services.

Following this, we began travelling to the different tables at the conference. There were a large number of companies that attended that were in the lab automation sector for biomaterials and sciences, many of which integrated robotic arms similar to ours in their lab testing simulations involving pipetting and biomaterial culturing. One of the first companies we talked to, DiscoveRx, boosted our confidence about the direction of the product. They were a company that would use robotic arms to translocate their materials throughout the process, and expressed interest in being able to acquire an affordable tabletop robot to put in their screening lab. They believed that if the robot was sold somewhere in the $5-10,000 range, we could sell to them and a myriad of other companies who could not afford a $40,000, but would be willing to purchase the technology for a fraction of the cost.

From here, the next meaningful conversation we had was with Precise Automation. We saw that they were showcasing a four axis robot that slid along horizontal and linear planes but had no shoulder motion. Their goal was to "develop low-cost, desktop safe lab equipment". It was a kinematically driven system, which we believed could be appropriate for our model, should the price fit. The machine ran all on encoders, which is what an updated control system for our robot would also run on, so we saw promise in that as well.

The representative suggested that we focus on designing our model for small work spaces because there are labs out there that have the problem of needing to keep overhead at a minimum, so a small arm would be perfect. He also warned us that the robotics industry had a very volatile target market so it would be relevant for use to target companies, including startups, which had long term vision. Their product being showcased sold for $15,000.

Another company at the conference that was showcasing an arm similar to the PUMA 260 was Wako Lab Automation. The representatives absolutely believed that there was a market for six-axis robots, and that as the technology advances to make systems more user-friendly, more and more will be sold.

We met two parts companies that we believed would make great contacts throughout the redesigning process: Lin Engineering and Harmonic Drive. Lin Engineering produced step motors that had lower reverberations and heat output, which would allow us to change the material properties of the robot without worrying too much about deformation. Harmonic drive developed precision gearing technology that had virtually no backlash and took up significantly less space than the gear system currently in place in the robot. If these could be implemented, then the part count on the robot would drop significantly.

Tuesday February 7th

Tuesday was significantly less successful than the day previous, and as we travelled to the remaining booths, we realized that there were a significant number of companies at the conference who did not use robotics. High Res Biosolutions was showcasing the last of the six-axis arms we saw, but it seemed extremely cramped in its workplace. The PUMA 260 could potentially alleviate some of the complex coding that goes into making a large arm swivel around a small work place. Making a note of this advantage our robot would provide to smaller sized companies, we moved forward in our analysis.

The Questionnaire

There are no concrete results from the questionnaire, but we do believe that it was a valuable resource to create for two reasons: it can be used in the future as a customer satisfaction survey for RP, and as it was created, we thought about all of the potential problems customers could be facing with the robot. This allowed us to create an educated guess on how effective the changes we chose to make would be in maintaining satisfaction with the original customer base while also trying to expand into different sectors.

Conclusion

The PUMA 260 project was a great experiment in determining the decision-making factors that are associated with the renovation and re-entry of a product into a market. Using the existing market and the research that our team had done at the SLAS conference we made a few decisions that we felt would give this product some potential when trying to enter new markets. The conclusions we drew were important learning objectives that we believe will help future students make progress on any similar projects.

The first decision that out team had to manage was how to begin the research process. This was a critical part in our project because being able to narrow in on the direction you are trying to take the product can save a lot of resources in the long run. When this process is being carried out in an R&D setting, being able to make moves in the right direction will help get a product back to the market quicker. For our team we also had the added time limitation that made our first steps even more critical. Being able to look at what we were expected to accomplish and determine what was a realistic and optimistic goal helped us to prioritize what paths we were going to pursue. We decided that doing market research into an inexpensive small reach tabletop robotic system would benefit the product the most. This decision was based off of the multiple competitors we determined to be in the robotics field. Our team decided that there was a market opening in this type of technology and that by trying to offer a unique approach to many robotics solutions we could potentially enter many different industries. We were able to confirm these hypotheses after our research at the SLAS conference in San Diego when talking to many of the potential clients in the lab automation industry.

After we got back from the conference our team needed to start looking into the cost analysis of the current and potential robotics system. Due to the time constraints that we had on the project we had decided to focus our efforts on a smaller section of the robotics arm instead of the whole system. Looking only into the inner link containing the joint two and three components we were able to break down the materials used and the parts count in order to determine what might be changed in the arm. We were also able to look at the potential changes that we would need to make to the robotic arm in order to incorporate the new parts that we would use. This includes the harmonic drive systems that would allow for better repeatability and longevity of the arm, and the new material construction. The material was meant to be a metal substitute plastic that had some glass in the material to provide less creep over time and more structure. Our team wanted to go with the plastic material because it has the potential to be injection molded if the product were to have large market applications and need to be mass produced. The cost efficiency of injection molding and metallic molding were the main deciding factor when choosing a material to focus on for the revamped system. The harmonic drive systems were going to be used in order to reduce the part count for each of the gear input systems that were in the inner link section and increase the repeatability of the arm itself. The drive systems would also reduce the amount of backlash that was in the drive system and decrease the amount of wear on the drive systems allowing for the robot to run longer in the field creating more value to the customer.

Once we had discussed what changes we were going to focus on we needed to start putting together a plan and a bill of materials for the new product. Unfortunately this is where the time constraint caught up to us and forced us to limit the amount of work we could do in this part of the project. We would hope to have laid a solid groundwork for future teams to continue progress on this project. In order to see this project to completion, the engineering and incorporation of the new materials would need to be finished and eventually made into a working prototype. This would not be done using an injection mold due to the cost of creating a mold but in fact using a block of material and machining the part out of the blank.

Trying to bring back a product that had moved late into its life cycle is a difficult task that is not always accomplishable. Bringing back the PUMA system proved to be very consistent with this model and was no easy task. There is a very slim margin for error and as the product cycle continues on it becomes harder to bring this product back to the market. As it stands there are many changes that need to be made in order to capture new markets and make this a profitable product. In many of the entrepreneur classes taught here at Worcester Polytechnic Institute, we focused on product life cycles and the innovations that must be made in order to continue a product line. Using the lessons learned in these classes we determined that the PUMA has moved past the point where changes should have been implemented and now lies in a questionable area of the chart where the product can be dropped or requires drastic changes. At this point it really depends on the decision of the sponsor on weather or not to continue the product or to make the effort to revive it.

Our research shows that the PUMA 260 system can be brought back to market, but the radical changes that would need to be addressed may not be efficient enough for the sponsor to address. If the company chooses not to change the PUMA system, it will most likely continue servicing the product until the product runs out of replacement parts and customers are forced to find a replacement. The other option is for the company to manufacture more parts for the existing robot and find a replacement motor. The problem with this is that if a replacement motor cannot be found the company would have to pay a good deal of money in order to design and manufacture a motor that would replace the existing motors.

Appendix

The Questionnaire

Dear Valued Consumer,

RP Automations is a Robotic manufacturing and system design company focused on using the Unimate PUMA and Stäubli RX and TX robotic arm systems used commonly in semiconductor manufacturing, life sciences, and general manufacturing industries.

RP Automation is looking to expand their current robotic product line with a new model of the PUMA 260 robotic arm. The original 260 model was created in the early 1980s and was ahead of its time and we are now in the process of updating the control and feedback systems. The PUMA arm is still being sold to companies today, but when parts fail, replacement parts are expensive and some of the electronic circuit board components need to be redesigned. This is becoming a greater cost burden on our customers and we are looking into ways to improve the reliability of the PUMA 260.

