Design and Implementation of an Automated Pick and Place System for Johanson Technology, Inc.

by

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A Senior Project submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in Industrial Engineering

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Introduction

This project, in partial completion of degree requirements for a Bachelors of Science in Industrial Engineering, has been performed at Johanson Technology in Camarillo, CA. Johanson Technology was facing an increasing customer demand of Ceramic Single Layer Capacitors and needed to increase the throughput of their packaging station to meet this demand. Currently one person is designated to picking and placing capacitors into Waffle packs, plastic pocketed trays, while another person places capacitors onto Gel Packs or Ring Packs. Johanson had the choice of several solutions to increase throughput: hire additional packers, design a custom automated system, or purchase an existing automated robotic arm. This paper looks at the cost analysis and research that led to Johanson Technology's decision to purchase an existing robotic arm known as the RS20, manufactured by Stäubli, and the steps taken to integrate this robot into full production.

This project is a continuation of a summer internship with Johanson Technology in 2010. During this internship in the Single Layer and Thin Films department, focus was directed toward programming a newly purchased Stäubli RS20 robotic arm to pick up capacitors from a vibrating bowl feeder and place them into Gel-Packs, Waffle packs, and Ring packs. Additional tasks included:

- Designing a vacuum tool on AutoCAD that will handle the capacitors in the system
    - Insuring compatibility with the RS20 (Physical connection, weight, wiring)
    - Manufactured at Groth Engineering
- Programming, using VAL3 software, instructions of pick up and placement
    - Verification and support from Stäubli software engineers
- Performing necessary electrical wiring to the controller, computer, and voltage supplies
    - Integrating the compatibility between the Electrosort Bowl Feeder and the Stäubli RS20
- Researching additional functions such as position and vacuum sensors

Following this internship, this report was conducted to:

- Perform Cost Analysis of alternatives
- Construct a Bill of Materials (BOM) of complete Robot system
- Integrate Human Factors Engineering into work space design and controller interface
- Simulate alternatives as well as continuous expansion and improvement plans
- Reduce variability of capacitor movement on pick up and placement operations

The Cost Analysis will incorporate cost measurement techniques acquired in Cost Measurement & Analysis (IME 239) and Facility Redesign (IME 443). It will look at costs and benefits of implementing each alternative to increase the throughput of the packaging station in the Thin Films department. Next, a Bill of Materials (BOM) will be constructed to provide a means of structuring a material requirements list for future installments of additional pick and place systems. This section utilizes the knowledge of Material Requirements Planning and Manufacturing Resource Planning from Inventory Control Systems (IME 410). Next, the work station and controller interface will incorporate ergonomic principles that were studied in Human Factors Engineering (IME 319). To save on costs of implementing each alternative and to verify the potential benefits of a new packing system, a simulation will be ran using ProModel Simulator, a program taught in Simulation & Expert Systems (IME 420).

The end result of this project will be a fully functional and accurate pick and place system that can package Gel-Packs, Waffle Packs, and Ring Packs efficiently and with high repeatability.
This report begins with the background of the project and a description of why it is necessary for Johanson Technology; it then goes into research of key aspects in this project and follows up with details of the design considerations and the methodology process behind the system. And, in conclusion, summarizes the economical analysis of the system designed and its benefits, and recommendations.

Background

Johanson Technology provides High Frequency Ceramic Solutions for cellular, WLAN, Bluetooth, RF/Microwave, Millimeter Wave, and Fiber Optic applications, as well as custom high frequency ceramic solutions. They offer a broad range of Multi and Single Layer Capacitors, RF Inductors, LTCC based Chip Antennas, Baluns, Balanced Filters, Band Pass Filters, Low Pass Filters, Couplers, and Diplexers, as well as other components. With a highly experienced design team, they produce superior High Frequency Ceramic Solutions through optimization of ceramics, inks and RF circuit designs. Johanson Technology has received certification to the ISO9001-2000 standard and uses this widely accepted standard to ensure design control.

The company is owned by Eric Johanson. Eric Johanson's father started an electronic manufacturing company in New Jersey in 1945 called Johanson Manufacturing, Inc. and it is still run by Eric’s aunt, Nancy Johanson in Boonton, New Jersey. Eric became an Engineer and established Johanson Dielectrics, Inc. (JDI) in Burbank, California in 1978. In the 1980's, a Materials Science Engineering student, John Petrinec graduated and went to work as a Process Engineer for Eric Johanson at JDI. After a couple of years, John struck out as an entrepreneur and started his own company. After another 2-3 years, John sold his company and went back to work for Eric Johanson, starting a new company called Johanson Technology Inc. in 1993 in Camarillo, CA. One of the first innovative products was a laser trim capacitor that could be precisely tuned saving manufacturers of mobile pagers a lot of time in the manufacturing process. The company then focused on producing very small 402 and 201 capacitors for the wireless communications market; this is the primary product of the company. The third families of products are the thin film, single layer capacitors. JTI expanded and moved a few blocks to the current facility in 2006-2007 as seen in *Picture 1*.

The Thin Films and Single Layer department purchased the RS20 robot from Stäubli in February of 2010 but have not had enough time to spend setting it up, designing the pick-up tool, programming the code, and constructing the entire system. They decided to hire an intern, instead of a Stäubli consultant, to spend the summer working on these tasks and gain valuable engineering experience in the process. The Thin Films and Single Layer General Manager worked with the intern to supervise the design, fabrication, and installation of tools and equipment regarding the Robot Pick and Place Project.

The next section of this report continues on with a literature review of different capacitors, their materials, and a common form of electronic handling automation.

Picture 1 – Current facility for Johanson Technology in Camarillo, CA

Introduction to Types of Ceramic Capacitors

Multilayer

The ceramic capacitor is the most widely used passive component in modern electronics. In 2008, it accounted for 90% of the capacitor market in part volume and 40% in value. The multilayer ceramic capacitor (MLCC), characterized by its high capacitance and compactness, is the dominant form of ceramic capacitor. With hundreds of MLCCs used in typical electronic devices such as cell phones and computers, approximately 1.5 *trillion* pieces of MLCC were manufactured in 2009. Following that same trend, 2 trillion pieces will be manufactured in 2011. In the meantime, the volumetric efficiency (capacitance per volume) continues to increase at a rate that surpasses Moore's Law. Moore's Law states that the amounts of electronic components you can fit in a give space will double every year (Swartz, 1990).

The abundance of ceramic compositions and their diverse dielectric behavior make ceramic capacitors omnipresent in many extreme environments. A key limitation of ceramic capacitor applications is the difficulty in firing large ceramic components. As a result, they have been excluded from large-scale applications such as pulsed power weapons and power factor correction. In addition, the catastrophic failure mode of ceramic capacitors requires extra vigilance in circuit design (safety margin) to ensure operational reliability (Raboch, 2007). Conventionally, single-layer ceramic capacitors such as disk and cylindrical- type capacitors have been primarily used. However, the use of multilayer ceramic capacitors (MLCCs) prevails nowadays, because of their properties of high capacitance with small size, high reliability, and excellent high-frequency characteristics (Chen, 2001). The quantity of shipment of MLCCs has grown at an annual rate of about 15% due to the rapid increase of the production of cellular phones and computers, and the demand will further increase in the future.

Single Layer

The "parallel plate" or "single layer" ceramic capacitor has a very useful form factor for assembly into microwave frequency and similar electrical circuits. These circuits may be laid out on printed circuit (pc) boards, or be present on integrated circuits (ICs) within chip carriers and other packages where space is typically even more precious. The dimensions of the ceramic capacitor can be matched to the width of a strip line on the pc board or as microscopic as 5 mil. In assembly, the bottom face of the ceramic chip capacitor is typically soldered to or conductive epoxy attached to the surface of the pc board substrate. The top face of the ceramic capacitor normally presents one or more electrically conductive pads that are typically ribbon- or wire-bonded to another circuit connection point. Most ceramic chip capacitors currently offered are made by metallizing two faces of a thin sheet of sintered ceramic that is typically in the range of 4 mils to 10 mils thick. The metallized ceramic sheet is then cut to size by sawing or abrasive cutting techniques. Typical sizes of the chip capacitors range from 5 mils square to 50 mils (inches) square, although some applications use rectangular forms (Rogov, 2008).

While the form factor of these simple devices— used in quantities of hundreds of millions per year—is highly desirable, the amount of capacitance that can be achieved and quality of the devices realizing maximum capacitance is starting to limit their usefulness in certain applications. Their physical resistance to damage of the highest-capacitance "parallel plate" or "single layer" ceramic capacitors is innately poor. The design of single layer capacitors in general is a compromise between the use of thicker ceramic layers for greater strength and thinner ceramic layers for greater capacitance (Domonkos, 2010).

Ceramic Dielectric Materials

Classes

A wide variety of ceramic materials with a broad spectrum of dielectric properties can be used to fabricate capacitors. Modern ceramic dielectrics have a dielectric constant (K) that spans a range from as low as 5 to greater than 20,000. Commercially available ceramic dielectrics are categorized into three classes:

1) **Class I** dielectrics are low K (5 to a few hundred) ceramics with low dissipation factor (<<0.01). They usually have a linear temperature coefficient of permittivity from zero to several thousand ppm/°C with a prescribed tolerance.
2) **Class II** dielectrics are high K materials (1,000 to >20,000) based on ferroelectric ceramics with dissipation factor usually in the range of 0.01 to 0.03.
3) **Class III** dielectrics are the basis for barrier layer capacitors. Through a reduction-reoxidation process, each grain in the dielectric consists of a conductive core and a thin insulating shell, or barrier layer (Wakino, 2001).

Demand of Capacitor materials

Based on quantities reported by the U.S. Census Bureau in *Current Industrial Reports*, the top four types of capacitors by product share in 2001 were those made from ceramic, at 98.2 percent; tantalum, at 9.5 percent; aluminum, at 3.1 percent; and paper and film, at 1.6

percent. The share of ceramic capacitors increased from 39 percent in 1983, whereas the share of paper and film and aluminum capacitors declined from 19 and 13 percent, respectively. The share of tantalum capacitors held steadily during the 1990s. Ceramic dielectric single layer chips were by far the largest single type of capacitor in 2001, representing 97.6 percent of all capacitors by reported quantity.

In a comparison conducted by Paumanok Publications, Inc. of average global prices for critical materials consumed in the production of passive electronic components between January 2009 and January 2010, the average price for key feedstock materials consumed in the passive electronic component industry has increased by 105% on average year-on-year. The impact upon variable costs to produce passive components varies based upon the type of passive component in question. Film and aluminum dielectric capacitors, for example, count raw materials at 64% and 60 % of their costs to produce, and therefore these dielectrics are particularly sensitive to increases in raw material price. Other dielectrics, such as ceramic and tantalum have higher costs to produce associated with equipment and related costs. This is because ceramic is based upon stacking technology, while tantalum is based upon porous anode construction. Aluminum and film dielectrics on the other hand, have lower comparable costs to produce because their production method is based upon winding and winding equipment is not as costly to procure, depreciate and maintain when compared to the kilns and ovens associated with ceramic and tantalum capacitor production (Zogbi, 2010).

Market Capitalization

Electronic industries are responding to the increasing consumer demands in automotive, telecommunications, computer, and consumer sectors for product miniaturization with progressively decreasing costs. However, such miniaturization also requires an alternative technology such as integral passives that can potentially save a significant real estate on the board level. The worldwide market in passive components is estimated to be US $25 billion today. This is projected from the fact that according to the National Electronics Manufacturing Initiative (NEMI), 900 billion parts were shipped worldwide in 1997. A part cost of US $0.02 reflects a US $18 billion market. Passive components such as resistors, capacitors, and inductors are defined as the non-active elements in the microelectronic packaging industry (Bhattacharya, 2001).

Fabrication

Recently, in mobile electronic equipment such as cellular phones and personal computers, trends toward miniaturization, higher performance, and lower electric power consumption have become increasingly prominent. Integration and miniaturization into chips of passive components such as capacitors, inductors, and resistors used in these pieces of equipment have also been accelerated. The case size of MLCC also has been reduced every year. The current mainstream Electrical Industry Alliance (EIA) case size is 0603 (1.6 by 0.8mm^2) for general electronic equipment and EIA0402 (1.0 by 0.5mm^2) for mobile equipment (Yih-Chien, 2009). MLCCs are fabricated by the following method: Sheeting and printing methods are used in practice for forming the dielectric layers. An electrode paste of fine internal electrode powder is applied by screen-printing onto a dielectric green sheet. A predetermined number of printed sheets are stacked, pressed, and cut into pieces. After burning out the binder, the chips are fired. In order to sinter both the ceramic and electrode, it is important to control sintering shrinkage behavior of each material and the firing conditions (Kishi, 2003).

Automated Packaging

In today's competitive market, product packaging is playing a more important role than ever before. Changing packet designs, shorter times to the market place, and frequent product introductions are causing manufacturers worldwide to change their approach to the packing and packaging process. In the past, manufacturers have relied on traditional packaging technologies, such as dedicated machinery and manual production techniques. Unfortunately, dedicated equipment cannot always meet today's needs for increased production flexibility; and with higher labor and liability costs, manual alternatives are not always a competitive solution. This calls for a new approach to the packing and packaging problem, one which uses automation, but which also provides the flexibility of a manual operator. A key step in developing such a flexible packing system is the integration of intelligent vision feedback (Ho, 2010).

