Das BrauMatisch

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The objective of this design and construction was to build a three-tiered brewing system commonly seen in homebrewing practices. As the project evolved, it became an Arduino Microcontroller, controlled automatic brewing system. The BrauMatisch helps automate the brewing process by autonomously heating and transferring water to different tanks based on pre-programmed recipe temperatures and times. It’s simple, easy to use interface allows for the brewer to have constant updates on temperatures, times and other relevant information. In case the brewer is asleep on the job, an alarm has been built in to the control panel to notify the brewer operating the system of any required actions.

This system is designed for a typical homebrewing system, which holds a maximum of 10 gallons. This small system being automated has application to the brewing industry because more and more breweries are moving to semi-automated and fully automated systems. This senior project discusses the mechanical construction of the brewing stand, as well as, the electronic construction and automation of the BrauMatisch brewing system.
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**INTRODUCTION**

Beer production has been an important part of human civilization since the beginning of time. However, the brewing process has evolved over the years typically due to advancements in technology, such as the creation of the thermometer to monitor temperature. The King of Germany declared a series of laws called the “Reinheitsgebot” which mandated that all beer be made from four main ingredients: malt, hops, water, and yeast (Eden 1993). From that point forward, beer all over the world was only to be created using these four main ingredients. In fact, all beer today whether from a macrobrewery or a craft brewery, consists of at least these four ingredients. The chemical processes that occur during brewing are rather complicated. The brewing process requires large volumes of water to be kept at precise, high temperatures for prolonged periods of time.

The brewing process consists of three main stages, the mash, the sparge, and the boil. These processes are the same with every beer, however, the different temperatures and durations during each of these stages greatly effects the final product. Brewers also refer to this first process as “Mashing,” which consists of mixing crushed malt with hot water. This process is chemically known as Sacchrification, in which enzymes present in the malt are activated at a certain temperature and begin breaking down the complex carbohydrates in the grains to monosaccharaide. The temperature and duration of the mash effects the sugar content in the beer, which will later correlate directly to the alcohol content. It is critical to maintain precise control over the temperatures at this stage to ensure proper enzymatic conversion of starches to simple sugars. It is typical to hold the grain and water slurry, better known as the Mash, at temperatures between 145˚F and 160˚F for an hour or longer.

The next process associated with brewing beer is called the sparge. During this simple process, the mash is rinsed with hot water to extract sugars and end enzymatic conversion. The mash is drained of the sugar solution and the grains are rinsed off with water that is around 170˚F to denature the enzymes. There are a few methods typically used to accomplish this, however, this senior project will focus on “fly-sparging”. Fly sparging consists of draining the mash into another tank, while simultaneously adding the 170˚F water to rinse the grains without significantly disturbing the grain bed. The grain bed acts as a filter for itself holding back the large grain husks and allowing only the liquid to flow out. Once the grains have been successfully drained of all sugars, the next stage can commence.

The next phase of the brewing process is the boiling of the mash and addition of hops and other ingredients. Hops contain oils, which when isomerized in the boil, produce the bitter flavor in beer. Once again, time and temperature are critically important at this stage. The longer the hops are boiled, more oils are isomerized and thus the more bitter the beer. Bittering is not the only goal of the boil, however. Boiling also aids in breaking down the proteins present from the grains and sanitizes the sugary solution. This is critical later on to ensure the beer does not become contaminated. The boil time is typically a minimum of one hour to thoroughly break up all proteins and sanitize the solution.

The brewing process consists of many complicated chemical processes as well as physical processes that need to be done at precise temperatures for prolonged periods of time. The goal of this senior project is to provide an automated machine that significantly reduces the
necessary intervention of the brewer. Thus providing a less stressful brew-day and allowing the brewer to focus on the recipe ingredients and flavor profiles of a beer as opposed to ensuring temperatures are where the recipe requires them to be. The brew-stand should also provide a convenient interface for which the brewer can monitor the brewing process and record data.
LITERATURE REVIEW

**Brewing Automation**
In order to achieve a healthy fermentation, carbohydrates in grains and malts must be converted to simpler sugars using a technique called mashing. “The Enzyme activity depends on temperature, so automatic temperature control is very important to this process.” (Weeks 2015) Due to the fragile nature of the enzymes, the exact temperature must be reached in order to activate a specific enzyme. The enzyme will become denatured if the temperature is too far above. Therefore, having an automatic system that can shut heat off that was supplied an electrical heating element, then the brewer would not need to spend extra time ensuring the proper temperature has been reached. As Weeks puts it, “A vital part of beer brewing is temperature control.” (Weeks 2015)

**Large Scale Brewing Processes**
Due to the requirements needed in order to brew beer in the traditional manner of mashing to achieve Sacchrification and boiling to achieve isomerization, the brewing process requires lots of energy to heat up water at different points of the brewing process. The main largest amounts of energy draw in the system come from the power, steam and water. (Bai, 2011) This is again due to the large volumes of water that needed to be heated to nearly boiling temperatures. The main brewing process, boiling, can often pull large amounts of energy in order to heat a large volume of liquid. Water has a very high specific heat making it very difficult to change the temperature of water. As such the brewing system needs to be able to handle large power requirements.