We are looking to switch the system over to resolvers so that it will run on a more current PC control system. This will create a higher degree of repeatability, and improve linear accuracy.

We have requested that you fill out this questionnaire because we believe that the customer is the greatest source of knowledge we have when it comes to this remanufacturing process. It is our goal to make sure that every need your company will have when using the PUMA 260 robotic system will be met with the utmost care, while also cutting back on costs on the product itself. Adding superfluous changes that mean nothing to the customer would be a waste of time for both parties.

We will make every possible effort to accommodate the needs generated by the individuals filling out this form, and look forward to working with you in the future.

Daniel McCarthy and Maxwell Benko
Product Development Group

PUMA 260: A Metric Questionnaire for Innovation

1. What company do you represent (optional)?

2. What is your name (optional)?

3. At this facility, what industries do you engage in? (Semiconductor, Life Sciences, Research, General Manufacturing, Other)

4. What application(s) is your company using the PUMA 260 for?

5. What features make the robot useful in these applications?

6. Why did your company originally choose the PUMA 260 robot?

7. How many hours on average per month does your company use the PUMA 260(Circle One)?
    a. <80 hours (4 hours a day 5 days a week)
    b. 173 hours (8 hours a day 5 days a week)
    c. 224 hours (8 hours a day 7 days a week)
    d. 346 hours (16 hours a day 5 days a week
    e. > 400 hours a month

8. How would you rate the reliability of the PUMA 260?
    a. Excellent
    b. Very Good
    c. Good
    d. Fair
    e. Poor

9. What parts, if any, do you find malfunction or break the most on the robot?

10. What feature do you think the PUMA 260 could have that would improve its performance?

11. Are there any applications that the PUMA 260 could be used for that are being filled by other means? If so, what are they?

12. What features would make the PUMA 260 applicable to these situations?

13. Would you buy another system if it was an improved model?
    a. Yes
    b. No

14. If you would not purchase an updated model, what would you choose?

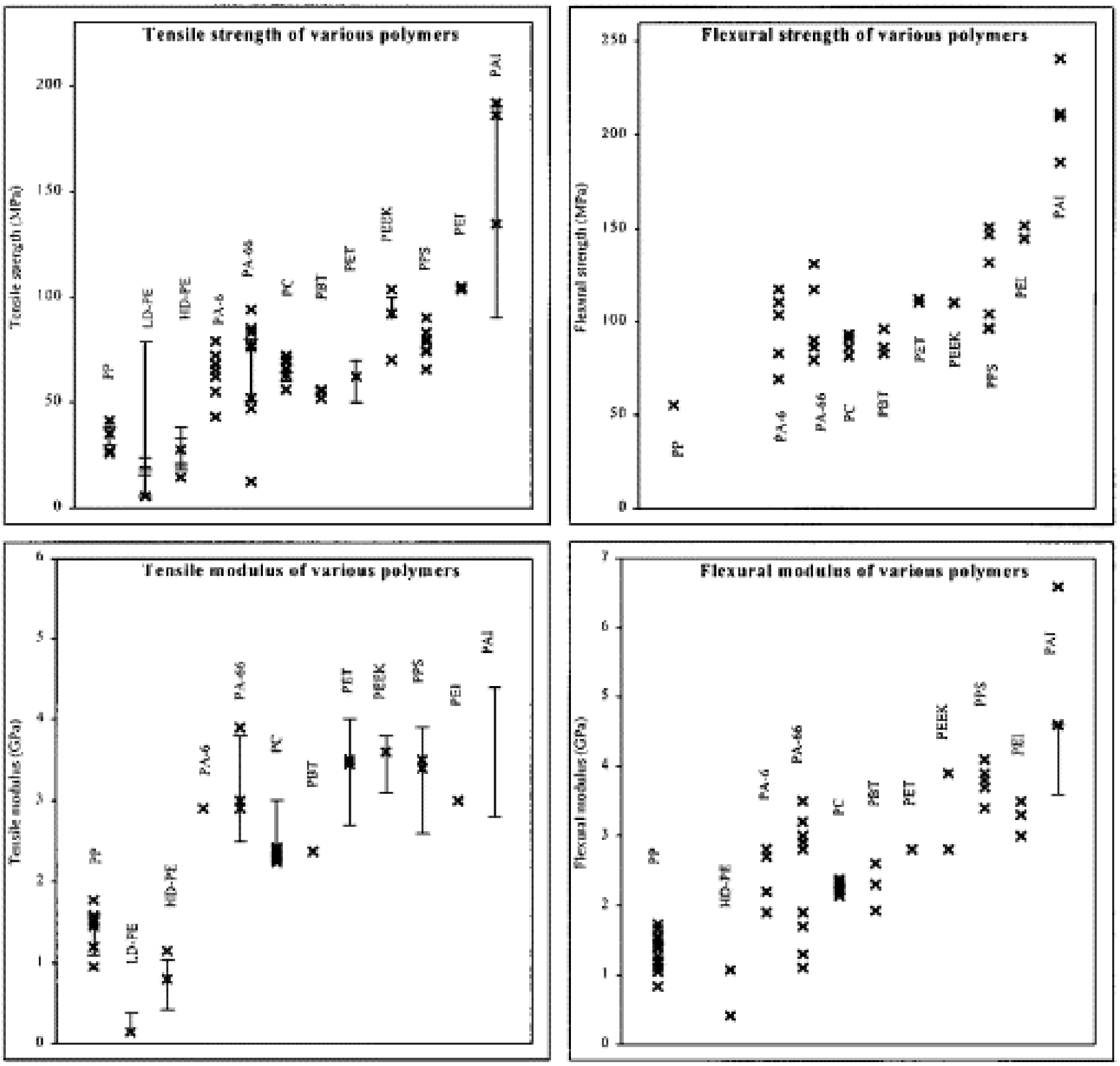
15. What makes this system better for the applications you are using it for?

Table 1: Mechanical Properties of Analyzed Polymers

Properties	Limits	Type of polymer											
		PP	LD-PE	HD-PE	PA-6	PA-66	PC	PBT	PET	PEEK	PPS	**PEI**	**PAI**
σ_{max} (MPa)	Upper	41.4	78.6	38	79	94	72	55.9	70	103.5	90	**104.9**	**192**
	Lower	26	4	14.5	43	12.4	53	51.8	50	70	65.6	**103.5**	**90**
E (GPa)	Upper	1.776	0.38	1.49	2.9	3.9	3	2.37	4	3.8	3.9	**3**	**4.4**
	Lower	0.95	0.055	0.413		2.5	2.3		2.7	3.1	2.6		**2.8**
σ_f (MPa)	Upper	55.2			117.3	131.1	93.2	96	112.3	110.4	151	**151.8**	**240.8**
	Lower				69	89.7	81.4	82.8	110.4	110	96	**144.9**	**185.6**
E_f (GPa)	Upper	1.73		1.07	2.8	3.5	2.38	2.6	2.8	3.9	4.1	**3.5**	**6.6**
	Lower	0.83		0.41	1.9	1.1	2.14	1.9		2.8	3.4	**3**	**3.6**
ε (%)	Upper	700	800	1000	150	>300	125	300	100	50	6	**60**	**12**
	Lower	15	90	12	20	35	90	100			1.1	**6**	
Izod, 1/8″ (J/m)	Upper	267		1068	160	854	908	53.4	26.7	50.2	133	**133**	**133**
	Lower	21.4	>854	26.7	42.7	16	534	48.1			10.7	**53.4**	**58.7**

This table identifies the Tensile Strength, Tensile Modulus Flexural Strength, Flexural Modulus, and Ultimate Tensile Strain of the polymers we looked into. ULTEM (bolded) out performed all others in these categories.