Robotic Capacitor Placement Solution

One example of a commercial solution for automated die bonding in the micro-electronics marketplace is the MRSI-501 Automated Die Placement System. The placement accuracy is +-0.002 to 0.003 inches. The system's throughput rate is 400- 450 die per hour for vision-guided placements and 900 die per hour for direct pick and place (such as from linear feeders). The major workhorse, the MRSI Vision System, is based on a 512 X 512 pixel resolution, 256 grey scale level, vision package. The MR-03 cylindrical robot is the handling device which has been configured with five degrees of freedom. The first axis provides a *340* degree rotation of the robot arm. The second axis provides a vertical travel of 5.3 inches, with 0.00015 inch repeatability. The third axis controls the extension of the robot arm and manipulates the radius from 10 inches to 17.5 inches. The remaining two axes control the rotation of the vacuum pickup tool on each wrist. The MR-03 robot was selected for its high precision and speed, unique configuration, large working area, and low maintenance requirement. Two cameras, one with high and the other with low magnification, are mounted on each of the robot's wrist. The magnifications are optimized to cover a range of part sizes and to provide enough detail within a pattern to resolve and decipher orientations of nearly symmetrical parts. The system is programmed to recognize die that are in any orientation and position within a Waffle pack cavity. If any pocket of the Waffle pack is empty, the system will detect the condition and move to the next pocket. If the pocket contains a die that is incompatible in size (misplaced or chip outs) or up-side-down, it will skip it and process the next pocket. The system can also pick epoxy or eutectic pre-forms from Wafflepacks.

To accommodate some users, the system can be equipped with automatic tip changing tools. In most cases the system *can* pick and place all the required components using the two on-the-wrist vacuum collets. However, some manufacturers require multiple size tips with different materials. In addition, the tip changing capability facilitates the use of inverted pyramid collets for eutectic scrubbing (Ahmadi, 1999).

An up-facing camera can be utilized to increase the placement accuracy of certain die and also used for flip chip bonding. The vision system also processes fiduciary marks on the PCB or substrates to compensate for any misalignments in feeding or positioning. A compliant vacuum pick-up device virtually eliminates damage to small delicate chips with air bridges. Compliancy also increases the tolerance to local unevenness of Waffle packs, substrates, and components. Force detection is built into the head enabling the user to pre-select a placement force for each type of die. In addition, a static eliminator helps discharge any static that may accumulate on the plastic vacuum pick-up tip. The system can be configured with any combination of tape feeders, stick feeders, Wafflepacks, Gel-packs, and wafers. For wafers, equipment manufacturers have recently developed unconventional means for preparing die for pick-up. One such method is to lace a stretched wafer on a "Gel-pack” like surface (rough). After pulling vacuum from below, the die are released from the tape. Through wafer mapping software, the equipment picks only "good” die from the wafer (Devoe, 2002).

Die placement is very critical to the manufacturing process, and the use of state-of-the-art automatic machines can make a major contribution towards achieving manufacturing excellence in an extremely competitive environment. Higher quality, lower cost products, greater customer responsiveness, higher margins, an enhanced reputation for quality, earlier deliveries, faster inventory turnover, and accelerated cash flow are all benefits of a successful implementation of automated pick and place systems. (Chalsen, 1991)

Stäubli RS20 Robotic Arm and CS8C-M Controller

Stäubli is a Swiss-French mechatronics company primarily known for its textile equipment and robotics products. Stäubli has been known worldwide for the quality of its methods and processes for more than a century. Since 1982, the Stäubli Group has brought its innovation to the robotics market place and today Stäubli Robotics is a leading player in automation around the world. Stäubli was founded in Horgen, Switzerland in 1892 as "Schelling & Stäubli" by Rudolph Schelling and Hermann Stäubli. In 1956, the company diversified its line of products into the field of hydraulics and pneumatics and commenced the production of rapid action couplings. They acquired the German dobby producer Erich Trumpelt in 1969, a French competitor Verdol SA in 1983, and an American competitor Unimatino in 1989. In 2004 they acquired German competitor Bosch Rexroth's robotics division and incorporated their products into their own product line.

Stäubli Robotics is Stäubli's automation and robotics related division founded in 1982. It produces SCARA and 6-axis robots for industrial automation. The RS20 robot is very compact 4-axis robot built for high speed. Entirely designed by Stäubli, it features the same qualities as the other robots in its range in terms of performance and robustness. Its harness is integrated inside the arm making it possible to connect any tool directly at the flange. The flange is the connection area where a tool can be mounted to the RS20. Key features and corresponding benefits are featured in Table 1.

Features and corresponding benefits for Stäubli's RS20	
Features	**Benefits**
Compact	Competitive package for A3 tabletop automation
Fastest robot in its class	Increased throughput
All cables running internally	Proven reliability of Stäubli design

Table 1—Features and benefits of the RS20 robotic arm made by Stäubli Robotics

Staubli's CS8C-M controller operates the RS20 arm through its programming. It is driven by programs written in VAL3, a language created specifically for Staubli robotics. The Controller includes two electronic connecting cables that run to the RS20 and several digital and analog inputs and outputs for connecting external equipment and devices. An Ethernet port at the controller's base connects to whatever network the company using the device has. This enables the owning company to program VAL3 code from any station within their network. Key features and their corresponding benefits are shown in Table 2.

Features and corresponding benefits for Stäubli's Controller CS8C-M	
Features	**Benefits**
Ethernet, field bus, digital inputs/outputs, serial connections	Open architecture
Dimensions: 520 x 200 x 258,5 mm (H x L x D)	Easy to install anywhere
IP20	Compactness
All connections on front panel	Accessibility
100 % digital technology	Reliability

Table 2—Features and benefits of the CS8C-M Controller made by Stäubli Robotics

Electrosort Bowl Feeder

The Bowl Feeder system, made by Electrosort Automation, is a system designed for organizing, moving, and position small part sizes. Bowl Feeder systems are often used to feeding parts such as capacitors into a process. Electrosort Automation was founded in 1956 when it was known as A-B Tool & Manufacturing, a builder of custom equipment. In the late 1960's, the company narrowed its focus to concentrate on the demands of the semiconductor and passive component industries. The result was a line of chip and die sorters and the creation of the Engineered Automation division, known to many as the passive component and semiconductor industry.

In 1989 the division changed its name to Electrosort Automation and refined its focus on those issues that determine exacting quality. Electrosort Automation has been manufacturing Die Sorters for over 30 years. Many of the employees are located at their plant in Easton, Pennsylvania and have been developing their knowledge of sorting and test fixture requirements for over 15 years.

Electrosort's stand-alone bowl feeder system works great for feeding parts to pick and place equipment. It contains a vibrating bowl feeder that moves parts up to a linear feeder. From the linear feeder, parts are aligned in a straight line and fed to a pickup location. A through-beam optic sensor stops the feeder from pushing too many parts through by detecting when a part has reached the end of the linear feeder. When the part is in the pickup location the feeder is turned off and an open collector output signals a pick and place equipment to come grab the part. Parts can be fed at rates as high as 30,000 parts per hour depending on part size and unique handling characteristics. Through-beam optics control the feeder so that part feeding is gentle and non-damaging on parts.

Conclusion of Review

A century of diligent research and development has resulted in a wide range of ceramic dielectrics and processing technologies. The technology used to manufacture an MLCC that costs pennies was unimaginable 30 years ago. The present trends of enhanced mobility, connectivity, and reliability in consumer, industrial, and military electronics will continue to drive future innovations in ceramic capacitor technology. In addition, power electronics applications are an emerging market in which ceramic capacitors will play an increasing role through improved breakdown strength, enhanced dielectric stability in harsh environments, and innovative packaging. The investment made by the US government to develop high energy density and high temperature capacitor technology will also contribute to the advancement of dielectric materials technology for electronic capacitors. (Pan, 2010)

Design

This section illustrates the steps taken to design the ideal pick and place system that would meet Johanson Technology's increasing customer demand of Ceramic Single Layer Capacitors. Johanson Technology hired a consultant to analyze their situation and come up with several solutions. The consultant offered several options: Johanson Technology could hire and train additional employees, hire the consultant to design a robot pick and place system over the course of 6 months, or hire a student intern to design the robotic pick and place system over a summer.

Current Situation

Presently, capacitors are placed onto Waffle Packs, Gel Packs, and Disks by one operator. This operator spends 40 hours per week looking through a microscope to pick and place parts using a pair of tweezers. During larger part orders, additional help from other operators is temporarily used to meet deadlines. A well trained operator can fill an entire Waffle Pack containing 400 parts in about 15 minutes, a Gel Pack containing 400 parts in 20 minutes, and a Ring Pack containing 3600 parts in 60 minutes. Picking and placing microscopic capacitors day in and day out is a tedious and monotonous task for an operator. The stations are set up as ergonomically as possible, providing a soft up right chair and an inclined stool for the operator to rest his or her feet upon. However, operators performing this process often experience problems with vision and pain in the wrists and hands.

Alternative 1

After meeting with the consultant to decide the best solution in automating Johanson's Pick and Place process, the Consultant suggested purchasing a small and inexpensive robotic arm made by Stäubli, a Swiss robotics manufacturer, for $12,849. The consultant then worked out rough designs of the tool that the robotic arm would use to handle the capacitors. After this meeting, the consultant gave Johanson Technology a price quote for his services to further design, assemble, and hand off a successfully running robotic pick and place system. The consultant would work at a rate of $150 per hour for 20 hours per week over 6 months. This would in total, cost Johanson Technology $113,000 in labor alone.

Alternative 2

After estimating the cost of hiring a consultant to design and complete the robotic pick and place system, Johanson Technology considered the option of receiving help from an Engineering student for the summer. The project could then become an internship for college student. Hiring a student intern would allow Johanson Technology to spend less on labor costs while in turn help a college student gain valuable engineering experience. The intern would be paid $14 per hour, nearly one-tenth the cost of the consultant, and would be able to work 35-40 hours per week for 3 months. This option would cost Johanson Technology around $4,900-$5,200 in labor.

Alternative 3

Johanson Technology also had the option to not automate their pick and place process and simply hire additional operators to keep up with the higher demand in parts. An additional operator would cost $12 per hour plus an additional 20% overhead cost per hour to count toward benefits and insurance. If this operator were to work 32 hours per week since operators work 4 days per week, it would cost Johanson Technology nearly $24,000 per year.

Johanson Technology's Alternative of choice

Alternative 2 was not the short term lowest cost for Johanson Technology but it was the most inexpensive choice over the long term; which is why Alternative 2, hiring a student intern, was the choice for designing this robotic system.

Design Scope

Johanson Technology first objective on the design scope was to purchase the RS20 robotic arm, CS8C-M Controller, and VAL3 Language Program Suite from Stäubli for $12,849. The next major task was to design a tool piece that would integrate with this robotic arm and serve as the hand that picks and places the capacitors. During this process of completion the scope further entailed:

- Designing and manufacturing a table mount and a couple pack holders for the three types of packs
- Programming the software of the RS20 to perform the needed procedure
- Connecting all necessary electrical wiring

- Mounting the RS20, CS8C-M Controller, Electrosort Bowl Feeder, and Bowl Feeder Controller onto a work table in a functional, safe, and ergonomic arrangement
- Creating a slide out shelf for the Electrosort Bowl Feeder Controller
- Testing and measuring performance for statistical analysis and developing areas of improvement
- Creating a BOM and cost analysis of all three alternatives
- Writing a detailed instruction manual for future operators of the robotic pick and place system

Through the completion of these tasks, this project involves improving an existing system by increasing throughput, reducing operational costs, performing cost analysis of alternatives, running simulations, and creating an ergonomic work station for the operator.