The brewing process is also often controlled to further extents in production facilities due to the ease of contamination that beer poses. Automatic Processes such as the Opto 22 automatic system is being used in New Belgium Brewing Co (Valuyevu 2003) This shows that the brewing process is constantly being automated for a variety of reasons both in industry and at home. These large industrial systems obviously require more power than the small homebrewers would require.

**Electric Water Heater**
Most industrial breweries use Steam jacketing system to easily heat tanks for a multitude of reasons. Steam systems are typically the way to go in large scale breweries due to the wide range of applications a steam generator can provide for heating water, as well as sanitizing and sterilizing anything that may come in contact with the beer. (MacMaster 2015). For most homebrewers, a steam system would be very convenient to have; however, due to the expensive nature of a steam generator, often times homebrewers will find alternative means to heat liquids. Homebrewers will typically modify an electric water-heating element. Replacement water heating elements can be retrieved from many local hardware stores. The replacement elements are also typically under $40 making it a cheap and effective tool for the homebrewer to use as an electrical heating option. However heating elements must be used safely to ensure no one is harmed. In fact, 6.4% of all burn victims from 1996 to 2001 were the direct result of an electrical water heating element. (Shiow et-al2003)
Chemicals in Beer
Although the chemical make up and process that the brewing process consists of there are certain chemicals that will cause off flavors and should be avoided in the materials used in brewing equipment. That being said, there are also chemicals that are necessary in order to have a healthy fermentation of the beer has been brewed. Some breweries in the United Kingdom will also add chemicals at certain points of the brewing process to improve yield. In fact, Selenium is often used in the grain to enrich it. Selenium is an essential micronutrient for both the yeast that make the beer and the humans that drink it as well. (Rodrigo et-al 2015) According to Rodrigo et-al, “Low SE status has been associated with increased risk of mortality.” (Rodrigo et-al 2015) It is, therefore, very important for a little bit of Selenium to be inside of the beer.

There are other chemicals and elements that are added throughout the brewing process to ensure not only a healthy fermentation but also to control variations in taste in the finished product. For example, adding salts to the water used to make beer, will affect the enzymatic process of Sacchrification by changing the pH of the water. Before the chemistry in the beer was well known, the chemicals in water were affecting the beers long before the brewers knew about how to control them.

Water and the composition of the water used in the brewing process plays a significant role in determining the final taste of the beer once it has been fermented and becomes a final product. In fact in Plzen, Czech Republic, the birthplace of the Pilsner style of beer, has incredibly soft water. This means that there are very few residual ions in the water making the flavor of the beer crisper than the typical beer. (Palmer 2006) On the other hand, the water in Northern Ireland where the World famous Guinness beer is brewed, has an exceedingly high number of bicarbonates in the water making it “hard” water. (Palmer 2006) These two styles of beer have completely opposite taste profiles due mostly to the fact that the water composition is different in each location. Therefore, the flavor profile is directly correlated to the chemicals that make up the products used in the brewing process.

Microcontrollers
The use of microcontrollers, such as the Arduino Uno is seen more often and more often due to their ease of use and utility when controlling various electrical components. Microcontrollers operate very simply, by merely turning off and on power supplies of equipment that is plugged into the microcontroller. Code is written and saved on the microcontroller, which then acts as the brain of the system turning on and off the electrical components as the code dictates. Although this senior project will comprise solely of the Arduino controller research was done on PID controllers to ensure that the Arduino platform would provide a more customizable platform than a PID controller.

PID Controllers.
The PID controllers used in most breweries are very easy to use. The PID controllers are specifically designed for controlling temperature. The PID system simply displays the
current temperature and the target temperature. The brewer can then simply plug the element into the PID controller and without needing to program anything. The controller will automatically regulate the heating element for the brewer. However, there are a few negatives to the PID controller. It will often overshoot the temperature, which as mentioned before, will denature enzymes during Sacchrification. This can ruin the final product if it is not corrected for, something that the brewer would need to be ever vigilant of thus making the system not so automatic. According to a study done by V. Mukherjee and S Ghoshal, on the PID controller “[The] PID control is not at all effective.” (Mukherjee 2007) It is likely that this PID system was not properly tuned. There are a variety of factors that will affect the PID control, if they are not properly tuned for the system the PID will not be effective.