Graphic 1: Error Bars of Physical Properties of Polymers



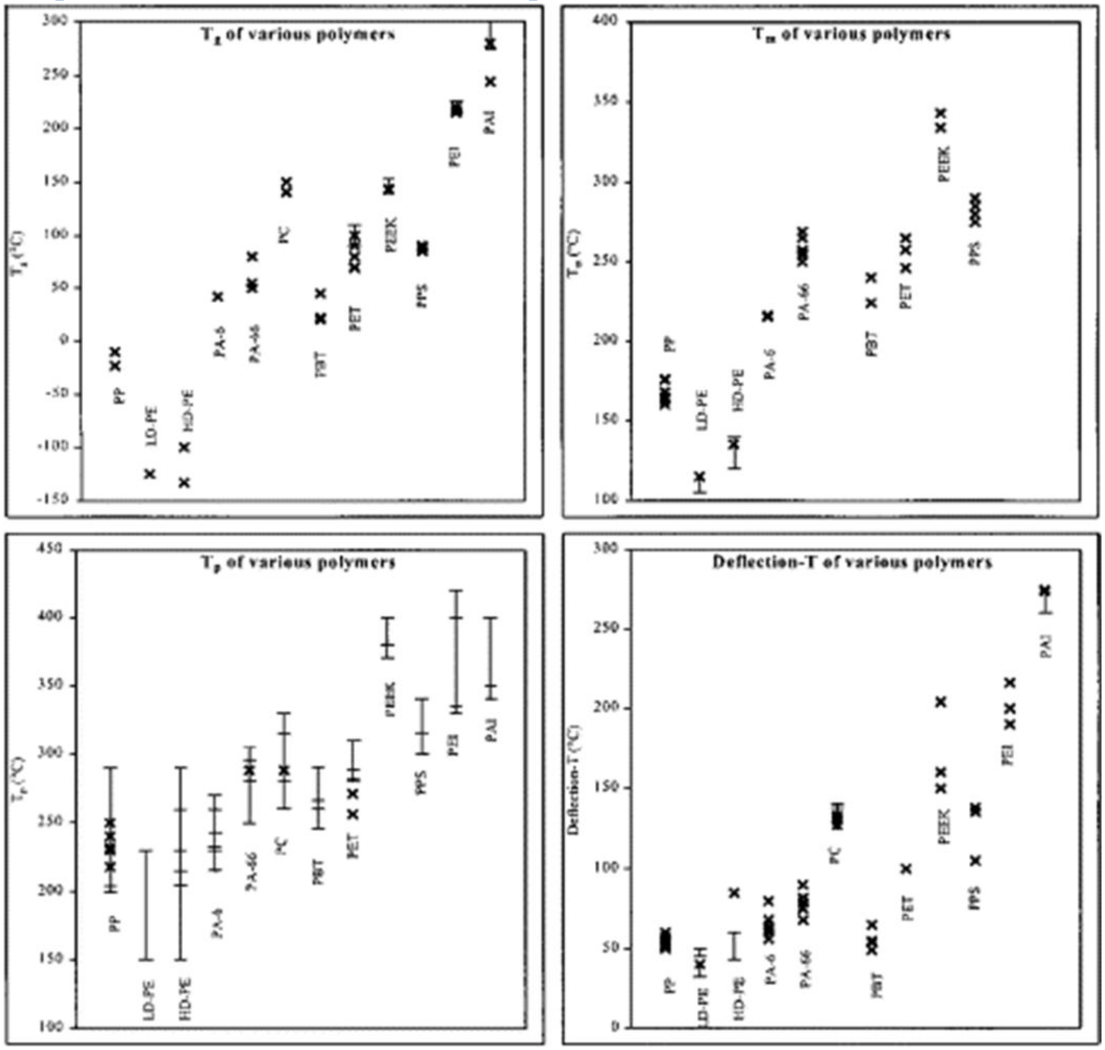
This graphic shows the relative ranges of the materials from Table 1.

Table 2: Thermal Properties of Analyzed Polymers

Properties	Limits	Type of polymer											
		PP	LD-PE	HD-PE	PA-6	PA-66	PC	PBT	PET	PEEK	PPS	**PEI**	**PAI**
α_T (10^{-5} °C^{-1})	Upper	13.5	10	13	8.6	9	7	7.2	6.5	5.5	5.4	**6.1**	**3.6**
	Lower	6.8		12	8	7.2	6.5	7	5.9	4.7	4.1	**5.6**	**2.9**
Mold shrink. (%)	Upper	2.5	5	5	2.6	2	0.8	2.3	2.5		1.2	**0.7**	
	Lower	1	1.5	1.5	1.2	1.5	0.5	1.6			0.8	**0.5**	
G (W/m/°C)	Upper	0.2			0.17	0.24	0.19	0.2		0.25	0.29		**0.73**
	Lower	0.14											**0.2**
Specif. heat (kJ/kg/°C)	Upper	1.9	1.989	2.281	1.599	1.68	1.26		1.146	1.1			
	Lower	1.7	1.901	1.566			1.17		1.103				

This table identifies the Linear Thermal Expansion, Mold Shrink, Thermal Conductivity, and Specific Heat of the polymers we looked into. ULTEM (bolded) also outperformed all others here.

Graphic 2: Error Bars of Thermal Properties of Polymers



This graphic shows the relative ranges of the materials from Table 2.

Dan's Journal

11/04/11

Research into past MQPs that may have information that could help us in our project

→ Humanoid Robot Development → since we are dealing with an arm, joint creation in this project may help us find improvements to make on our model

→ Design of a 5-axis fixture system

→ we have a six-axis system; could be helpful

→ Manufacturing from scratch → may have some interesting decision making processes.

11/07/11 MQP Meeting

Introduction

- product show case
- meet and greet with project sponsor - Ben Clark

RP-1982 System Integration

Calls that manufacturers want supporting equipment buying and developing

Specialty field for robot is always changing

Our goal is to do something of value to the sponsor along with something broader

* Investment wax lost process

Looking into making it cheaper out of plastic

- consider the out gassing of a cleanroom environment
- currently used mainly as a transfer device

Looking for redesign and new market applications

Buying RP is paying for the name not the robot

4 Distinct Projects (linear time line)

- Marketing aspect
- how do we change manufacturing
- cost of associating those changes to
- Final selling value

2

We can look into a whole new industry

there is a space where we can look into a large amount of new product markets.

Budgeting - Determine what we need for money

Travel to south carolina to visit Staubli

to date, applications for the product have travelled by word of mouth

we need to whittle down the wealth of options set forth by RP

Physical changes
- staubli control system/feed back system
- plastic casing
- change the manufacturing process.

note: get access with Professor Stafford for a storage situation where we could use the robot and no one would touch it.

currently $40,000 dollars, shooting for $120,000

- look into repeatability (gear differences)
    ↳ ability of the robot to go from point to the same point over and over
- laser mapping
ability to design and characterize the vision of the project

11/07/11

Goal is to finish research by Friday
Problem statement by monday
- outlined a problem statement
- discussed travel plans
  - have to go to Duncan to visit Stockl
- Budgeting for trips

- we have to discuss surveying methods for companies that do a product evaluation

4

More potentially useful past MQPs 11/12/11

Market Analysis: Wave trend Technologies

- Key primary source was a survey distributed to a number of Wave Trend's customers while our secondary sources..."