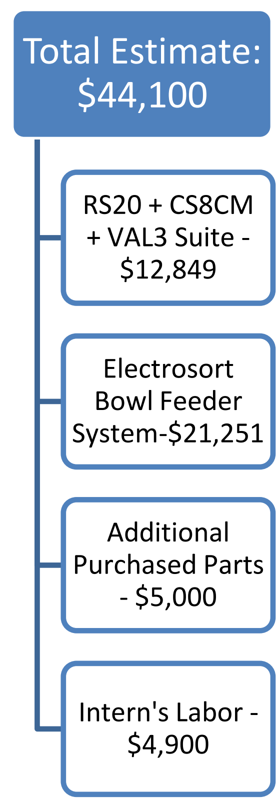
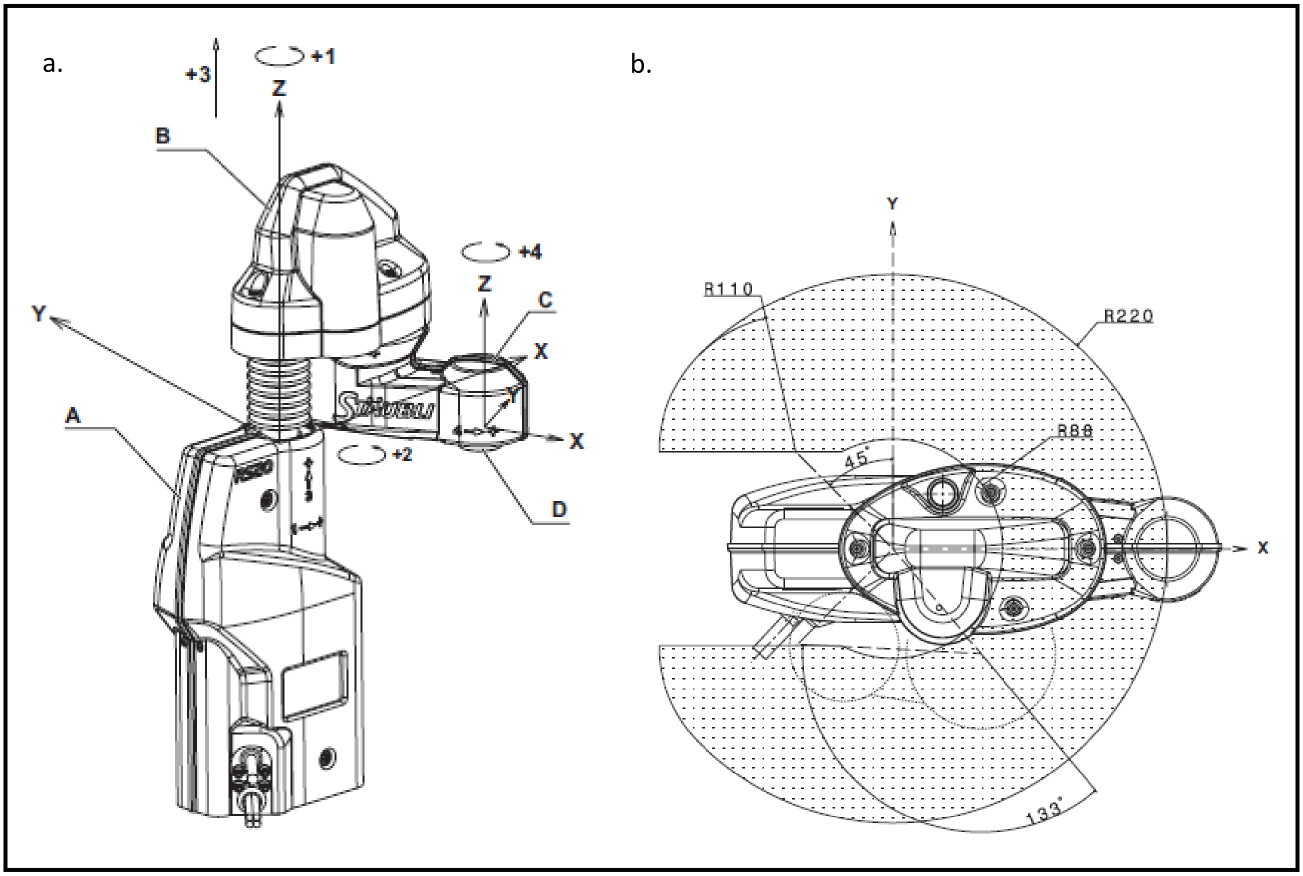


Figure 1. - Initial cost estimate for hiring an intern to design an automated pick and place system.

Initial Cost Estimates

The Initial costs of this project were estimated to be about $44,100 according to the logic in Figure 1. Johanson Technology had already known the price for the Stäubli package and Electrosort Bowl Feeder System but performed cost estimates for additional purchases and labor required for the design and development of the pick and place system. The additional purchased parts were estimated from previous orders Johanson Technology had made with Groth Engineering, a custom manufacturing facility, and from Catalogs of pneumatic and mechanical part companies such as Clippard, SMC, McMaster

Carr, and Festo. The Intern's labor cost was estimated by the following equation: $\frac{\$14}{hour} \times \frac{35hrs}{week} \times 10\ weeks = \$4{,}900$.



Drawing 1. – a. RS20's 4 axis's and XYZ coordinate plane. b. The RS20's reach from 88mm to 220mm away the Z axis.

Design Requirements and Constraints

Constraints of the RS20

Stäubli's RS20 is a 4-axis robotic arm capable of high speeds and accurate movements. However there are some constraints when designing a functional pick and place system with this robot. As illustrated in Picture 1-a, the RS20 operates on a XYZ coordinate system. It is capable of pivoting around its shoulder joint around the Z axis, around the elbow joint, and around its wrist joint. The fourth axis comes from the vertical rise and fall along the Z axis. The RS20's height can range from 21 – 25 inches depending on the extension in the Z axis. The RS20's reach can range from 88 mm() to 220 mm() around its core Z axis as seen in Picture 1-b.

Additional constraints of the RS20 are featured in Table 3. Stäubli suggests that the RS20 can operate with repeatability within ±0.01mm (0.3937mil). This would prove to be very convenient for this pick and place system since parts must be placed accurately within 2-4 mil in some instances. The RS20 is a floor mount robot and requires a sturdy surface to be mounted on. Johanson Technology purchased a 3'x3'x1.5" slab of aluminum to mount the RS20. Also, however large or small the tool in which the RS20 was going to pick and place parts with was going to be, it had to remain under 1 kg (2.2 lbs) and ideally around 0.5 kg (1.1 lbs).

Main characteristics of RS20	
Model	**RS20**
Number of degrees of freedom	4
Nominal load capacity	0.5 kg
Maximum load capacity*	1 kg
Reach	220 mm
Repeatability	±0.01 mm
Attachment methods	Floor
Stäubli CS8 series controller	CS8C-M

Table 3—Main characteristics of the RS20, including a picture of the RS20 in the right panel.

Constraints of the CS8C-M Controller

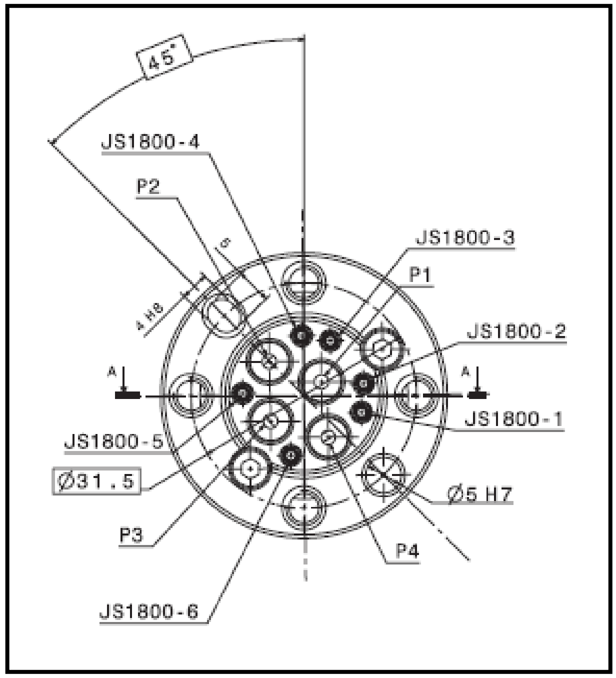
The size of the CS8C-M Controller is a bit cumbersome; it weighs 17kg (37.5 lbs) and stands 520mm (20.5 in) tall. Due to its size, it would need to find a location where an operator would not accidentally run into it or be forced to maneuver around it. In order to properly operate the CS8C-M controller, it was a requirement to program commands in Stäubli's own robotics language—VAL3. Further design constraints included finding out a way to integrate foreign power supplies into this controller to power the sensors on the tool. Table 4 below illustrates the main characteristics of the CS8C-M controller as well as provides a picture of the controller in the left panel.

Main characteristics of the CS8C-M	
Model	**CS8C-M**
Dimensions: H x L x D	520 x 200 x 258,5 mm
Protection class	IP20
Memory capacity	64 MB RAM (min.)
Memory storage	64 MB RAM (min.) Flash Disk
System/ Programming language	VAL3 (multitask interpreted language)
Communication	RS232/422 serial link - Ethernet Modbus server
Inputs/ Outputs (I/O)	1 or 2 boards 16/16 digital inputs/ outputs, optional
Field bus	DeviceNet, Profibus, CANopen, ModBus
Weight	17 kg
Stäubli arm	RS20 series

Table 4.—Main characteristics of the CS8C-M, including a picture of the CS8C-M in the left panel.

Tool design requirements

When designing the tool, which would act as the hand for the RS20, it was noticed that the RS20 had specific design requirements to its connector piece as seen in Drawing 2. The RS20's instruction manual illustrated the shape of the input flange our tool would need to have in order to properly function with the RS20. The other main constraint regarding the tool was that we had to stay around one pound in weight ideally and could not go over 2.2 lbs. If the tool weighed more than the maximum of 2.2 lbs, it would throw the RS20's rotary gears out of alignment. Aluminum was chosen as the material for the tool for its relatively cheap cost and ease of manufacturability.



Drawing 2—Design requirements for the RS20 flange. Each JS1800 number corresponds to an input on the CS8C-M controller and the "P series" represent pneumatic valves.

Table Space

The aluminum slab was to serve as the surface that the system would be mounted on. It was 32" x 32" in size and 1" thick—a standard for most of Johanson's automated machinery. The challenge was to find the correct arrangement of the RS20, bowl feeder, and pack mount so that everything is accessible for the operator. The space is very confined and none of the objects may get within a couple inches from the table's edge, since a metal frame with glass panels would be mounted around the table in the future. Also, in the occasion that the RS20 ever went rogue, it should be placed out of reach of any side wall so that it would not collide with any walls.

Design Tools

AutoCAD 2000

This program was used to design each of the tool's components, the table mount, pack holders, and overall arrangement of the system. Many of the purchased parts had available AutoCAD drawings online which helped in the design of custom manufactured parts.

Stäubli VAL 3 Studio

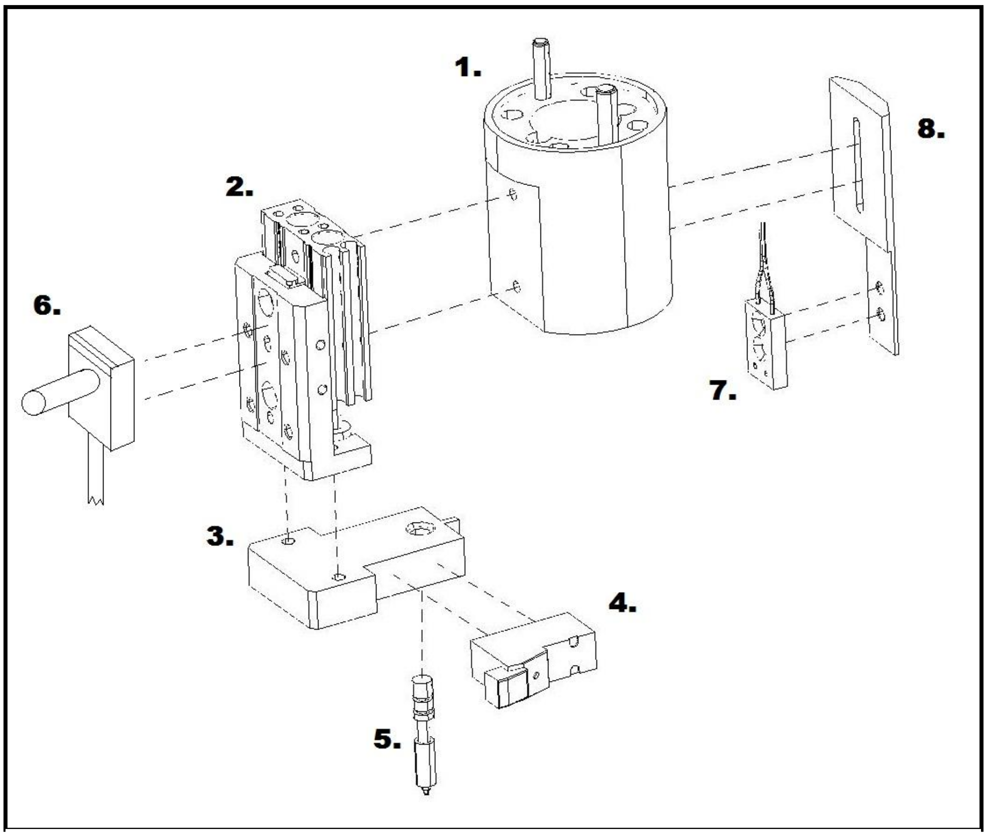
Stäubli has its own custom computer language known as VAL3 in which all of their robots are written in. VAL 3 is similar to coding with Visual Basic on Microsoft Office products such as Excel, but also incorporates some ladder logic that one would use when programming Programmable Logic Controllers (PLC). VAL3 enables a wide range of connection possibilities from digital and analog inputs and outputs to field bus. All of the code can also be accessed from a single teach pendant interface.

Stäubli 3D Studio

This studio creates a visual simulation of the RS20 and provides a way for the programmer to test what the code will cause the robot to do, before testing it in real life. It creates a safe environment to take coding risks and work out glitches. See Picture 2 in the Appendix for what the RS20 looked like in the 3D Studio.

Tool Design

The tool that was designed to pick up and place capacitors is made up of seven different parts all functioning as one (See Drawing 3 below). The tool needed to be able to incorporate a vacuum, air pressure, and exhaust valve. The suction from the vacuum would pick up the parts from the Bowl Feeder, the pressurized air would be able to blow off stuck parts, and the exhaust would be able to let the parts drop from the vacuum nozzle.



Drawing 3—The eight main components of the tool used on the RS20. 1-End Effector, 2- SMC Slide Table, 3- Pickup mount, 4- Clippard valve, 5- Vacuum tip, 6- Vacuum Sensor, 7- Keyence Sensor, 8- Keyence Sensor mount.