ARDUINO
Arduino, this MCU provides many options to control things electronically through a pre-programmed code the user writes. This MCU also has the ability to interface with other devices, such as screens, temperature sensors, buttons, buzzers and more. The Arduino MCU was chosen for this design because it allowed for any sort of automation to be designed.

SOLENOID VALVES
One of the main instruments used in automating the brewing process is a solenoid valve. Solenoid valves are valves that can be controlled open or shut based on if you have electricity powering it or not. Sending power to these valves opens them allowing for the liquid to flow through the device and out the other side. These valves have allowed for the automation of transferring the liquids between tanks and vessels.

HERM Systems
A “HERM” system or Heat Exchange Recirculating Mash system is one method in which brewers can gain accurate control over the mash temperature. It is important to control the mash temperature because it is a vital deciding factor on taste and alcohol content of the final product. This precise control is managed by creating the volume of liquid in the system at Mash temperature, therefore increasing the amount of energy required to decrease in temperature. A typical HERM system is done by pumping the liquid in the mash tun through a long copper coil placed in a large volume of water at the desired Mashing temperature. As the mash liquid circulates through the coil it maintains it’s temperature with the large volume of water the coil is sitting in. This provides a larger reservoir for heat and creates a more constant temperature when brewing.
PROCEDURES AND METHODS

THE BREWSTAND

The initial design and thought process for this design revolved around a semi permanent, yet still moveable platform from which to brew beer. The brewing process has a number of steps in which hot liquid needs to flow from tank to tank safely and efficiently. A few concerns were taken when designing the brewing stand to ensure that the stand would be most ergonomic for the brewer.

The first major consideration for this design was the creation of a stable platform to create a “three tier” brewing system as shown below in Figures 1 and 2. During the sparging phase of beer brewing grains that have been soaking in hot water are rinsed with fresh water and both are fed into a kettle. As shown below, hot clean water around 170°F is being stored in the white bucket. The valve on the bucket is opened and clean water is allowed to rinse the grains soaking in the orange “Mash Tun”. The sugary solution from the grains is then drained into a kettle. This technique is called fly-sparging and is a common technique amongst brewers to get the maximum amount of sugars out of the grains.

Figure 1: Three Tier System Location A

Figure 2: Three Tier System Location B

The fly-sparging method can be difficult on college students, moving from location to location where changes in environment required accommodations to be made for a three tier, fly-sparging system. The initial design was intended to provide merely a more stable platform from which to brew using a three-tier system. In addition to a stable platform, it was also important to plan for the future and potentially allowing for a larger volume to be a brewer. A broken leftover keg provided the shell to make a “keggle” or a large vessel that can be converted into a kettle that can hold 15.5 Gallons, well over what a typical homebrewer would require.
The vessels were all measured out and designed in SolidWorks, computer aided design software, to design the brewing stand to the correct dimensions and requirements for the system. Figure 4, Below show the design of the stand with all of the vessels located properly and appendix attached show dimensions of the stand in inches. The kettle from Figures 1 and 2 has been replaced by the keggle mentioned earlier, and the kettle replaced the white bucket. This will again allow for larger batches to be brewed in the future. The brewstand was designed arbitrarily with 2” square tubing. The assumption was that the 2” square tubing would be able to withstand the weight of the large volumes of water that will be on the brewstand.

After ordering the required amount of steel tubing designed for in the figure above, it was revealed that there might be an issue with the weight of the design. The tubing alone
weighs approximately 300 pounds so having a semi-portable system weighing that much may prove difficult to create. It was decided to separate the stand into two halves. The bottom half consisting of the first tier and then the second half that will house the middle and top tier areas.

Both halves of the BrauMatisch are the same dimensions for the drawing above; however, there is an extra square frame that allows the top half to slide onto the bottom half connecting the two halves into one machine.

**AUTOMATING THE PROCESS**

After continued research on three-tiered systems, it was discovered that there were brewing systems on the market that would automate parts of the brewing process, if not the whole process. Automating the brewing process, not only makes brewing beer easier on an individual, it also helps remove a number of variables if something is automatically controlled. Repeatability is extremely important to brewers because a product must taste the same every batch to ensure happy consistent customers. A process automated by a microcontroller will likely remove a number of variables from the brewing process and increase the chances of repeating a consistent flavor profile.