→ "when conducting an industry analysis, the first step to be completed is identifying which industry a particular company is a part of." (page 16)

→ Market trend

→ "actual and potential size of the market, market and segment growth, market and segment profitability, the underlying cost structure and trends, current and emerging distribution systems, the importance of regulatory issues, and technological changes." (Kluyver, 2009)

→ Customer analysis

→ (1) identify targeted customers

→ (2) convey the needs of these customers

→ (3) show how EP's services/products satisfy these needs.

→ goals of a survey

- to create a clear, concise, and easy survey from the survey taker's perspective
- Create questions that will qualify the survey taker
- create questions that will provide the most information in the little time to work with.
  - we would need to formulate question objectives.

15

11/12/11 Go Read Don Dillman's ⇒ "Surveys: the tailored design Method"
→ his method was designed to improve response rates and increase quality of feedback
→ social exchange theory → use incentives to increase response rates → Brilliant!
→ question and layout design are directly related to quality of information received

Product research 11/13/11

U.S. Becomes a Bit Player In Global Semiconductor Industry: Only One New Fab Under Construction in 2009

By Richard A. McCormack 02/12/2009

- plants cost upwards of $8billion generating thousands of jobs
- Saratoga County, NY, a Global Foundries facility that will produce 90,000, 300mm wafers per month.
- Every country except the United States tries to attract investment in semiconductor manufacturing by offering companies tax holidays, tax abatements and subsidies
- a semiconductor manufacturing company wants to make an investment in another country those incentives will save at least $1 billion in costs over a 10-year period
-

7

11/13/11 Hemlock Semiconductor Construction work force in Clarksville, Tenn estimated to hit 1,500 by mid-20

By Andrew Dodson 12/27/2010

- Hemlock semiconductor group
- Project was under way since 2009 and is designed to meet the global need for polycrystaline silicon - the ultra-pure building block to fashion solar cells and semiconductor chips

Looked into Hemlock semiconductor group homepage.

Polycrystalline silicon for demanding semiconductor and Photovoltaic applications

Flowchart for semiconductor construction →

www.hscpoly.com/images_hsc/flowchart 0605.jpg

Contact information
12334 Geddes Road
PO BOX 80
Hemlock, Michigan 48626

Tel → (989)301-5000
Fax → (989)301-5574

8

Chartered semiconductor Manufacturing 11/15/11

- comprehensive wafer-fabrication services and technologies to semiconductor suppliers and systems Companies
- Chartered Semiconductor Manufacturing, one of the world's top dedicated semiconductor foundries, offers leading-edge technologies down to 90 nm, enabling today's system-on-chip designs

Wiki page

Acquired by global foundries

Customer base is primarily high-growth, technologically advanced companies operating in the communication, computer and consumer sectors. Does not provide design services and works from customers' designs to produce communications chips.

9

11/13/11 Global Foundries.com

Attempt to be the world's first universal foundry company

Customers - over 150 worldwide
- includes many of the world's largest semiconductor companies.

10

Semiconductor Electronics/Diode/Construction and Operation 11/13/11

en.wikibooks.org/wiki/Semiconductor_Electronics/Diode/construction_and_operation

A diode is formed by joining two equivalently doped P-type and N-Type semi conductor. When they are joined an interesting phenomenon takes place. The P-type semi conductor has excess holes and is of positive charge. The N-type semi conductor has excess electrons. Due to this difference, Some of the electrons get attracted to the corresponding nearest holes and become neutral. This process takes place until an equilibrium is reached in the surrounding region of the contact surface. This leaves a layer with neutral charge of thickness nearly less than 0.1 mm known as the Depletion Layer. This layer is responsible for the development of resistance inside the junction Diode.

Not sure how relevant this is.

Legitimate Company for a questionnaire

11/13/11 NXP: How we make semiconductors.

- The raw material for a 'chip' is silicon
- Front-end operation
  → a blank wafer, typically silicon, is the start.
  → Semiconductor manufacturing uses chemicals to create circuits by adding and removing layers onto the wafer.
  → An insulating silicon dioxide layer is is grown onto the silicon wafer.
  → then, the electrical characteristics of the individual transistors are altered by diffusing or ion implanting precise amounts of impurities into the silicon
- Backend Operation
  → 1) Die preparation cuts the wafer into individual integrated circuits or dice.
  → 2) Die attach attaches the die to the support structure
  → 3) Bonding connects the circuit to the electrical contacts of the package
  → 4) Encapsulation gives physical and chemical protection to the circuit

The chip making process

www.nxp.com/wcm_documents/about/corporate-social responsibility/sustainability/Chipmakinggraphic.jpg

12

Advisor meeting minutes Prof. Hoy Present 11/14/11

Really want to find out what current users of the product like about the project
- don't want to change some thing consumers like.

Survey barometers are very dangerous.
- get the easiest book you can find on how to do survey research

- best bet for this project is to do face to face interview style surveys
  - Ben Clark is a good resource to talk to companies and make ourselves a credible source and not a nuisance

- Prof. Hoy likes looking at past projects to find things that have already been done.

- for interviews, need a citation that develops the guide lines for the interview process

- research into current competition for the PUMA 260 so we know what we're up against

- How will the manufacturing process need to be changed in order to build the new product?

- Changes of the construction material

B

11/14/11

- Look into other industries the robot is used in
  - Biotechnologies
- within the next few days looking into having a new place for the robot to be
- Ben believes in learning through doing
  - important resource.
- Send out the most recent copy of the Gantt chart and the statement of purpose for the project

14

11/15/11

Ohio State University hand book on evaluation

aside → Further reading for face-to-face interviews,
Fowler, F.J., and Mangione, T.W. (1989). Standardized survey interviewing. Newbury Park, CA: Sage Publications

McLaughlin P. (1990). How to interview: The art of making questions. North Vancouver, B.C.: International Self Counsel Press

Rubin, H.J., and Rubin, I.S. (1995) Qualitative Interviewing. Thousand Oaks, CA: Sage Publications.

→ This is a guide for people doing center evaluations but it is extremely applicable to the general style of problem solving anyone should use

→ there are 6 steps (It would be pertinent to make a novel slide show for this strategy)

1. Focusing your evaluation
2. Measurable Objectives (ABCD Rule)
3. Barriers to evaluation
4. Methods of Data collection
5. Organizing, Analyzing, Interpreting, Summarizing and Reporting results.
6. Developing the Evaluation Management Plan.

→

15

11/21/11 Advisor Meeting (Schaufeld)

→ two parts of the process

→ market research

→ manufacturing process

- Most intrigued about how we are going to decide what to do.

→

Kasouff → check with him about the surveying process

Take names of people who already use the product

→ what would it take for them to buy the next version

→ Do not approach this generally

- the people who have it bought it for a reason

- what was that reason.

- Get direction on redesign from Companies who use it.

- Talk to Ben about getting link lengths, angles, and statistics

- and a bill of materials

- Staubli annual report → look at their expenditures and usages.

- adding a new feature might retain customers
- Start formulating questions to ask Consumers
- determine comparable robots

17

Advisor meeting (Schaufeld and Hoy)

- We have a guy who does injection molding
  - he will get us a price once process is estab[lished]
- Toss around how to get the information
  - survey monkey
  - face to face meetings
  - phone calls
- Make sure that you are not getting rid of a feature that is useful to the customer.