Part 1 – End Effector

The End Effector part is the main body of the tool in which all other parts of the tool connect to. The top of the End Effector includes a compatible mount with the RS20 with two rods that slide into two positioning holes on the RS20. There are 4 holes drilled into the sides to attach the SMC slide table and Keyence sensor mount. The center of this piece is drilled out, much like a tube, to allow for vacuum and air hoses coming from the RS20 to pass through (See Drawing 4 in the Appendix).

Part 2 – SMC Slide Table

The slide table was purchased from SMC Corporation of America. It is designed to have pressurized air separate the two sliding halves. However after installing Part 3, the Pickup Mount, onto the bottom of the slide table, it was discovered that gravity kept the sliders separated as it was. This discovery saved space and weight on the tool since a pressurized air hose did not need to be connected to the slide table. The slide table is intended to be fully extended so that in case of an accidental collision in the vertical Z axis, the slide table would compress and send a signal the Keyence sensor that the tool has collided with an object and needs to perform an emergency stop.

Part 3 – Pickup Mount

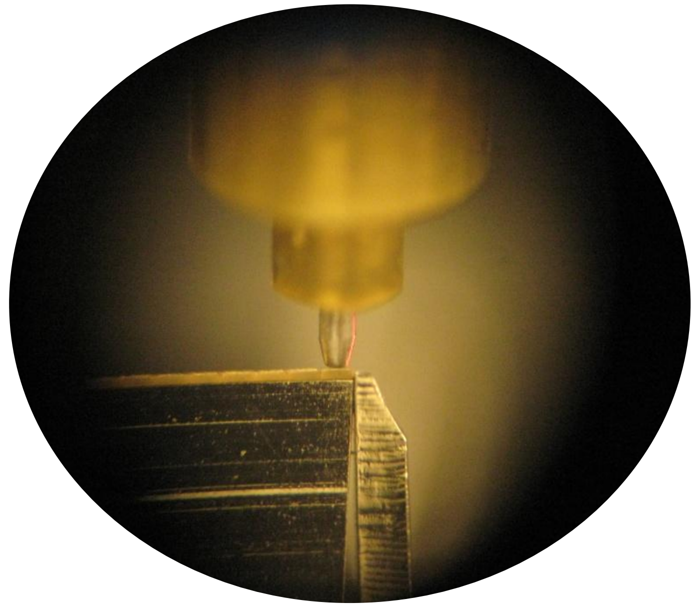
The pickup mount was designed by Johanson Technology and attaches directly to the bottom of the SMC slide table. This mount contains 3 air ways that run from the Clippard vacuum and pressure valve to the hole where the vacuum tip is placed. The air ways include air pressure, vacuum, and exhaust. The front face of this piece also functions as the face the Keyence Sensor sees to detect tool movement.

Part 4 – Clippard Miniature Vacuum and Pressure Valve

This part is attached to the side of the pickup mount and switches the air lines to the vacuum tip from pressurized air, to vacuum suction, or to exhaust (See Figure 2 in the Appendix). Pressurized air and vacuum suction is always being fed to through the RS20. The initial idea was to have this valve switch the vacuum suction to pressurized air, when a capacitor is being placed, to blow the part off the tool's tip. However, after experimenting with the blow-off capabilities of the air pressure, it was found that no matter how small the amount of air pressure fed through the tool, it blew parts out of the Waffle Packs. To fix this problem, the Clippard valve switches only from vacuum to exhaust when picking and placing parts. When a part is placed, this valve opens the exhaust valve and lets outside air in—releasing the tool's suction on the part. Then right as the tool hovers over a new part, the vacuum is turned back on.

Part 5 – Vacuum Tip

The vacuum tip is the piece that actually makes contact with capacitors as seen in Picture 3. Air can travel forcefully outward with air pressure and inward through vacuum suction. Vacuum tips are interchangeable and must be adjusted to fit the specific size of capacitors. The vacuum tips used in the tool are the same tips already being used in many of Johanson Technology's other capacitor handling machines. The tips are made by Electrosort Automation, the same company that provided the Bowl Feeder system. This vacuum tip that makes contact with the capacitors can sometimes break parts if it travels too far down and collides with a part, causing pieces of ceramic to become lodged inside the nozzle. If this happens, it takes an operator about 15 minutes to clean the vacuum tip for reuse. It takes an operator about 5 minutes to change from one vacuum tip to another, and then afterward the operator must adjust the positioning of the tool by reteaching the location where it picks up parts from the bowl feeder.



Picture 3—View through a microscope of the vacuum tip making contact with a capacitor.

Part 6 – PS1100 Vacuum Sensor

This vacuum sensor made by SMC Corporation of America detects the presence of air flow as well as directional change. A red LED light appears on the sensor when air pressure or vacuum is detected. This device serves as a “double check” in the code. The RS20 will not move to pick up or place a part unless it detects that the vacuum has properly been activated or deactivated. Running out of room on the tool itself, the vacuum sensor was taped to the back side of the slide table.

Part 7 – Keyence Motion Sensor

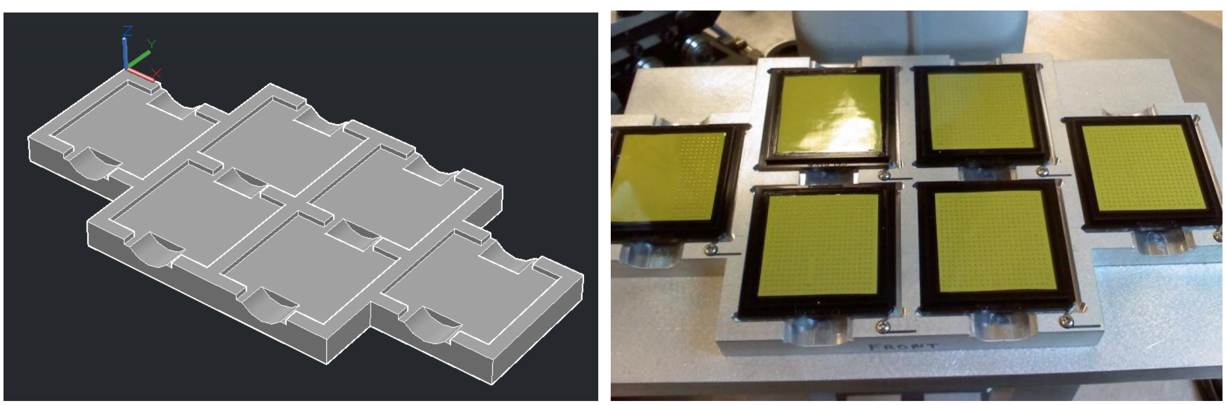
The motion sensor purchased from Keyence detects movement. Two infrared lasers project from the sensor and triangulate at a focal point. The reflection from this focal point is collected back into the sensor and a percentage collected is displayed. If the amount of reflection collected falls below a designated percentage, a signal is outputted to the CS8CM to stop the RS20 from moving. This decrease in reflection collected is caused by the pickup mount sliding vertically upwards after colliding with an object.

Part 8 – Keyence Sensor Mount

This mount was designed to hold the motion sensor purchased from Keyence. Its form fits its function and the width of this mount fits the width of the Keyence Sensor and the width of the End Effector. There are two holes where the Keyence Sensor is mounted and an open slit for where it can be adjusted on the End Effector.

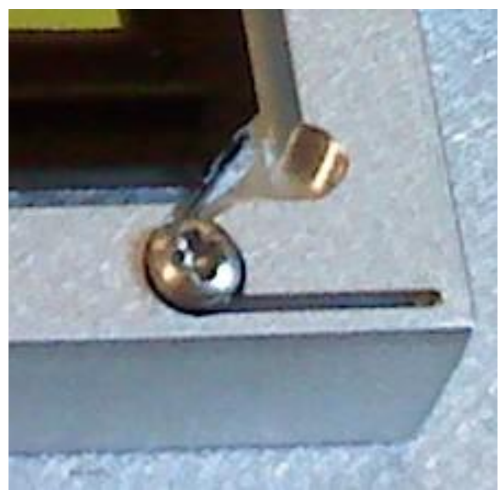
Pack Mount Designs

Waffle and Gel Pack Holders



Picture 4—On the left, is an AutoCAD drawing of the Waffle/Gel Pack holder. On the right, is the actual manufactured holder from Groth Engineering with sample Gel Packs placed inside.

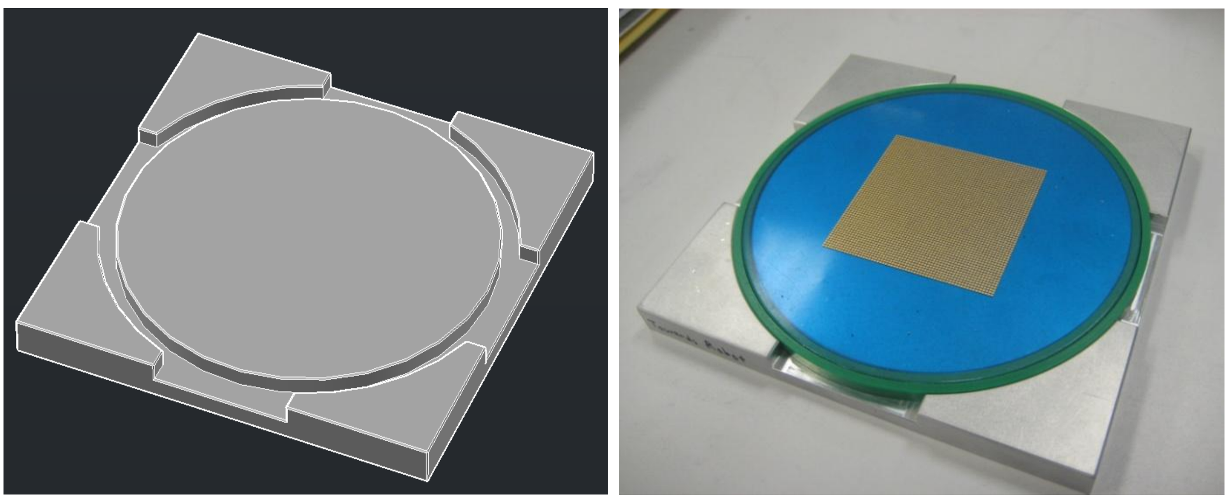
Waffle and Gel Packs share the same width and length but vary in height. Johanson Technology needed to design a holder that would be able to contain a sufficient amount of packs to run a pick and place cycle on. Six was determined to be the ideal amount of packs the holder should contain as seen in Picture 4, because it was the maximum amount of Waffle Packs that could fit, facing the same direction, in front of the RS20's body. The packs needed to be positioned within the RS20's radius of reach, and adding any more packs would cause the robot to reach around its body. This further movement to pack one additional pack around the RS20's body would add 12 minutes onto the overall cycle because of the longer distance away from the Bowl Feeder and the curved path of travel. With six packs in front of the RS20's body, the motion of placement can remain linear. It takes the RS20 between 43-45 minutes to successfully fill all six packs. The furthest pack from the Bowl Feeder takes about 10 minutes to fill and the pack closest to the Feeder takes about 4 minutes to fill. Having too many packs on the holder would cause the RS20 to be underutilized because it would be a waste for it to travel long distances to fill a pack. On the other hand, having the RS20 only fill one pack at a time closest to the Feeder, would require the operator to be permanently stationed at the workstation at all times. Johanson Technology wanted the pick and place system to operate for a sufficient amount of time to allow the operator to attend other tasks. Drawing 5 in the Appendix illustrates the positioning of the Waffle and Ring Pack Holders into the RS20's area of reach. One concern with the design of the Waffle and Gel pack holder was how to maintain consistency with where the packs lie in space. One could create square holes with the same dimensions as the packs and just press fit each pack into its designated spot; but this would cause trouble for the operator



Picture 5—Coiled wire used to position each pack into the opposite corner of the slot.

when they remove the packs because a sudden jolt from the holder would cause parts to fly out of their place. The holder design was taken to Groth Engineering, a custom manufacturing shop in Camarillo. They suggested installing a coiled wired that could push each Waffle and Gel pack into a corner (Picture 5). The operator would then have to pull the coiled wire back, insert the pack, then let the coiled wire press the pack firmly into the corner of its holster. This would enable the holder to maintain a consistent positioning of Waffle and Gel packs.

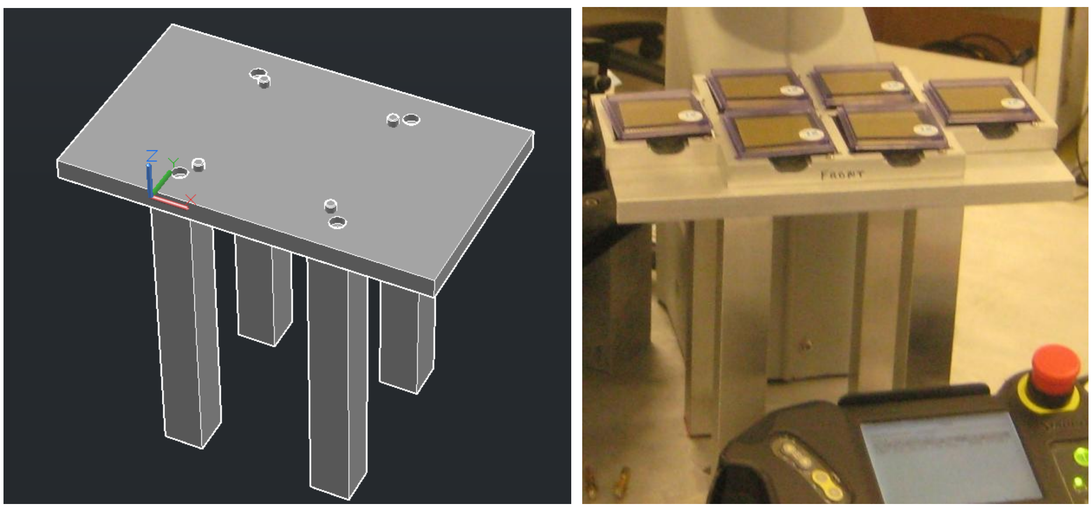
Ring Pack Holder



Picture 6—On the left, is an AutoCAD drawing of the Ring Pack. On the right, is the actual manufactured Ring Pack from Groth Engineering with a sample Ring Pack placed inside.