Temperature and time are the two factors that most impact the Sacchrification during the mashing stage of the brewing process. There are a variety of systems on the market that will help maintain a set temperature for a set duration, such as the Zymatic system. Many of these devices, however, require 240V of power, which is the same voltage as large load appliances like electric ranges, electric dryers, etc.. There are not typically many 240V outlets in a home where they are not needed, so it would be more convenient to have a device that automated the process that requires only the standard 120VAC supply source.

A constraint of this project was the availability and quality of the electricity that could be provided to the device. There are brewing systems on the market which use 240 V power from the main breaker panel of a house. Of course, many of these systems need to be tethered to a specific location or outlet. The brewstand was meant to be somewhat portable, so the availability of high voltage electricity was ruled out as a possibility for the design. Designing a system that would require high voltage would limit the portability of the stand, and would be difficult to supply in all locations the stand could be placed.

Many popular homemade temperature-controlling devices used 120V water heaters with programmable PID controllers. These can set and maintain a temperature. Many of the PID controllers were not able to function as both a timer and a temperature controller. Being able to condense the two into a single functional system would drastically simplify the interactions required by the brewer. This sparked an interest into further developing the idea of automating brewing and creating a more custom design of the functions of the brewstand.
Brewing Steps To Automate

Initial heating of water to prepare for mashing-
- Requires filling the “HLT” Hot Liquor Tank on the top tier with water
- Heating the water to the desired temperature for mashing in the grain
- The water then needs to be drained to the Mash Tun to mix the grains

Mashing In-
- While mixing the grain in the mashtun, water should be filling up the HLT
- Water in HLT should be heated to Mash Temp
- Once Mash Temp is achieved HERM system should activate

HERM System-
- The HERM system requires Mash volume to be pumped through coils
- This process should end automatically after the desired amount of time

Sparging-
- After the desired amount of mash time, the system should raise temp to sparge temperature
- Once the temperature has been reached the valves should open automatically and begin sparging.

Boiling-
- Once the sparging has been completed the system should begin to heat up
- Once the liquid now in the keggle reach a boil the system should start a timer
- The electronics should also alert the brewer to any additions needed, such as hops, yeast nutrients etc

Whirlpool & Chilling-
- Once the boil time is over, the system should begin a whirlpool in the keggle
- After a few minutes of whirlpooling, the system should begin sending the boiling liquid through the chiller and into the fermenter

OTHER DESIRED FEATURES

Easy Notifications
A Piezo Buzzer was used to create sounds to notify the brewer of any required actions. This includes any actions that could not be automated and need to be completed by the brewer, as well as, hop additions. This may not be necessary at all times, so a switch will be placed on the board to turn off the buzzer when need be. Also to make an easy to see notification there will be an alarm light. The alarm light will sound with the buzzer for any required actions by the brewer, and if the there is an issue with one of the burners.
Visualization of Major Steps
There are basically 3 basic steps that Das BrauMatisch help automate for the brewer, Mash, Sparge, and Boil. Large LEDs are placed on the control panel to notify about the general progress of the beer can be seen from a distance. This way the brewer can leave the device alone and check in on it from a distance.

Accurate Temperature Reading
This device uses TMP36’s a common small hobby electronics temperature sensor that is very compatible with Arduino coding. When these devices were initially used to calculate temperature, reading the temperature every half-second produced a wide range of temperatures. It is likely that this is due to the Arduino reading a lot of noise in the signal coming back from the sensor. There was a simple solution to this problem, rather than the Arduino taking one measurement every half-second; the code made the Arduino take the average of 100 measurements in just 1 millisecond. This provided a much smoother transition when the temperature was changing.

Screens
A large 16x2 LCD screen was placed in the center of the control panel. This will show relevant information such as set temperature vs current temperature for the tanks and other tasks that need to be completed by the brewer. Also desired for this project were constant readings of the temperatures of each tank. Constant readings were achieved by using 4 digits, 7 segment displays that conveniently display 3 digits and the letter “F” for Fahrenheit.

SAFETY CONSIDERATIONS

Fire Safety
Once the selection was made to use propane burners as opposed to an electric water heater, a few safety measures needed to be taken. This device uses two infrared light sensors that can detect the existence of flames. These were placed directly under the burners to have the Arduino sense the existence of the flames. In the code, the device checks regularly if the propane valve is open, but there is no flame the alarm will sound immediately to notify the brewer of the issue.