- Email Joe Gemma

- ask for a bill of materials

Contact LVelligu@intersil.com and RHERREN@intersil.com.
→ Intersil Florida.

→ Budget parts for the robot
  → find out if Stäubli will supply us with the controllers and motors.

- Talk to mom about getting the Survey Monkey up and running.

* Validate the usage of injection molding as a way to increase cost effectiveness.

18

Advisor Meeting (Schaufeld and Hoy) 12/05/11

- Robot locked down and ready to go
- find out what uses people wish it had
- make it more programmable
- programming is easy to understand and read
- warranty card → intended uses → find some warranty cards from companies and use them for the start of the data base.
- ~~need a female to male converter~~
- no problems with the controller

19

Survey Questions 12/06/

What company do you represent?

What application is your company using the PUMA 260 for?

What features make the robot useful in these applications?

Why did your company originally use the PUMA System?

What feature do you think the PUMA 260 could have that would improve its performance?

What products does your company produce?

Are there any applications that the PUMA 260 could be used for that are currently being filled by other applications?

What features would make the 260 applicable to these situations?

What applications would you have liked the PUMA 260 to have?

Would you buy another system if it was an improved model?

20 If not, what would you choose?

What parts, if any, do you find break/malfunction most often

Metal injection molding versus Machining and Casting 12/6/11

→ Key advantages
→ decreased production time
→ repeatability
→ decreased need for secondary operations

→ reduction in manufacturing time allows manufacturers to meet the JIT, "Just in Time" requirements of customers in today's lean economic environment.

→ Candidates for this process
→ small parts with a complex geometry

→ Alloys available
→ Copper, Gold, Gold-Copper alloy, Silver, Silver-Copper alloy and some Active Braze Alloys
→ 17-4 PH SST, 316L SST, 304L SST and F-15 alloys.

Properties of parts machined like this
→ Density: 95/99%
→ size: .0005 - .22 lbs ← small pieces

Process requirements
→ tooling - mold cavity
→ mixing - combines metal powders with a multicomponent thermo plastic Binder system
→ Molding - occurs in typical plastic mold machines
→ stripping - debinding to permit sintering
→ Sintering - removes residual binding in a controlled atmosphere and causes the whole part to shrink to virtually full density.

21

12/06/11

Chart that shows advantages versus
- Die casting
- Investment Casting
- Machining
- Powder metal and sintered

Relative cost of fabrication pi chart
→ the more complex the part, the more cost effective MIM becomes (savings from 25-70%)

12

Meeting with professor Kasouf to discuss the survey questions we have constructed. 12/12/11

→ Any kind of data collection is exchange.
  → people you are collecting data from want to have a reason to respond
→ best single resource for questionaire design is Don Dillman
→ why is the problem important?
  We are asking you specifically because your input is valuable and there is interest for your company.
  → this creates a positive response that will allow the data we receive to be useful
→ Backward questionaire design → Harvard 1980s (Business review 1985)
  → Begin research by knowing where the information you get is going to be used
  → this drives your collection
  → what information/decisions does the data help you make!
→ Cover letter → most important part of the questionaire
  → why important?
  → why important to them?
  → why is it important they respon?

23

12/15/11 Trying to get the computer to talk to the robot

→ PuTTY so far ineffective. (look into this)
→ All fixed → COM4 port.
- Faulty nesting system. Really finicky.

Joint 6 error → Broken wire on the motor
→ have to get a sodering iron to fix a broken wire.
Besides that everything is up and running

codes
cal → calibrate
do ready → ready position.
do nest → nest

24

More questions 12/20/2011

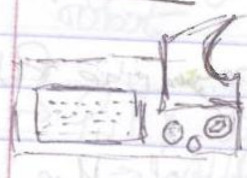
How often does your company use PUMA 260?

How would you rate the value of the product

25

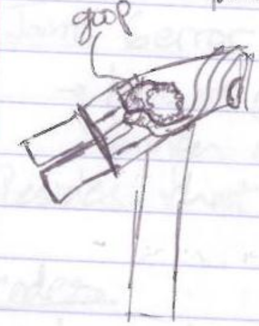
12/13

Robot



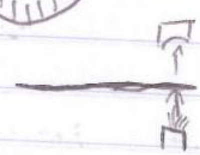
major motor

minor motors are just smaller



arm head

Experiment with covers that snap on.



26

Questions for Ben 1/19/12

When did you start working with the PUMA systems?

When did you start RP automation?

What were the reasons behind the start up?

What type of business is RP

What are some of the diff. markets RP represents?

How do you see the PUMA system being used in the near future?

What tasks would you like to see completed by the project team?

What market did you see for the system when you first started working with it?
- How has it changed?

What makes the 260 unique compared to others (same line/type of product)?

Why is it important that this is the product to be updated?

27

1/19/12 Background

→ potential sections

- Injection Molding
- Gear ratios / friction coefficients of synthetic materials
- semi-conductor physics
  - how the RWMA applies

JB

01/22/12

Interview with Ben Clark

→ I studied a manual.

→ with the current gear design, grease is necessary, but you could potentially do some jesgears for the PUMA.
→ look into some polymer/spray to lower friction.

→ "pancake motor" that fits inside the gear assembly

We went to the lab to work but the BATRAM had been wiped so we had to build a new serial cable to reinstall the data. This will allow us to calibrate the robot.

When bringing this robot up to date, I think it would be relevant to get the data off of floppy drives and onto more modern technology.

29

01/30/12 MQP Advisor meeting Prof Hoy.

→ memory issues to address in the future.

→ in San diego → Zimark - look them up to check out sample preparation

- if we update it, there will be a market for it.

- looking up vendor competition.
  - what is currently seen as the key elements this robot provides that is not on the market.

- Out put is a chart
  things we want to do vs. where things are go

if repeatability goes down, what new markets does that open up?

What does new things enable the robot to do that it hasn't before?

where is the threshold for capital expenditures?

the innovation cycle.

30

What is the real value of the cost reduction exercise?

Check into semiconductor plant in San Diego.

- Extends to new Market
- displaces other products
- advances reach in current market.

31

Sunday walkthrough

ReTiSoft works with Staubli TX

GNF systems also has Staubli stuff. RX

Ruro → RFID technology → could the robot be used for place ment?

Precise Automation

Oasis → looks like they have a different system
→ definitely a company to talk to

Material Bioscience → had a similar robot.
on a track → large setup.
→ Mitsubishi S-series

Custom Laboratory Automation
→ has a 6DF robot.

HiRes bio solutions → looks interesting to talk to

Biotix - uses a tabletop calibration system →
Check in with Artel

Schaeffler → using a similar robot.

Peak robotics - (2DF)

Cyth systems

32

What makes the staubli product useful in ? your application?

do you feel there were limitations with the ? equipment

were there any size limitations?

are there any other applications in your company that use similar equipment?

Why did you choose the robotic system you currently use?

Do you find any limitations with the system?

How easy is the control system to use?

If presented with a "betteroption" would your company make a switch?

Are there any applications in your company that could make use of a six degree-of-freedom roboticarm?

33

Monday

ReTiSoft

GNF

RoRo

Precise

Oasis

Material Bioscience

Custom Lab Automation -6DF

Miles Biosolutions

BioTix

Schaeffler

Peak Robotics - 2DF

Cyth systems

CyBio

Jameson Mattice

Application Engineer

Dan Chu

Brian Woods

Sales Reps.