The holder for the Ring Pack was, contrary to the Waffle and Gel Pack holder, designed to have more of a press fit. An exact fit was good for this pack because the positioning of the parts was not too critical, as long as they were placed near the center of the pack as seen in the right panel of Picture 5. Also, Ring packs have an adhesive film that the parts stick too. Even if the operator jarred a bit when lifting the Ring pack away from the holder, the parts would stay intact to the film. In order to make it easier for the operator to handle the Ring Packs, a few 2 inch slots were cut away from the middle edges of the holder. This allowed for the surface area of the pack's outer ring to be exposed and available for the operator's handling. Along with the Waffle and Gel Pack holder, aluminum was used as the material of choice. The circular aluminum face of the holder supports the blue film and makes sure the film does not puncture during part placement. Placement of parts on the Ring Pack must be very ordered and straight. No part may skew or rotate more than 3 degrees away from the overall direction.

Table Mount Design



Picture 7—On the left, is an AutoCAD drawing of the table mount that holds onto the different pack holders. On the right, is the actual manufactured table mount from Groth Engineering being used in the system.

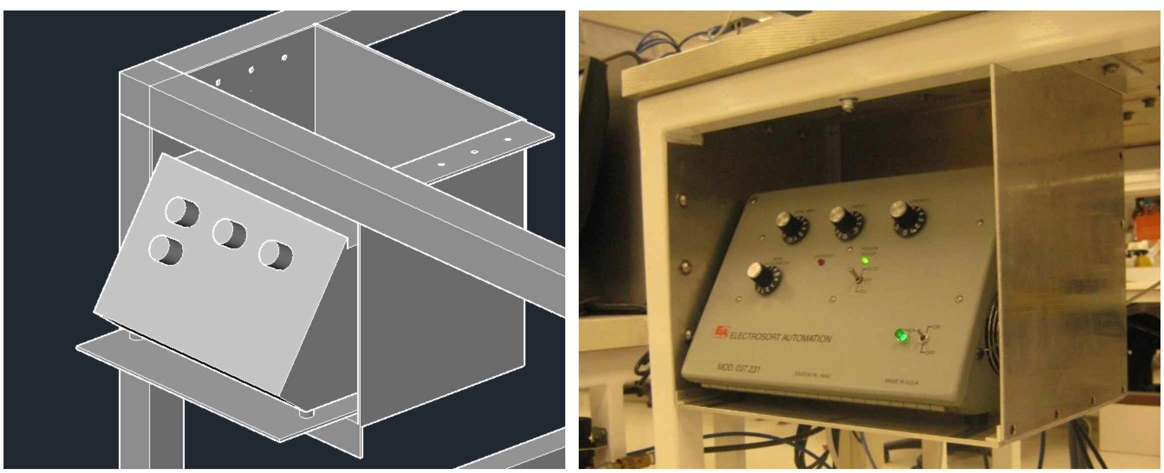
The Waffle, Gel, and Ring Pack holders needed a surface to be mounted on that would bring the packs within the RS20's vertical reach—so a table mount was designed as an area for the holders to lay. This miniature table would be compatible with both types of holders so that an operator would not need to adjust and replace table mounts as well. The top surface of the table mount was long and wide enough to support both holders firmly. Aluminum was chosen as the material once again in order to reduce vibration effects from the Bowl Feeder's powerful vibrations and create a nice tight grasp onto the holders that were of the same material. Each holder has compatible holes on their undersides that fit perfectly with the alignment rods on top of the table mount—this provides a tight, accurate, and repetitive fit. The interaction between the Waffle and Gel Pack holder and this table mount can be seen in Picture 7.

Bowl Feeder Accommodation Designs

Aluminum Railings

Two aluminum railings were purchased from a company called Speedy Metals to raise the bowl feeder off the table and bring the pickup location to the same height as the Waffle, Gel, and Ring packs. This would minimize the distance that the RS20 has to move, and increase the pick and placement speed as a result.

Bowl Feeder Controller Shelf



Picture 8—On the left, is an AutoCAD drawing of the shelf created to hold the Bowl Feeder's control box. On the right, is the actual manufactured shelf constructed by Johanson Technology.

There was no room on the surface of the workstation's table to place the controller for the Electrosort Bowl Feeder so a shelf was designed and constructed underneath the table, on location at Johanson Technology, to support and contain it. This shelf needed to be strong and sturdy so it was bolted into the frame of the table as well as underneath the aluminum slab. Next, a pull out surface that the controller could rest on was included as illustrated in the left panel of Picture 8. This would allow the operator to pull the controller out when adjusting the bowl feeder's speeds. Since the cords connecting the bowl feeder to its controller were rather short, the controller's shelf was positioned directly below the bowl feeder. The cords were then able to go through the aluminum slab and travel the shortest distance between the Feeder and the controller.

Electrical Wiring

The Clippard vacuum valve, SMC vacuum sensor, Keyence sensor, and two additional power supplies to provide them voltage needed to be wired to the CS8C-M controller in order to operate effectively. In Figure 3 of the Appendix, an electrical diagram illustrates how each of these devices were wired to the robotic pick and place system. Ports J601, J602, and JS1207 are located on the CS8C-M. Port JS1800 is located at the connecting flange where the tool connects to the RS20. The Clippard valve and PS1100 vacuum sensor use port JS1800 to travel through the RS20 and connect to the CS8C-M controller at Port JS1207. However these two devices need additional power through a 12V and 24V power supply and connect through the J601 and J602 ports. In order for the Bowl Feeder to communicate with the CS8C-M controller and let it know that a part is ready for the RS20 to pick up, it be powered by the 24 V power supply and pass through the CS8C-M through port J601.

Methodology

Coding

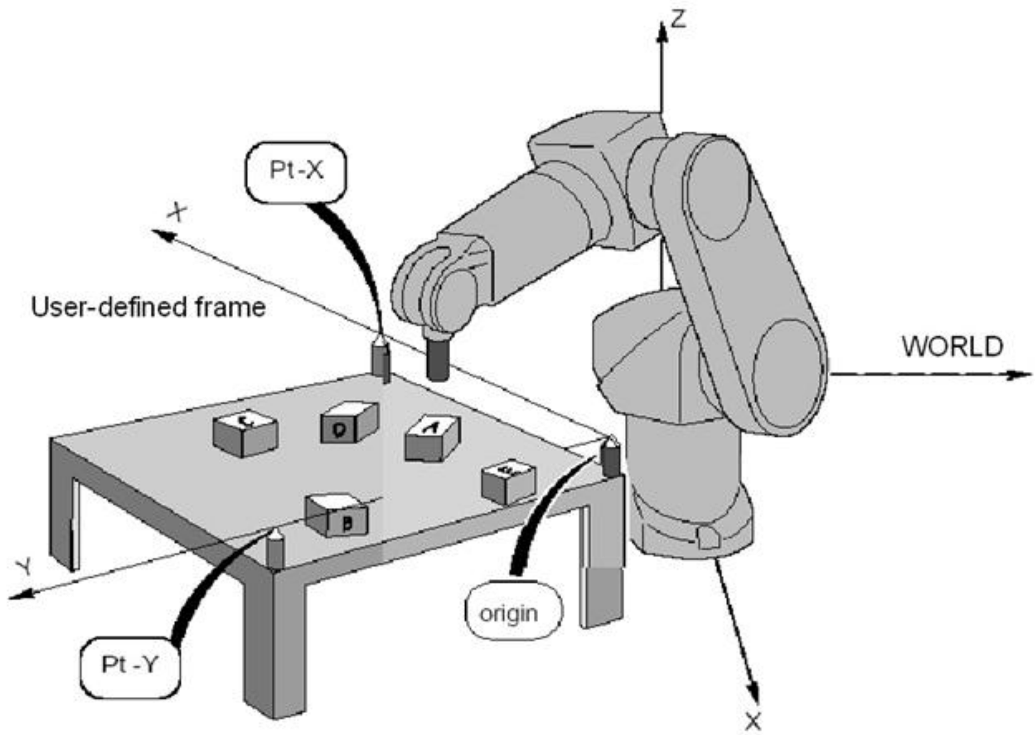
VAL3 is the language in which the CS8C-M controller operates the RS20. VAL3 is very similar to Visual Basic for Applications (VBA) code in that the programs begin with a start and stop function use similar command functions. Many programs can be called upon, looped, and put through if-statements much like VBA. However VAL3 introduces many custom Staubli specific commands that can only be learned through the VAL3 user's manual. Much of the code was written by Jim Cook, a code and software Engineer at Staubli. Johanson Technology informed Staubli software engineers of what they wanted their RS20 to do and Staubli replied with example programs. From there, Johanson Technology was able to adjust the code to match measurements and figures used in the pick and place system.

Bump Code

The Bump code was incorporated in the code for Waffle Packs. When the RS20 went to place the parts into the Waffle Packs, the parts would not drop from the vacuum tip. The exhaust would open properly to allow gravity to take over, but gravity was not enough to drop the part every time. This was primarily due to a slight presence of static friction and the impression of the vacuum tip into the gold plate of the capacitor. To compensate for this mishap, the Bump code made the vacuum tip on the tool position itself level with the top surface of the waffle pack with the part submerged into the pocket of the pack. From here, the tool moves horizontally until the part collides with the side wall of the pocket and gets knocked off of the vacuum tip. After the part has gently fallen into its designated pocket the tool removes itself and returns to the Feeder to pick up the next part.

Teaching

In order for the RS20 to know specifically where to pick and place capacitors, a coordinate system needed to be taught. Teaching involved manually positioning the robot in a key location and telling it to remember its position and save the coordinates. The first points to be taught are the RS20's frame of reference in the world. A frame is composed of the Origin point, X axis point, and Y axis point as seen in Drawing 6. The Waffle and Gel pack holder was first taught with one reference frame containing an Origin, X axis, and Y axis around the entire holder. This proved to be very inaccurate and required a lot of calculations and measurements. To fix this, six separate frames of reference were created. This meant that each pack would have an Origin, X axis, and Y axis point that defined its plane. From these taught frames of reference, the distance could be calculated in between the Origin and it's corresponding X and Y axis points and divided by 19 to calculate the distance between rows and columns in the different types of packs. This taught the RS20 how to move in a grid formation when placing parts. Not all teaching was done through physical placement however. Manual inputting of specific code and numbers also known as "hard coding" was used to make adjustments to the code after testing. All of the coordinates of placement would be outputted from the CS8C-M once a program is ran into the program itself. If the RS20 needed to be moved slightly in any direction to make a placement more accurate, the number could manually be adjusted.



Drawing 6—Teaching a robotic arm how to move within a frame of reference. The world frame is how the robot perceives itself in the world and the user-defined frame is what the user teaches the robot to move in.

Tests

Testing the VAL3 code on the RS20 was a “Guess & Check” process. Stäubli’s 3D Studio was used to test every movement the RS20 made while following the instructions of the code to make sure the movements looked visually sound and safe. If the robot was not following a grid placement pattern, flailing randomly, or randomly shutting down, the code would need to be adjusted to fix the problem. Experimental trials were then run to test the accuracy and repeatability of the RS20. Each test was measured with a stop watch to record the speed of completion from the moment the operator pressed the start button on the controller to the last part being placed. After the last part was placed, the operator would press the stop button and the RS20 would return to a location up and out of the way of the packaging area so that the operator could remove the finished packs. Each pack was inspected for accuracy of placement and damaged parts. Each Waffle and Gel pack contains 400 parts, so each would receive an accuracy score out of 400 for correctly placed parts. The final trial for the Waffle pack test is located in the Appendix under Table 5.

Results

Placement Accuracy

After running test trials for the pick and placement codes for the Waffle, Gel, and Ring Packs, it was noticed that the parts were not being placed in a perfectly square grid. In fact, the shape of the grid could be described as more of a diamond or skewed shape. This mishap was caught when testing the program for Waffle Pack placement. It's assumed that the plastic molded Waffle Pack is not perfect, but it's pretty close to being a perfect square; and in fact, the frames for each Waffle Pack were taught off of the pockets in the corners of each pack. So why was the RS20 not returning to the location it was taught? The answer is that the RS20 perceived its location differently electronically than where it actually was in the world. The Y axis was where the problem lied. The first row on the Waffle Pack from the Origin point to the X axis point was the most accurate, but from the next row on it became more and more inaccurate in the Y direction. Within the programs, the coordinates of each and every placement are displayed. The points for where the RS20 were taught can then be compared to where the RS20 actually went. The data of coordinates for where the RS20 actually went calculated out to be placing in a perfect square. This meant that the coordinates taught were not electronically perceived as a square and the CS8C-M controller decided the correct these points and align them as a square instead. However, the grid that it thought was a perfect square was actually skewed in real life. This resulted in the Programmer having to adjust the data points manually to fit the placements in the real world.