Electrical Safety
Because this device will be made of metal both sides of the stand will have a connection to the main grounding line. This will ensure that if any stray voltage is present due to a wire being exposed the device will automatically ground rather than going through someone. In addition, each of the solenoid valves will be grounded on their surface to make sure that there can be no harm in touching any of the devices.
CONTROL PANEL

Designs
The control panel was meant to house all of the electronics of this project. A plastic case was initially considered, however, the cost of an industrial style, waterproof, control panel was rather expensive. It was discovered that it could be cheaper to construct the panel out of wood, and then spray with a waterproof coating to prevent water from soaking into the wood. Waterproof wood glue was also used again to help ensure that water would not enter into the device and ruin electronics.

Figure 5: AutoCAD design of Control Panel Face

The figure above was the final design for the face of the control panel. This design was created in AutoCAD and was designed to scale to allow for it to be created on wood with a laser printer. This design was chosen after a few iterations because it seemed to be the most understandable and showed a rough sketch of the process flow of the unfermented beer.
Back Panel
The control panel was to be built of wood, and because the front was being etched by the laser printer, this student took advantage of the access to the laser printer and also etched out the back panel. The back panel needed to have some sort of interfacing with all of the electronics so that it could be removed without having to remove all electronics from the stand. There was a large sale on Duplex outlets at the time so the interface was designed to accommodate this, and properly label each of the interfaces. The design below was the final design chosen to laser etch on the back panel, figure 6.

![Back Panel Diagram](image)

**Figure 6:** The Back Design of the control panel

Top Panel
The Top panel contains only one functional aspect; it was designed only for aesthetic purposes. The only functional purpose of this part of the panel is the large circle on the left-hand side. Figure 7 below shows the top of the control panel.

![Top Panel Image](image)

**Figure 7:** The top Design of the control panel
LASER ETCHING

Each side of the control panel to be etched was designed to scale in AutoCAD. Once the designs were satisfactory, 1/8” thick Birch plywood was purchased and placed under the laser printer. The laser printer was able to both etch and cut the holes through the wood. The designs were simply downloaded to the laser printer and the panels were quickly etched and cut out. The figures below show the final products cut out of the wood.

CONSTRUCTION OF THE CONTROL PANEL

The sides and bottom, the only remaining sides not etched, were also cut to length using the laser printer. These were then glued to the back panel, however, this would prove later to be not as stiff as desired. To strengthen the box 1” x 6” thick boards were cut and glued into place to allow for added strength to the thin boards. A 45˚, 1/2” angle piece was cut to glue into the corners of the control panel to increase the surface area of areas to be glued to increase the strength of the box. The box was then lightly sanded and sprayed with waterproof varnish.

Small studs were placed on the side of the back panel to support the 8-Channel Relay that will be driving a few of the electrical outputs of Das BrauMatisch. These studs were epoxied into place using instant 5-minute epoxy.

ELECTRONICS

HOA Switches
The pumps need to be controlled electrically in order for the BrauMatisch to be automated, however, the ability to turn the pumps on by hand was also desired as a feature for this project. This is accomplished by the use of an HOA switch or a Hand-Off-Auto switch. These switches have three positions to allow the pump to be both manually operated and automatically operated when the automation process is in motion.

LCD & Button
There were some steps in the brewing process that were not terribly feasible to automate. For example, mashing in the grain would require a large electric motor to stir and mix the grain in. A large electric motor is not really possible in this design so a simpler way to achieve these bigger actions was required. Having the Arduino communicate with the brewer via the LCD screen helped meet this. Commands for the brewer to complete are displayed on the LCD screen. When the brewer has completed the task, the button should be pushed to allow the program to know the task has been completed.
LED Modification
The large LEDs used in this designed were purchased under the assumption that they ran off 12 Volts of DC power. However, the LEDs purchased required 120 Volts of AC power, which was not a feasible option. Only a 15 V DC power source was available so each light had to be modified to work with 15V DC. Luckily, the only modifications necessary was the removal of a single capacitor from each light. The capacitor can be seen below, in Figure 8, as the brownish orange mass on the right side of the LED arrays centered in the photo.

![Figure 8: Disassembly and modification of LEDs](image)

12V DC Power Supply
Solenoids often require a large amount of current to operate. The solenoid valves were tested using a multimeter to see how much current each pulled at 12V DC. The stainless steel solenoid valves purchased pulled 3 Amps of current and the propane solenoid valves pulled 1.3 Amps. There is a possibility that a few of the solenoid valves will be operating at the same time. Pulling lots of current from the 12V source.

To ensure that the power supply will be able to provide the proper amount of current to the valves, a large DC power supply was purchased. This large power supply converts 120V AC power into 12V DC power and has a maximum current rating of 16.7Amps. This will ensure that even if there are a few valves open, the power supply should still be able to provide enough current.