Dan 100-700
Max 800-End

Stopped @ Staubli

Nikon

Lets Go Robotics

Applied robotics

Interlab service

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Staubli → TX 60 demo.
→ seems like alot of the applications are enclosed.
→ ±.02mm
The difference between TX and TXL is the length of the arm
→ Staubli controller runs a 110 option (this is what the Puma uses)
→ inside cabling
→ pharmaceutical/medical
→ neat clear jobs
→ meets iso Standards
→ easy to clean
→ can use most chemicals on it.
→ fanuc and kuka are the biggest competitors
→ upand comers → denzo
↳ biggest competition for th
↳ they have more small robots.
→ biggest buyer is Bowman in Europe
→ Germany is the biggest.
→ Just got into photo votaic market → solar panels
→ many customers here.
GNF – offshoot of Novartis
Definitely go talk to them.

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Bürkert

4.5mm valves for pipeting

doesn't quite need a six → Shoulder Effect.

sells the valves to companies who use the robots

Rutledge resource solutions → use him to market potentially

Terry Rutledge

* → lines customers up with fabricators
  → commissions it for the customers
  → aligns with an integrator

Bürkert

could use a small tabletop six axis.

Lab automation / Drug discovery / Genomics

* DiscoveRx
  - use it to put the compounds into the plates
  - use the arms to work with the drugs
  - screening grp could use the table top robot.
  - Neil Charter - automation
    ncharter@discoverx.com

Chem speed

Automate sample prep.

* Thermo

Assembling cell phones

sharpening drill bites

Industrial

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Select Science

selectscience.net

information hub for scientists.

4titude

seals

and plates

→ heat sealing unit, manual plate loading

→ small arm robot could be useful here

* Precise Automation

$15,000 → product estimate.

repeatability for linear → 50 microns

50 → 85 °C temperature automation

Goal is low cost desktop safe lab equipment

Kinematically driven → very important.

~~[illegible]~~

all on encoders

focus on designing work cells (so much empty / small lab space → you want to accomodate for people with this problem.

very volatile target market

need to target people with a long term vision.

CS8C → Staubli controller

works on resolvers.

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* Bio Sero
  scorpion arm for plate stacking and sealing
  plug and play system.

* Pacific_iD
  - bar code reading
  - Cannot read anything that isn't flat
  - 6axis could open up market in wrapped codes around vials.

* igus
  PMA lowcost tubing
  could dress outfit of a robot at low cost.
  plastic bearings
  going to send a catalog so we can look at products

  mark wall providence
  mwall@igus.com.

* Epson
  Scara robot. linear need with the plates.
  also produces the sixaxis → competition.
  175mm → 1000mm Scara
  600mm → 1000mm 6axis
  Scaras are easier in programming and teaching
  True windows based programming for epson.
  takes pictures of different colors → in the industry different colors mean different things.
  "leader in PC based Assembly Robots"
  C3 is base 20K

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ReTiSoft
→ mostly does programing

GNF
- the more machines you put around it, the larger the reach needs to be
-

* Lin Engineering
step motor specialists
→ lower reverberations and heat output.
how much power do we need on the robot?
Torque to move what we want to move.

Elmo
light weight drivers

(geneva mechanism) Helical
springs → looks like what is in the robot

* Automation Solutions (wako lab automation)
→ absolutely thinks there is a market
→ lower payload on the one they bought
→ you can actually grab it and stop it with your hand. that increases the usefulness
→ really easy to teach positions
→ you can push a button to release it, move it with your hand and teach it that position

- Can rotate 720° → no dead spot.

UR → Brand of the robot being used. (Universal Robots)

±5/100 of an inch (ish)

Matrical Bioscience

→ Ceiling mounted mitsubishi s series.
→ they sell the system/whole work cell
→ selling to compound management
high through put screenings
pharmas
universities
niche market in agriculture

Harmonic drive

precision gearing
high reliability
zero backlash

servo actuators
high torque density
Hollow shaft design

CHD ①CSD 2UF
SHF
②SHD

Thermo

could have a need.

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Tuesday

Mini Fab

→ Injection molding small plastic pieces

Perkin elmer _ Caliper

→ very unique pipetting robots.

→ doesn't move the plates

*Perkinelmer

any market for a six axis → hands off.

theirs is just doing plate movement.

*Tapbiosystems

uses the arm for moving flasks

shaking

pipetting

grab plates post culture and get them to a new work station

Custom Laboratory Automation → astech products.

→ integration.

Brooks life science

not necessarily using a lot of six axis

High Res Bio Solutions
Using a Denso six axis.

Their cell seems cramped in its work place.

Biodirect
used equipment → system integration
(thermo)

Peak Robotics
strictly 4 axis → sometimes 5 axis.
mostly plate movement and storage
notes helpful as others

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02/10/12

→ finish writing the part on evaluation
→ methodology on the trip
→ how the robot works. → programming.
→ load testing
→ explain the questionnaire
→ get Ben to email that list *
→ email helpful companies from the conference.
→

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Schaufeld and Hoy both present 02/13/12

- → Learned a lot about the industry
- → most companies were very up front with their data.
- → mostly plate handling and movement.
- → robots are always useful in integration
  - → they do not take vacations
- → there is room for the robot in the industry but it may have too small of a reach.
- → people tired of lab techs making mistakes and spending too much time on lab prep. They would rather have them reviewing data and making calculations.

- → people concerned with getting their tests done quickly and accurately.
- → smaller robots better for cramped spaces.
- → the analytical process has gotten faster.

- → if we stay at a $40,000 price point, sales of the robot will be low as market entry due to competitors will be high.

- → is there a reason that no one at the conference had already looked into a plastic polymer Chassis

- → still going to target a low cost robot.

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need to contact the:
step motor people
harmonic drive gear people
injection molding people

need to look up pancake motors
get the robot up and running and determine where changes can be made.

analyze the bill of materials
→ take it in modules
→ address the new pieces by removing old pieces
→ lowering the parts count should theoreti lower the price point

If we can only sell these as cheaper modules to people who already buy the robot and cannot break into a new market with new customers, then it shou be abandoned.

If we can only gut out the robot to make it a shell of what it was, then it is not worth hitting this market, but selling to a new market could be an option if we can determine what market would exist.

45 Concise but sufficient data in writing.

Filling at the Evaluation Bulletin:

Page 4 What will be evaluated?

We will be evaluating the market capacity for a table top six axis robot and establish what chages need to be made to the robot to make it market relevant

Page 5 Describe the purposes for your evaluation.

→ To clarify the role this robot will play on the market.

→ to modernize the technology to increase ease of use and accessability to spare parts for broken machines

→ to inject the market with a new presence should it be deemed viable.

→ to determine whether the project is worth the resources it will consume.

Page 6 Who will be affected by or involved in the situation?

Ben Clark / RP Automation → wants to know if the project will net him a positive revenue in the future

Schaufeld / Hoy → want to understand the decision making process

Benko and McCarthy → evaluation will produce a grade for a major assignment.

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meeting w/ popovic

2/16/12 - good adaptive control system could make up for temperature change properties of acrylic → (vision based)

- without adaptive control you need to use metal chassis

Check into adaptive control system.

Cheaper/intelligent machine.

for the tasks we want to do, bad hardware with smart control system.

need to look into the ability to make acrylic clean room safe.