Waffle Packs

After the test trial results were collected, the final trial for the program containing the placement code for the Waffle Packs, in Table 5 of the Appendix, received 99.21% accuracy. This mean that out of all six packs overall, there were around 10-20 parts out of 2,400 missing or incorrectly placed. The RS20 finished placing all parts in an average time of 45 minutes.

Gel packs

Table 6 in the Appendix shows the final test trial for the Gel packs when it received 99.71% accuracy—missing around 5 parts out of 2,400. The RS20 finished placing all parts in an average time of 43 minutes. This was expected to be slightly faster than the pick and placement into Waffle packs because the Bump code is not included in the Gel Pack code. The parts are able to stick to the Gel surface, and do not require an air blow off, scrap off, or bump.

Ring Packs

Ring Packs were tested and proved to be accurate at placing the parts in the correct position, but could not be accurate enough on the rotation of each part. Parts placed on a Ring pack must be very straight and unidirectional. No part can be rotated more than 2-3^{o} out of alignment. This resulted in 10% accuracy. The RS20 will not be used for Ring packs in the near future because it is much faster and accurate for an operator to pack them by hand.

Bill of Materials

A Bill of Materials, as shown in Table 7 of the Appendix, was created to keep track of all the materials and products manufactured and purchased. This list of materials is used to total the overall costs of the project but could also be used in the future as a parts list in case Johanson Technology would ever like to create additional pick and place systems. The list includes the requisition number for the order form in which the purchases were made, the title of the item purchased, the quantity, cost per quantity, and total cost for that item.

Cost Analysis

The cost estimates from the beginning of the project were very accurate to what the overall costs would be. It was estimated in the beginning of this project that to hire an intern for 3 months to design the entire pick and place system it would cost around $44,100. The actual resulting costs for the entire project, as seen in Table 8 in the Appendix, ended up totaling $50,104. However, $3,375 of that total was costs of labor for people other than the intern. Also even though $8,765 in labor alone was a large amount; it was nowhere near the $72,000 as seen in Table 9 that would have been required for a consultant’s labor alone if alternative one was chosen.

Conclusion and Discussion

The RS20 pick and place system proved to be not as accurate as a process as was expected. Stäubli advertised their robot to be much more accurate than was experienced through its use at Johanson Technology. Stäubli stated that the RS20 has a strong repeatability and a placement accuracy of < 2 mil. However after running our tests we experienced the robot being off by as much as 20 mil. On a good note, it was accurate enough to put into full production. Even if there were 10-20 misplaced parts out of every 2,400 an operator can inspect the parts and replace any damaged or missing parts easily.

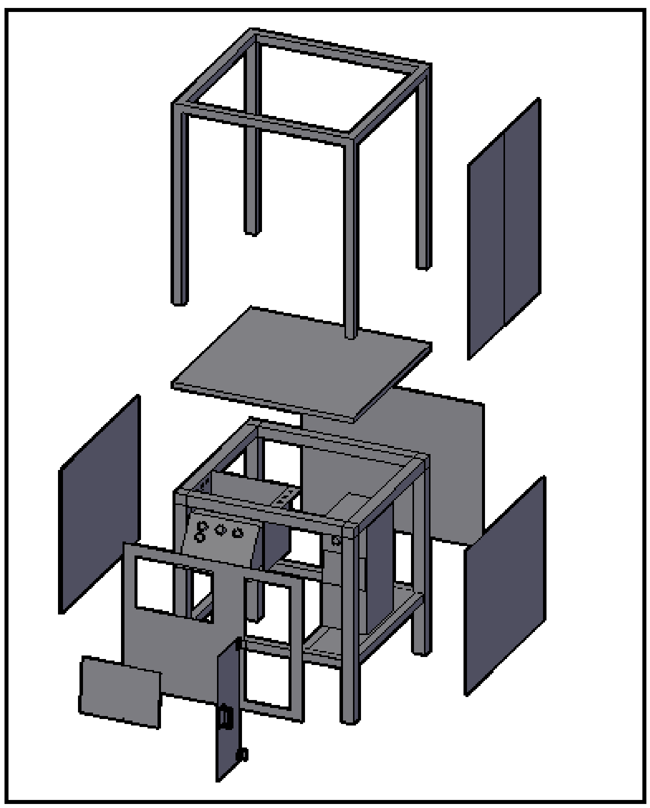
Benefits

Most importantly by the conclusion of this project, Johanson Technology was provided with 3 main programs, each for their three types of packs—Waffle, Gel, and Ring. Johanson Technology's Single Layer Department uses over 30 sizes of Waffle packs. Although there was not enough time to teach the RS20 to work with each size, the base code that was provided can easily be modified by Johanson Technology's Single Layer General Manager to fit any size of Waffle pack. As for the Gel packs, only the size of parts placed will change between packs. So once again, only minor adjustments to the code will be necessary to fit Johanson's needs.

Future tasks

Had there have been additional time allotted to work on this project, there would have been further developments and designs to expand and perfect this system. The following is a list of tasks that are recommended to be accomplished in order to fully complete and perfect this project:

- Manufacture walls around the table and glass panels around the RS20 and Bowl Feeder.
- Mount an emergency button on exterior of the workspace
- Install visual sensors to detect when the glass panels are open or shut
- Program an easy-to-use human interface with the CS8CM controller
- Test operator interaction with the CS8CM controller
- Change the power source to fit the needs of the Keyence Sensor so that it can be read by the CS8CM
- Further teach the RS20 to be compatible with all variations of parts and tools
- Permanently connect the vacuum tips with the pickup mount to decrease variability when switching tool sizes.
- Create a holder for all tool sizes



Drawing 7—Future metal panels and frame work to be added to the pick and place system.

Appendix

Point No.	TC*	Taught Placement		Actual Placement		Difference		Skew from Origin	
		Xo	Yo	X,	Y,	X,-Xo	Y,-Yo	XC on Y	YC on X
0	O(0)	127.920971	105.861	127.92097	105.86097	0.000	0.000		
400	O(1)	**98.251913**	47.05245	98.251913	47.052447	0.000	0.000		
800	O(2)	**157.194134**	47.15962	157.19413	47.159621	0.000	0.000		
1200	O(3)	98.151658	-11.5775	98.151658	-11.577459	0.000	0.000		
1600	O(4)	157.183738	-11.472	157.18374	-11.471961	0.000	0.000		
2000	O(5)	127.763363	-70.1129	127.76336	-70.112852	0.000	0.000		**Trail 6**
19	X(0)	168.261443	105.9219	168.26144	105.9219	0.000	0.000		
419	X(1)	**138.517364**	46.99514	138.51736	46.99514	0.000	0.000		
819	X(2)	**197.645651**	47.17912	197.64565	47.17912	0.000	0.000		
1219	X(3)	138.46	-11.5775	138.46	-11.577459	0.000	0.000		
1619	X(4)	197.616767	-11.472	197.61677	-11.471961	0.000	0.000		
2019	X(5)	168.09	-70.1519	168.08846	-70.1519	0.002	0.000		
380	Y(0)	**127.722998**	65.6611	**127.9817**	**65.660668**	0.259	0.000	**0.061**	**0.061**
780	Y(1)	**98.107736**	6.968983	**98.19498**	**7.026725**	0.087	-0.058	**-0.057**	**-0.057**
1180	Y(2)	157.12523	7.064368	157.28397	7.06413	0.159	0.000	**0.090**	**0.019**
1580	Y(3)	98.177786	-51.4738	98.15148	-51.473813	-0.026	0.000	**0.000**	**0.000**
1980	Y(4)	157.149015	-51.6315	157.18374	-51.631544	0.035	0.000	**0.000**	**0.000**
2380	Y(5)	127.84	-110.294	127.72444	-110.29401	-0.116	0.000	**-0.039**	**-0.039**

Comments:
The RS20 travels to the exact locations as taught for the Origina and X axis coordinates. However, the taught Y axis coordinate is off in the X direction. This skew is caused by the skewness of the Y coordinate of the taught X axis.

= change

*TC=Teaching Coordinate
*XC on Y= X Coordinate on Y axis
*YC on X= YCoordinate on X axis

Vacuum Tip:	014-301-05-23-14
Date:	1/29/2011
Time:	4:12pm
W.Pack:	H20-050-16
Part #:	160U03A302MN4R
MO:	056200-00
Vacuum Force:	-14

Performance:	*Correct*	*Out Of*	*Accuracy*
Pack 1	400	400	100.00%
Pack 2	397	400	99.25%
Pack 3	397	400	99.25%
Pack 4	398	400	99.50%
Pack 5	395	400	98.75%
Pack 6	394	400	98.50%
Total	2381	2400	**99.21%**
Speed:	4:12	4:56	0:44

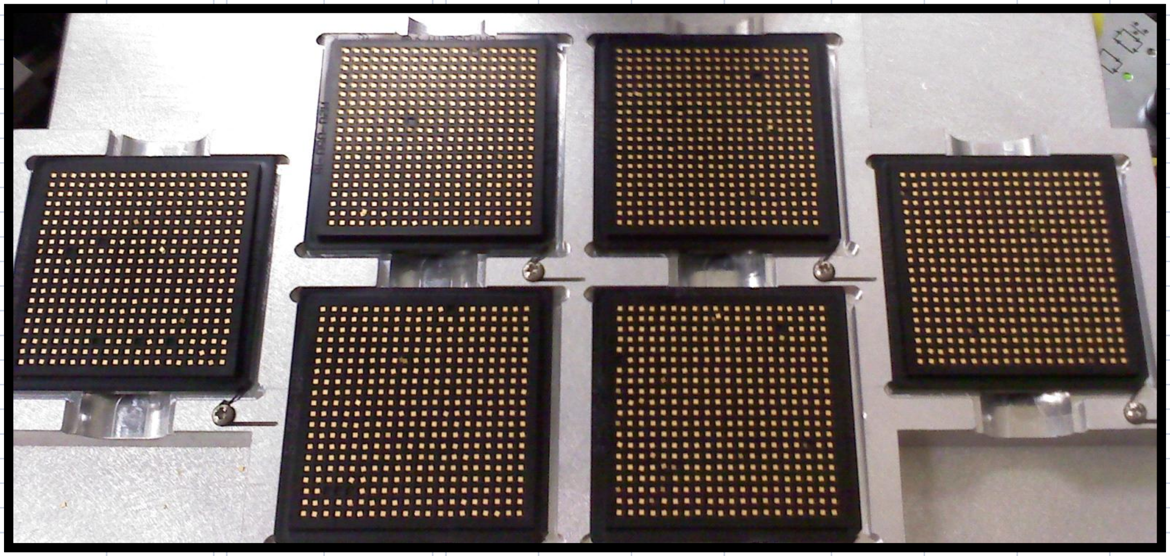


Table 5—Final test trial sheet for the Waffle Pack program.

Point No.	TC*	Taught Placement		Actual Placement		Difference		Skew from Origin	
		Xo	Yo	X,	Y,	X,-Xo	Y,-Yo	XC on Y	YC on X
0	O(0)	130.786317	102.824796	130.78632	102.824796	0.000	0.000		
400	O(1)	101.124135	43.979672	101.12414	43.979672	0.000	0.000		
800	O(2)	160.107889	44.146091	160.10789	44.146091	0.000	0.000		
1200	O(3)	101.010685	-14.568826	101.01069	-14.568826	0.000	0.000		
1600	O(4)	160.027824	-14.518127	160.02782	-14.518127	0.000	0.000		
2000	O(5)	130.570989	-73.16413	130.57099	-73.16413	0.000	0.000		
19	X(0)	165.42513	102.744564	165.42513	102.744564	0.000	0.000		
419	X(1)	135.688253	43.860305	135.68825	43.860305	0.000	0.000		
819	X(2)	194.780825	44.090212	194.78083	44.090212	0.000	0.000		
1219	X(3)	135.636611	-14.720035	135.63661	-14.720035	0.000	0.000		
1619	X(4)	194.744962	-14.662429	194.74496	-14.662429	0.000	0.000		
2019	X(5)	165.211948	-73.492783	165.21195	-73.492783	0.000	0.000		
380	Y(0)	130.935355	68.551511	130.7069	68.551279	-0.228	0.000	**-0.079**	**-0.080**
780	Y(1)	101.321024	9.833375	101.0051	9.833005	-0.316	0.000	**-0.119**	**-0.119**
1180	Y(2)	160.312849	9.900988	160.05218	9.900416	-0.261	0.001	**-0.056**	**-0.056**
1580	Y(3)	101.293347	-48.660986	100.86139	-48.661836	-0.432	0.001	**-0.149**	**-0.151**
1980	Y(4)	160.378777	-48.707241	159.88537	-48.70875	-0.493	0.002	**-0.142**	**-0.144**
2380	Y(5)	130.997276	-107.46335	130.24525	-107.46446	-0.752	0.001	**-0.326**	**-0.329**

Comments: Lowered the Z axis placement on Gel Packs 0, 1, and 3

= change

*TC=Teaching Coordinate
*XC on Y= X Coordinate on Y axis
*YC on X= YCoordinate on X axis