Writing the Coding
A major obstacle for this project was writing the code. Often due to the complicated nature of many of the electronics pieces, there are often libraries that help simplify the coding process. There is a wide variety of open source programming libraries for use on the Internet, and the free Arduino software also contains several libraries to make interfacing with devices very easy.
The code took around 6 months of trial and error in the Arduino IDE software to finally come up with the proper codes and procedures to have the BrauMatisch fully automating the desired processes. Much of the research conducted for this project was conducted through a variety of online libraries. These provided the groundwork for much of the coding and helped in discovering different methods for using the libraries and having a variety of functions. It is attached as Appendix C.

**Prototypes**
Initial designs and tests were initially conducted on a solderless breadboard. Components were tested on a breadboard and as more equipment was added and tested the breadboard began to expand. Prototype designs have been attached in Appendix A. Large equipment was simulated by using a simple LED to make sure the process flow could work. Once the design was tested and the process was confirmed to work, rather than soldering these small electronics components together, a printed circuit board was designed.

**Printed Circuit Board**
A printed circuit board was designed in Eagle 7.5 Light to configure the best way to electrically connect all of the electronics components. There were quite a few designs initially designed for when planning the printed circuit board for the BrauMatisch. There were a large number of electrical components that needed to be included on the board. Designs were selected and altered based on their location on the board and their effectiveness to discreetly operate properly. Appendix B contains a few of the printed circuit board designs that were initially going to be used for the BrauMatisch.

**Etching the PCB**
The printed circuit board was created in-house in the CalPoly BRAE labs. Copper clad board was spray painted with dark paint to cover up all of the copper on the surface of the Fiberglass board. The board was then loaded into a laser etcher to etch off the paint. The circuit designs were inverted in color and then loaded onto the laser etcher. Inverting the color of the board allows for the etched away surfaces to be where copper is not desired in the circuit diagram. The laser printer etches off the paint exposing all of the copper cladding; copper traces required for the circuits remain protected by the spray paint.

After the first side had been etched and the paint had been removed on one side, holes were drilled in specific locations to align with the other side of the board. After the alignment holes were drilled the board was flipped and aligned under the laser printer. Again, using the holes to align the second side of the board with the first so all components would line up properly.

After the paint had been removed in the areas outside of the copper traces the board was submerged in a Ferric Chloric Acid Bath. This bath reacts with the copper and removes all of the exposed copper in the bath. All copper covered under spray paint will not react with the acid bath; this process removes all of the copper from the board and leaves copper traces that connect to create electrical circuits. After the bath, the board is run under mineral spirits and the spray paint falls off of the remaining copper traces.
CONSTRUCTING THE BREWSTAND

The frame was made out of 2” square tubing with 1/8” wall thickness. Each length of tubing was cut to length using a large band saw the dimensions of the stand are located in Appendix E. After being cut to length each of the cuts was ground down using a grinding wheel. Once all edges were deburred and all sharp edges were removed, the lengths of pipe were laid out on a table. The lengths of pipe were put temporarily in place and held temporarily with large magnets. The magnets helped hold the metal material together but allowed for slight movement so the proper alignment could be created.

Each vertical piece of pipe was held together with the magnets before being leveled with a vertical level on each side to make sure the column was perfectly vertical. After the vertical pipes were deemed square, tack joints were placed in each corner to fix the vertical beam in place. Once the vertical beam was tacked in place using a MIG welder the beam was checked again to ensure that it was level and square. Once deemed sufficient, the magnets were removed and larger welds were placed over entire edges of the joints to fix them in place. This process was repeated for each of the vertical beams on both the top and the bottom halves of the frame an example is shown below in Figure 9.

![Vertical pipe lengths, notice magnets and level on table](image)

The horizontal cross members were much easier to place, however, the process was similar. Horizontal beams were measured out and the pipe lengths were positioned according to the design. Once the pipe was square with the frame it was tacked into place, double-checked, and then a large weld went over the seam to fix the pipe in place.
RESULTS

THE BREWSTAND

As mentioned previously, the brewstand came out heavier than expected and far more difficult to move around than expected. Issues also arose when welding the pipe lengths together. A lack of experience with MIG welding pipe led to some poor joints as pictured below in figure 10. Fortunately or unfortunately, you can see an improvement in quality going up the stand as practice made for better and better welds. More photos of the final stand are attached in Appendix E.

![Figure 10: Poor joints between pipes that was later redone](image)

TROUBLESHOOTING

Another difficult part of this project was troubleshooting the electronics. Many of the electronics would become “fried” and non-operational after too many soldering to the sensitive pins. Another issue is that any poor connection in the electronics would cause gross failure for equipment like the LCD screen picture below in Figure 11.