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2/16/12

What are the critical questions the evaluation must address?
- What does the market demand that the product do?
- Is it pertinent to follow through with this project?

Step 2 → Measurable Objectives

ABCD Rule
Audience - who is involved?
Behavior - how must they act?
Conditions - what must the environment be?
Degree - how important is it?

Step 3 → Barriers to evaluation
There are multiple categories listed that could provide an obstacle for completing the project. They must be considered when moving forward because unless you know what you might be facing, the implications of hitting an obstacle could be huge.

Organizational Politics:
Is there support? RP and Staubli are both helping. This is a very secure project. Some of the information has to stay in house.
Project Leadership: The project is being run by RP and our advisors. They want to see a completed project (RP) and an understanding about how a group comes to a conclusion about an idea.

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2/17/12 Professional influences:

There could be professional groups interested if we could finish the project out. small companies who need integrated technology could be interested.

History:

Stable project. This has not been done

There is a current product

Organizational Setting:

The job is for a major company.

we need the people running the project to get us information when we need it.

Economics:

we will definitely have the money we need to cover the project.

Interpersonal patterns:

no inner controversy.

Legal guidelines:

no rulings/laws that should affect the projec

Resources:

enough resources to move forward.

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2/19/12

Step 4 Methods of Data Collection

see later date

Meeting with Max 2/22/12

We want to split up the methodology that I wrote and put some into the background.

We use the robot almost as a base for the decision making process.

Interesting how different background individuals can come to the same conclusion about a topic not similar to either of their ideas.

Results — Concluded that if changes are not made to the robot, clients will be lost anyways.

Floppy drive capacity is really annoying

Methods of Data Collection. 2/23/12

Chosen Data collection methods:

- → performace tests
- → Questionnaire
- → Individual Interviews

Issues:

Availability of info

Reliability of respondents.

Section on Questionnaire helped us form our version.

→ Implementing.

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2/23/12 Step 5: Organizing results.

even before collecting information, the evaluation team needs to know wh[at] they are going to do with the informat[ion]

Results can be extremely varied based on the scope of the evaluation so it is important that each bit of information recevied finds its pl[ace] in the project

Type of Data	Data analysis Method
Questionnaire results	Opinions will be dig[ested] and applied to [the] prototype idea
Interview notes	Market analysis data to determine the direct[ion] of the robot
Performance tests	Gauge the current strength of the robot to determine base for remanufacturing

* interesting point (page 36)
suggest an evaluation report written in the typical style of an MQP@W[PI]

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Step 6: Developing an Evaluation management plan 2/23/12

Organization of who is in charge of what.

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Prof. Hoy Present

ADVISOR Meeting 03/29/12

ETR form

- Meeting w/plastics person Tuesday,
  got a good material. - $20 a part
  30% glass
- not cost effective to injection mold
  because we would need to be selling 200 robots.
  -
- issue w/ cost reduction was reducing the # of parts.
- who gets points in the company for cost reduction?
- cost reduction adds market extender.
- is the small arm not being updated because they don't need it
- adaptive control system.
  - if the part reduction does not do enough to reach the market extender, write a section on beyond phase I.
- culturally - Japan.
- meeting with Popovic soon
  - need to go more with cost reduction.
- check on achieving profitability from this cost reduction.

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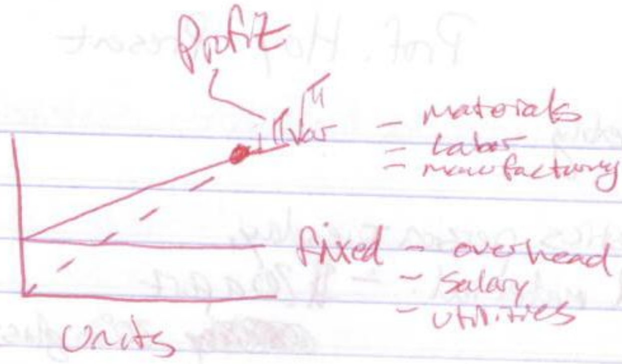
03/29/12



have to increase units sold
orelse variable will fall below fixed costs
else there is no profitability.

spread sheet # of parts now
vs # of parts after.

04/10/2012

Background research Semiconductors
(market, construction, use for the robot)

- Construction of a new semi conductor wafer fabrication plant costs upwards of $8 billion (2009) and generates thousands of jobs, revenue for local communities and massive investments in research, equipment and materials.

- Every country except the United States tries to attract investment in semi conductor manufacturing by offering companies tax holidays, abatements, and subsidies.

- Richard A. McCormack / U.S. Becomes A Bit Player In Global Semiconductor Industry: Only One New Fab Under Construction In 2009 / Manufacturing and Technology News / Feb. 12, 2010 / Volume 17 No. 3 / www. manufacturing news. com/news/10/0212/semiconductor.html

Hemlock Semiconductor constructs Poly crystalline silicon for demanding semi conductor and photovoltaic applications.
Located in Europe, Japan, Korea, Beijing, Michigan, Tennessee

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Potential market extender research

From the Department of Veterans Affairs

04/10/2012

*** Clinical Evaluation of a desk top robotic assistant.

Joy Hammel, Karyl Hall, David Lees, Larry Leifer, Machiel Van der Loos, Inder Perkash, Robert Crigler

Journal of Rehabilitation Research and Development Vol 26. No. 3 Pages 1-16

- Johns Hopkins/Applied Physics Lab designed a workbench mounted robot similar to a prosthetic arm controlled by head motion joystick and sip/puff controller
- Tufts - NE Medical center developed universal software language, Calvin
- Boeing - voice controlled work station
- Canadian Neil Squire Foundation - low-cost manipulator for desk top applications
- Netherlands - wheel chair mounted joystick controlled manipulator.

- Study conducted on the DeVAR system, specifically the third generation, which was standardized to focus on Daily living applications

- Study used a Unimation PUMA-260 mounted to a 3'x6' table
- prosthetic hand end effector

- The PUMA's reliability (based on hundreds of man-years of industrial experience) has allowed the DeVAR system to maintain commercial standards of performance, robustness and safety.

- Safety measures built into the program: 1) user can say STOP 2) stop switch on the wheel chair 3) robot interprets any loud noise as a stop command. ⟶

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4) Stops moving and shuts off when feeling a resistance of 5+ p
5) The robot only accepts appropriate commands
6) Before initiating a task, the robot checks to make sure that its hand is empty and the table top is clear

→ Measurements for evaluation: Questionnaire
1. Pretest - asked disabled users their opinion on robotics before they had an opportunity to to work with the robot
2. Post-Test — asked to comment on perform
3. Interview
4. Observer assessment
5. Computerized history list

→ results showed that most users were satisfied/neutral in the usage but preferred the robot to a personal attendant on average.

→ people liked the independence.
Concerns: reliability/workstation size.

→ large shift in opinion of robots for users pre

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Semiconductor Wafer Mathematics 04/10/12

By Michael Hackett 05/09/2011

Wafer map is described with overlapping cartesian coordinate systems for reticles and dies.

→ Mainly about translation and rotation on a coordinate plane.