Vacuum Tip:	extra small		
Date:	2/21/2011		
Time:	12:07pm		
W.Pack:	Gel Pack XL 195RC		
Part #:	101V20X470MT4W		
MO:	120680-00		
Vacuum Force:	**-20**		
Performance:	*Correct*	*Out Of*	*Accuracy*
Pack 1	400	400	100.00%
Pack 2	398	400	99.50%
Pack 3	400	400	100.00%
Pack 4	397	400	99.25%
Pack 5	400	400	100.00%
Pack 6	400	400	100.00%
Total	2395	2400	**99.79%**
Speed:	12:07	12:54	0:47

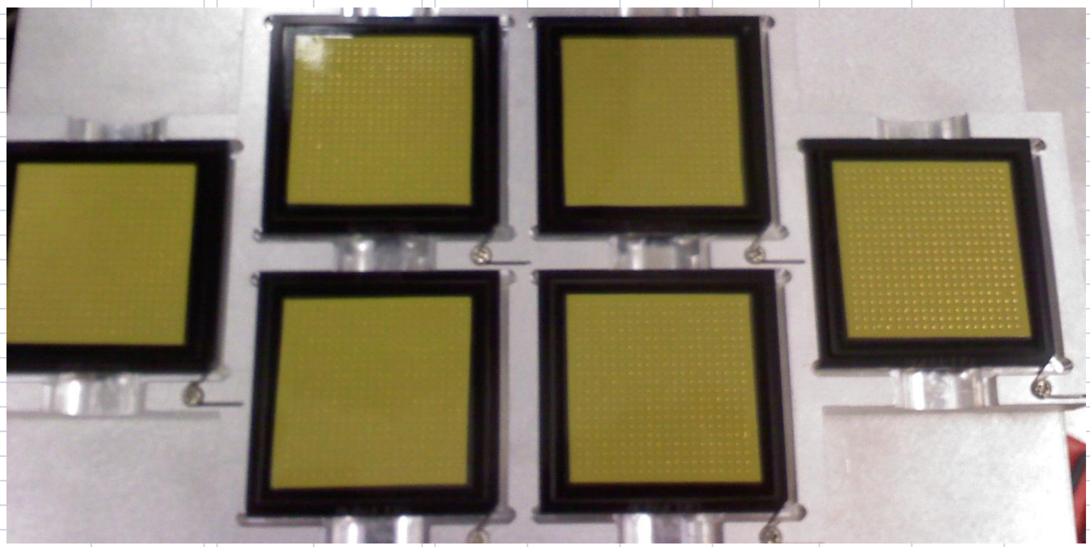


Table 6- Final test run for Gel Pack program.

Bill of Materials

Total Purchased Parts

Req. #	Automation Consultant	Quantity	Price	Total
100311	Nathan Stelman (6hrs)	6 hrs	$150.00	$900.00
Staubli				
90901	RS20 & CS8CM	1	$11,364.00	$11,364.00
90901	VAL 3 StudioSoftware	1	$1,485.00	$1,485.00
Electrosort				
91215	Bowl Feeder, w/o X-Y table	1	$19,987.47	$19,987.47
91215	Adaptive 2nd stage track 0.02x0.003	1	$402.57	$402.57
91215	Adaptive 2nd stage track 0.03x0.003	1	$402.57	$402.57
91215	Adaptive 2nd stage track 0.04x0.003	1	$402.57	$402.57
100908	Extension cable	1	$56.20	$56.20
Clippard Instrumental Laboratory, Inc.				
100311	3-way Miniature valve #E310C-2C012	24	$1.08	$25.98
100311	Connector w/11.8" wire	3	$2.17	$6.50
101109	2-way 10mm Miniature valve #E210C-2C012	1	$26.09	$26.09
101109	E10M-01-M5 10mm single station manifold	1	$10.59	$10.59
100806	PQ-FC12Q-PKG Female Connector 3/8" - ¼"	1	$24.10	$24.10
100806	PQ-MC06M2-PKG Male Connector 6mm- ¼"	1	$12.50	$12.50
100806	PQ-FC08P-PKG Female Connector ¼" - 1/8"	1	$15.90	$15.90
100806	PQ-MC04MR-PKG Male Connector 4mm - 1/8"	1	$12.50	$12.50
PNEUAIRE				
101111	VR1000N01 Vacuum Regulator 1/8"	1	$92.01	$92.01
101111	15110-30Hg125 Class B Center Back Mount	1	$18.67	$18.67
Festo Corporation				
101110	#159500 Pressure Regulator	1	$230.72	$230.72
101110	#161126 Precision pressure gauge	1	$17.14	$17.14
101110	#159503 Bracket	1	$3.37	$3.37
100623	Straight Connector QSM-M5-3 (x10)	10	$2.61	$26.10
100624	Straight Fitting QSM-4-3	10	$3.88	$38.80
100624	Straight Fitting QSM-6-4	10	$3.97	$39.70
Keyence				
100804	NEO-MEGA Power Fiberoptic Amp	1	$169.00	$169.00
100804	Fiber unit Reflective, Definite Reflective 2M	1	$198.00	$198.00
McMaster Carr				
100608	Mitutoyo Electronic Outside Micrometer	1	$107.10	$107.10
100616	Semi-Flexible Rule - made of steel	1	$21.50	$21.50
100617	Replacement bulb. Part #6619T53	5	$0.42	$2.10
100617	Flexible Nylon Tubing, Part #50405K32	25	$0.25	$6.25
100617	Choose-A-Color Polyurethane Tubing	25	$0.17	$4.25
100617	Elbow Tube fitting, Part#51495K231	3	$3.09	$9.27
100617	Elbow Tube fitting, Part#51025K371	3	$3.96	$11.88
100617	AS568A Dash Number 901 O-rings, Part#1201T288 (100/pack)	100	$0.13	$12.85
100617	AS568A Dash Number 007, Part#1201T17 (pack of 50)	50	$0.10	$5.12
100624	M5 X 65 mm, Part# 91290A270, 25/pack	25	$0.19	$4.78
100624	M5 X 65 mm, Part# 91290A111, 100/pack	100	$0.04	$4.05
100624	M5 X 65 mm, Part# 91290A120, 100/pack	100	$0.05	$4.86
100624	Cable Tie Holder Adhesive Backed, Four Way	1	$12.38	$12.38
100624	Standard Nylon Cable Tie 4" L, pack of 100	200	$0.02	$4.12

Continued on next page.

Bill of Materials Continued.

SMC				
101109	Vacuum Regulator, 1/4" ports, with Bracket and Gauge	1	$168.46	$168.46
100722	Fitting, mini male connector, M3x.5 thread, for 4mm tube	4	$9.49	$37.98
100622	SMC Slide Table, part # MXS6-10	1	$216.80	$216.80
100624	SMC Vacuum sensor, part # PS1100-R06L	2	$54.36	$108.72
100624	Blue Polyurethane tubing, 4mm OD	66	$0.21	$13.54
Hotek Technologies				
100311	#25001900PVSAD Femto Vacuum Sensor/Switch	1	$205.00	$205.00
100311	Adaptor Flange for Vacuum Pressure Switch	1	$25.00	$25.00
100311	Part#110 26 300 Connector Cable, length 15 ft.	1	$25.00	$25.00
100311	Angle Bracket for Adaptor Flange	1	$15.00	$15.00
Total Designed and Machined				
Groth Engineering				
100616	End Effector Cylindrical Mount	1	$514.19	$514.19
100625	Rectangular Pick-Up Mount	1	$622.44	$622.44
100902	(Modification) Rectangular Pick-Up Mount	1	$108.25	$108.25
101021	2nd Rectangular Pick-Up Mount	1	$622.44	$622.44
100804	Waffle Pack Mounting Plate	1	$1,028.38	$1,028.38
100804	Ring Pack Mounting Plate	1	$324.75	$324.75
100804	Table w/ 4 legs	1	$433.00	$433.00
100811	Bracket, Aluminum	1	$216.50	$216.50
Speedy Metals				
100722	Aluminum Railing (x2)	2	$31.20	$62.40
	Total Purchased		**$40,926.39**	

Table 7—Bill of Materials for purchased and manufactured parts

Name	Title	Hours	Wage	Total
	Engineering Time			
Alex	Intern	385 hrs	$14.00	$5,390.00
Tom	Single Layer General Manager	100 hrs	$25.00	$2,500.00
Julio	Single Layer Operations Manager	10 hrs	$25.00	$250.00
	Construction Time			
Rafael	Maintenance	10 hrs	$25.00	$250.00
Dave	Maintenance	5 hrs	$25.00	$125.00
Clemente	Maintenance	5 hrs	$25.00	$125.00
Ted	Maintenance	5 hrs	$25.00	$125.00
	Total System Cost including Labor		**$50,104.71**	

Table 8—Total Costs of Alternative 2. This is Table 5 with the addition of labor costs.

Name	Title	Hours	Wage	Total
	Engineering Time			
Nathan	Consultant	480 hrs	$150.00	$72,000.00
Tom	Single Layer General Manager	50 hrs	$25.00	$1,250.00
Julio	Single Layer Operations Manager	10 hrs	$25.00	$250.00
	Construction Time			
Rafael	Maintenance	10 hrs	$25.00	$250.00
Dave	Maintenance	5 hrs	$25.00	$125.00
Clemente	Maintenance	5 hrs	$25.00	$125.00
Ted	Maintenance	5 hrs	$25.00	$125.00
	Total Purchased		**$115,051.39**	

Table 9—Total Costs of Alternative 1. This total is Table 5 added to the labor costs of hiring a consultant which would also cause the General Manager to spend less time on the project.

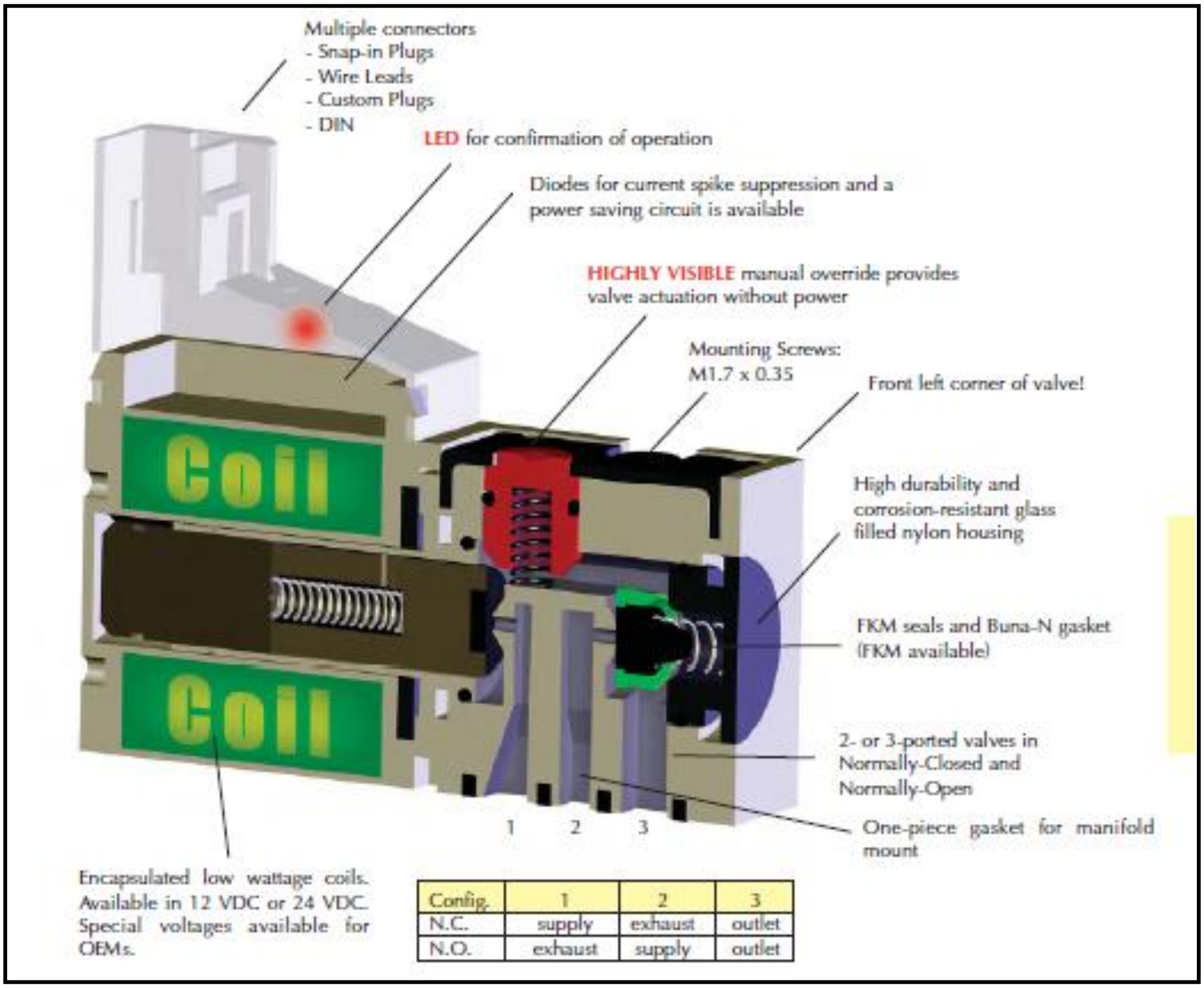


Figure 2—Detailed diagram of the vacuum and pressure valve made by Clippard.