![Figure 11: Troubleshooting the LCD screen during programming](image)

The smaller electronics of the control panel work however due to issues with the relays, the control panel cannot control some of the larger electronic devices. The device is still functional now as a brewing timer with multiple temperature sensors. Some of the automation steps are still being resolved, this is due to the failure in communication with the relays.
DISCUSSION

As mentioned previously, the brewstand is far heavier than originally planned for. A future stress test should be conducted to more accurately size the material used in the structure. Using smaller material would make the brewstand lighter and cheaper improving the overall design. An anticipated future project is adding wheels to the frame to create a sort of wheelbarrow with the frame to make it easier to move. The frame will also receive a coat of spray paint to try and prevent rust from building up on the all steel frame.

The current water sensor has some issues with its reading a requires a lot of wires. Another future project to improve the water measurement is attaching a servo to raise and lower a float switch based on the desired volume. This would require far fewer wires and has the potential to also be more accurate depending on the servo used. It would be nice to have additional sensors on the control panel that indicate the water level continuously in the Hot Liquor Tank. This may be a future project as well as a variety of other smaller improvements; it is likely that this project will never truly end; it will always have room for one more gadget.
REFERENCES


ProtoType 1.0 – Very basic controls not much automation.
Prototype 2.0 – Prototype with LEDs removed more automation, this prototype was the first with a water level sensor.
Prototype 3.0 – More automation than previous prototypes and this time has an added clock to keep track of the main brew time.
Prototype 4.0 – “iBrew” more 7 segment displays to display temperatures of each tank
this was the last prototype designed before manufacturing began
Top and Bottom Designs of an initial printed circuit board design
Final top and bottom designs to be used to create the printed circuit board
The homemade PCB created before and after it was populated
Wiring Diagram
APPENDIX C – Functions used to operate the Arduino running the automated system

String Recipe = "INGWER";
double MashVol = 2; //Gallons
double StrikeTemp = 77.3; //Degrees F
double MashTemp = 78.6; //Degrees F
double MashTime = 2; //Minutes
double SpargeVol = 3; //Gallons
double SpargeTemp = 73.9; //Degrees F
double BoilTime = 3; //Minutes

String Add1 = "1.5 Oz CHINOOK";
double Add1Time = 2.75; //MINUTES

String Add2 = "3 Oz CASCADE";
double Add2Time = 1.25; //MINUTES

String Add3 = "2 Oz NUGGET";
double Add3Time = 100; //MINUTES

String Add4 = "FERM NUTRIENT";
double Add4Time = .75; //MINUTES

Easy to change variables located at the top of the code to define each automated “Recipe”

```java
double ReadTemp(String Heater){
    double tTemps = 0;
    for(int i=0; i<101; i++){
        double VoltRead = 0;
        double Voltage = 0;
        double TempC = 0;
        double TempF = 0;
        String Element = String(Heater);
        if (Element == "HLT"){
            VoltRead = analogRead(HLTProbe);
        }
        if (Element == "TUN"){
            VoltRead = analogRead(TunProbe);
        }
        if (Element == "BKE"){
            VoltRead = analogRead(BKProbe);
        }
        if (Element == "MAT"){
            VoltRead = analogRead(ChillerProbe);
        }
        Voltage = VoltRead * 5;
        Voltage /= 1024.0;
        TempC = (Voltage - 0.5) * 100;
        TempF = (TempC * 9.0 / 5.0) + 32.0;
        tTemps = tTemps + TempF;
        delayMicroseconds(10);
    }
    return (tTemps/100);
}
```

Code used to measure temperature of each tank
Heating the separate tanks to the target temperature desired

```c
int Heat_To(String Element, double Target){
  double Temp = 0 ;
  String Probe = String (Element);
  if (Probe == "HLT"){
    Temp = ReadTemp("HLT");}
  if (Probe == "TUN"){
    Temp = ReadTemp("TUN");}
  if (Probe == "BKE"){
    Temp = ReadTemp("BKE");}
  if (Probe == "WRT"){
    Temp = ReadTemp("WRT");}
  if (Probe == "BKE"){
    if (Temp < (Target-1)){
      TurnOn("BKE");
    }else {
      TurnOff("HLT");
      TurnOff("BKE");
    }
  }else {
    if (Temp < (Target-1)){
      TurnOn("HLT");
    }else {
      TurnOff("HLT");
      TurnOff("BKE");
    }
  }
}
```
int Display (String Top, String Bot) {
    String First = String(Top);
    String Second = String(Bot);
    int one = First.length();
    int two = Second.length();
    one = (16 - one) * .5;
    two = (16 - two) * .5;
    lcd.clear();
    lcd.setCursor(one,0);
    lcd.print(First);
    lcd.setCursor(two,1);
    lcd.print(Second);
    Serial.println();
    Print("About to be display on LCD:");
    Print(String(First));
    Print(String(Second));
}

int Center(String Phrase, int Line) {
    String First = String(Phrase);
    int NewLine = Line;
    int One = First.length();
    One = (16 - One) * .5;
    lcd.setCursor(0,NewLine);
    lcd.print(" ");
    lcd.setCursor(One,NewLine);
    lcd.print(First);
}