04/10/12

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Max's Journal

Plastics Meeting. 27/3/12

GoTo Meeting to discuss arm molding

current state is not moldable

material is common metal replacement

amodel - better creep over time

Injection molding
- maintain 3-4 mm wall thickness
  - 80-90% of nominal wall
  - draft 1° per side

need more than 100 parts
- best 500 parts

~~mold cost~~ = $3500 tooling
$20 Mat / ~~cost~~ Part

Hartland robotics

need prototypes
- machine out of cast part first
  - for prototypes

263-417-3489
gregg mathews

Edd Flaherty

4. Jt 3 assembly
   - extrude bull gear and "cover"
     → .25 below center
     → 1.558 off center
     → big circle lines up with arm edges
   - cut cover
     → same as Jt 2 process

5. Cut remaining material from link

6. cut input gear holes

7. Screw holes

Solid work steps

Jt 2/3 inner link

1. Extrude main block
   - 10.625 total length
   - use jt 3 bull gear cutout as outer radius
   - 1 7/16" flat on top 1.540
   - direct to arch
   -

2. Extrude motor mount
   - solid max outline
     - total = 1 7/16"
   - cut top and bottom
     - leave lip
   - cut wedge
   - cut motor holes

11.75
2.59
-.25
2.34

3. JT 2 assembly
   - extrude extended "covers .213"
     - 2.25 r on bull gear
     - r = .625 "cover"
       → 2.37 of center
       → .1 above center
   - cut JT 2 housing
   - extrude Jt 2 mount
   - cut wire pull through
   - cut gear housings

2.673" x .385'
1.373" x 1.18"
x 1.465

cheap but quality construction could be the first move towards "throw away" robotics.

Conference Notes

After talking to many of the industry leaders in lab Automation, we determined there are a few different approaches to entering such a market. Unfortunatly it seems as ~~though~~ that the reach of the 260 does not benifit the robot. Most of the applications require that the robot be able to reach various different stations that are placed within the work cell. The limited reach of the 260 greatly decreases the number of stations lab automators might require.

On the other hand, table-top design would be great for repetitive tasks that don't require a lot of space. The flexibility and compact size of the 260 can benifit this area of the industry.

Anothe big factor upon entering this industry is cost. Many labs are budget concience and would rather move towards cheaper equiptment if possible. Hitting a lower price point is crucial to getting interest from more laboratories. Although there is a fair amount of robotic arm competition, all tend to be upwards of 20 thousand and have a much larger reach.

10. Ben thinks there is a market for it

→ very few products that have similar quality for same applications

→ very global (not russia)

7. like to have a final product

→ analyze manufacturing process

→ reduce part count

→ change feedback system

12. have a successful product

→ manufacturing it

→ viable product for customer

9. Programable Universal Machine for Assembly

→ first came out
- most repeatable robot
- first table top design

→ Staubli (now)
- more expensive
- tightest repeatability
- very fast

6. currently, 26 eaton epi reactor applications [illegible]
→ deposit conductive or insulating layer onto waffer

bio instruments field

☆ 260 is ceiling mountable in current settings

Small parts assembly

11. everything is obsolete

Answers from Ben

1. 1982 working for AFC Catennas For communications) tocamac
   - meet employee of unimation
     -> continued from there

2. RP was started in 1984

3. Westinghouse was moving to pitsburg
   -> didnt want to go
   -> became hang gliding bum
   -> calls from Kawasaki
   -> installed 250 robots and started business

4. engineering and support services for Puma and Staubli robots

5. bio med, Pharmaceutical, semi conductor, generall mfg.

8. mostly biomed,
   first project was brain tumor research
   a.) progressed into automotive
   -> bio med. eng
   -> pharmaceutical
   -> semi condutor
   -> +I etc.

√11. Why is the new control system important?

√12. what ~~will you~~ do you hope to gain from this project?

Questions For Ben 19/1/12

✓1 When did you start working on the PUMA systems?

✓2 When did you start RP Automation?

✓3 What were the resons behind starting this type of business?

✓4 What type of business is RP?

✓5 What are some of the ~~more~~ different markets that RP represents?

✓6 How do you see the PUMA system being used in the near future?

✓7 What sort of tasks do you want to see completed?

✓8 What market did you see for the ~~pu~~ system when you first started working with it?

a) → how has it changed?

✓9 What makes the 260 unique?

✓10. Why is it important that this is the product to be updated?

Kasouf Meeting 12/12/11

any data collection has to have a reason
- how is it attractive to them
- benifit etc.

Don Dillman
- library for questionnaire resource

Why this is important is key in cover letter
- make sure it is attractive to the selective companies

Backward market research design
- begin research by knowing how the info will be used.
- what decisions are made from our report

Internet vs. hard copy
- depends on the audience
- cover letter is most important
  - → why important
  - → why important for them
  - → why should they respond.

Ben being first contact will help

Proposed survey Questions

What applications ~~are~~ is your company using the Puma 260 Robot for?

What features make this robot useful in these applications?

Why did your company originally choose the PUMA system?

What feature do you think the PUMA 260 could have that would improve its performance?

What products ~~does~~ your company produce?

Are there any applications that could use the Puma 260 that currently are filled by other solutions?

What features would make the 260 applicable to these applications?

What applications would you have liked the Puma to do?

Would you buy another with better features?
If not what would you buy?

Development and Application of a Multiple Opportunity Analysis Tool — TS Lynch

Ideas → Opportunities tests

- can you talk to some potential customers?
- do they think the idea satisfies a need they may have?
- are they willing to pay for that value

if yes, potential opportunity

How opportunities arise

1) discovery
2) creation
3) understanding market need

Figure 2 - process Map of entrepreneurial Alertness

Figure 6 - opportunity Identification, evaluation and selection

5 types of survey

Questionnaire - on paper (Gillham)
- multiple choice or scaled questions
- no open ended questions
- participants can not ask questions
- large sample sizes

Interview - verbal (Gillham)
- face-to-face
- more open ended
- still very specific questions

Focus groups - verbal (Willis)
- interview with larger group

Distance Methods (Greenbaum)
- telephone
- email
- internet
  - hard to get feedback
    - seen as a disturbance

Sources

Gillham, B. (2005) Research Interviewing: The Range of Techniques. New York: University Press

Greenbaum, T.L (1998). The Handbook for Focus Group Research Sage Publications, Inc

References

Malone, Bob. "George Devol: A Life Devoted to Invention, and Robots." *ieee Spectrum: Inside Technology*. N.p., 26 Sep 2011. Web. 4 Mar 2012. <http://spectrum.ieee.org/automaton/robotics/industrial-robots/george-devol-a-life-devoted-to-invention-and-robots>.

Ricker, Karen T., Larry C. Brown, and et al. "Water Quality Project Evaluation: A Handbook for Objectives-Based Evaluation of Water Quality Projects." *OhioLine*. N.p., 1998. Web. <http://ohioline.osu.edu/b868/>.

Figure 1. George Devol. < http://www.washingtonpost.com/rf/image_606w/2010-2019/WashingtonPost/2011/08/17/Obituaries/Images/OB-MAIN-DEVOL_1313620202.jpg>.

Figure 2. Programmed Article Transfer. <http://spectrum.ieee.org/image/1929929>.

Figure 3. Patent Design. <http://spectrum.ieee.org/image/1929980>.

Figure 4. PUMA 260. <http://i.ebayimg.com/t/Staubli-ASML-Robot-Arm-PUMA-260B-rebuilt-/12/!B61Wucg!2k~$(KGrHqV,!iMEyeLYuMs2BMyfC!O6og~~-1_35.JPG>.

SLAS Picture. <http://www.slas2012.org/images/m-logo.jpg>

Graphic 1,2 and Table 1,2. <http://www.sciencedirect.com/science/article/pii/S0142941801000174>