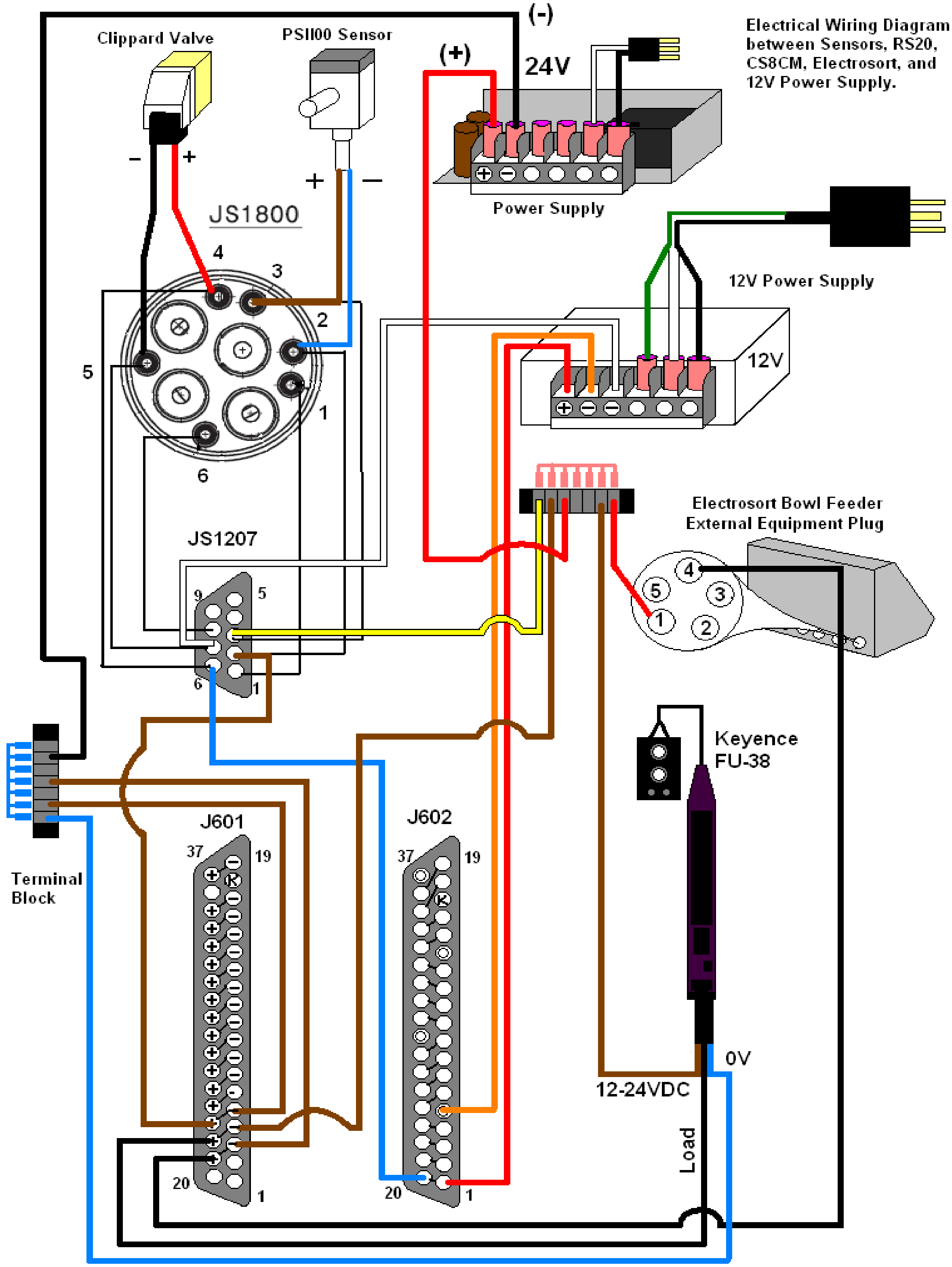
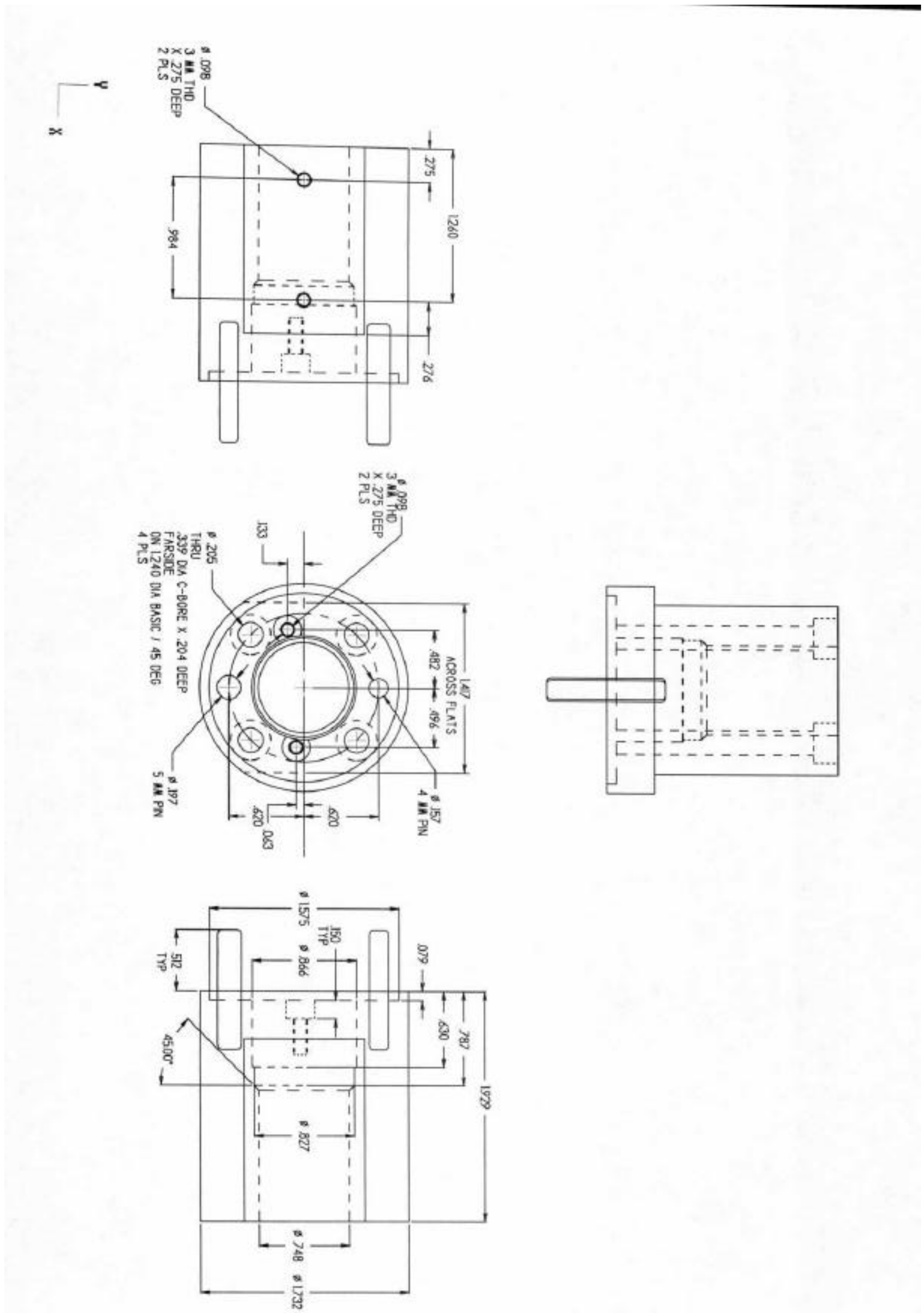
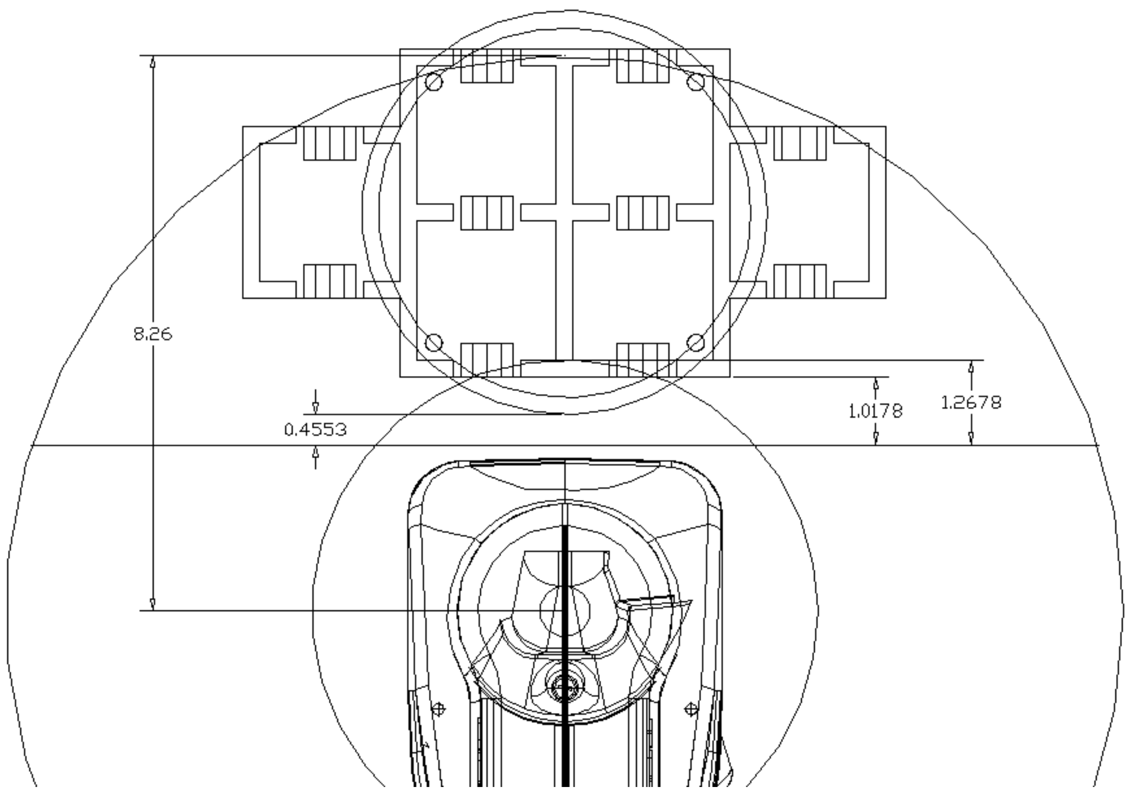


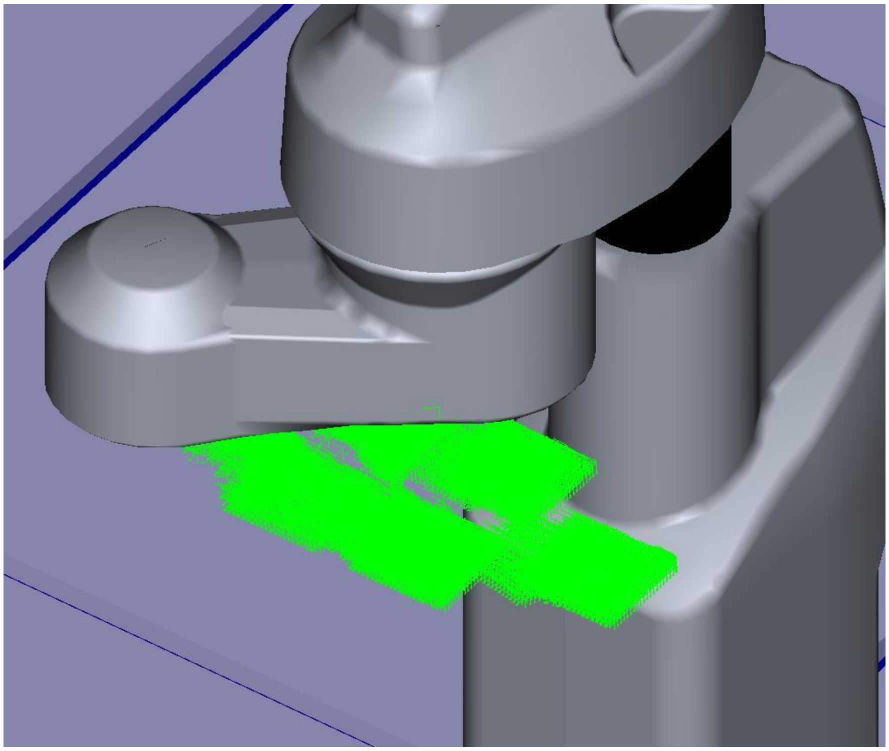
Figure 3—Electrical routing diagram for the pick and place system. This illustrates how to wire the Bowl Feeder, Clippard valve, vacuum sensor, and two power supplies into the CS8C-M.



Drawing 4—End Effector part drawing.



Drawing 5—Range of reach on the RS20. This drawing illustrates how the Waffle and Gel Pack holder and Ring Pack Holder were designed to fit within the RS20's area of reach.



Picture 2—Screen shot of the RS20 placing parts on a Waffle Pack holder in Staublie's 3D Studio program.

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