Code written to display and center lines of information on the LCD screen
```c
int TargetCurrent(double Target, String Heater, int CountDown, String Light){
    Display("TARGET : "+ String(Target,1)+"F"," ");
    double Temp = 0;
    int changer = 1;
    String aLight = String(Light);
    String Probe = String(Heater);
    int i = 0;
    do{
        if (i == 5){
            i = 0;
            for(int k = 0;k<10;k++){
                Stage = ReadTemp(Probe);
                Display("TARGET TEMP","IS "+ String(Target,1)+"F");
                CountDown = CountDown -.5;
                UpdateTime(CountDown);
                Heat_To(Probe,Target);
                delay(500);
            }
            Heat_To(Probe,Target);
            Stage = ReadTemp(Probe);
            Display("WATER IS ","CURRENTLY "+ String(Stage,1)+"F");
        } else{
            if (changer == 1){
                TurnOff(aLight);}
        }
    }while (Stage < Target);
    return CountDown ;
}
```

Code used to heat up the tank to a target temperature and display relevant information
int Addition(String Add, double AddTime){
    Display("NEXT ADDITION"," ");
    do{
        for (int i=0; i<8; i++){
            Center(Add,i);
            Heat_To("BKE", BoilTemp);
            delay(500);
            BoilTime = (BoilTime-.5);
            UpdateTime(BoilTime);
        }
        for (int i=0; i<8; i++){
            double rTime = (BoilTime-(AddTime*60));
            String Ctime = GetTimeString(rTime);
            if(rTime > 0){
                Center(" IN " + String(Ctime),1);
                delay(500);
            } else {
                Center(" IN 0:00",1);
            }
            Heat_To("BKE", BoilTemp);
            BoilTime = (BoilTime-.5);
            UpdateTime(BoilTime);
        }
    }while(AddTime < (BoilTime/60));
    Display("PLEASE ADD", Add);
    Stage = WaitForAlarm(0,"Boil");
    TurnOn("Boil");
}

Coding used to display each necessary addition during the boiling phase

int TurnOn(String Element){
    String Heater = String(Element) ;
    for(int k = 0 ; k < 16 ; k++){
        String Reader = String(Lights[k]) ;
        if(Heater == Reader && aState[k] == '1'){
            aState[k] = '0' ;
            Serial.println();
            Serial.println(String(Reader));
            Serial.print(" IS TURNING ON");
            UpdateSwitches();
        }
    }
}

Coding used to turn on or off different electronics. UpdateSwitches() updates the shift registers with the newest desired electronics on
String GetTimeString(double Time){
    String Now = "";
    if (Time > 0){
        int mins = 0;
        double secs = 0;
        mins = Time/60;
        secs = (((Time/60) - mins)*59.5);
        int newSec = secs;
        if (secs < 10){
            Now = String(mins)+ ":0" + String(newSec);
        }else{
            Now = String(mins)+ ":" + String(newSec);
        }
    }
    return Now;
}

Coding used to convert a given time in seconds and returns a useful string representation of that time

String UpdateTime(double Time){
    String Now = "";
    if (Time > 0){
        int mins = 0;
        double secs = 0.0;
        mins = Time/60;
        secs = (((Time/60) - mins)*59.5);
        if (secs < 10){
            int newSec = secs;
            Now = String(mins)+ "0" + String(newSec);
        }else{
            Now = String(mins) + String(secs,0);
        }
    }
    int Nsec = secs;
    if ((Nsec % 2) == 0) {
        UpdateClock(Now,0);
    }else{
        UpdateClock(Now,1);
    }else{
        Now="brew";
        UpdateClock("brew",0);
    }
    return Now;
}

Coding used to update the 4 digit clock display depending on if the second is divisible by two the code will either display a colon or not on the display.
The coding used to display each digit for the 4 digit displays. The device requires the binary information for which LED segments to turn on for each digit.
APPENDIX D – BrewStand Dimensions
APPENDIX E – BrewStand Photos

Top Half of Stand

Bottom Half of Stand