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Optimization of automated temperature measurement system for formed meat products

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OPTIMIZATION OF AUTOMATED TEMPERATURE MEASUREMENT SYSTEM FOR FORMED MEAT PRODUCTS

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by

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ABSTRACT

The Federal Safety and Inspection Services in accordance with United States Department of Agriculture require that formed meat products be cooked to a specified minimum internal temperature in order to eliminate the possible presence of harmful bacteria. The current system of verifying the internal temperatures of formed meat products consists of manually inserting a temperature probe into the selected sample as it exits the oven. Creating an automated system that measures and records the internal temperatures of formed meat samples as they exit the oven along a meat processing line has been the topic of an ongoing research. The most recent research conducted utilized the knowledge and results presented from previous work to create a 3-D simulation of a proposed automated system. The objective of this thesis was to analyze the previously created simulation and implement the necessary modifications to increase the efficiency of the system. At the conclusion of the research, a new automated system process was designed along with an additional implementation for further optimization.

I. INTRODUCTION

A. General Introduction

One of the major concerns in the food processing industry is ensuring the elimination of harmful bacteria from raw meats. Some of the harmful bacteria types that are often found in raw meats include salmonella, listeria, campylobacter, and E. coli [1]. Eating raw meats containing such bacteria can lead to food poisoning which has common symptoms of nausea, vomiting, abdominal cramping, and diarrhea [2]. However, some bacteria infected meat can lead to more seriousness illnesses, including death. In order to prevent such contamination, raw meats should be cooked to a specified internal temperature and avoid contact with any unsterilized surfaces. In the meat processing industry, meats are usually ground, formed to specific shape, cooked, and froze before they are packaged. Once the meats are formed, they will be sent through an oven along a conveyor belt where they are then cooked to the minimum required internal temperature for eliminating harmful bacteria. The safe minimal internal temperatures for meats determined by the United States Department of Agriculture Food Safety and Inspection Service should be measured as the meat patties exit the oven.

B. Research Problem

The purpose of this thesis is to use the knowledge and data presented in previous research to modify or create new designs in order to make the automated process more efficient. Reducing the number of wastes, minimizing the costs of the system, and increasing the number of samples tested during a shift are the main factors that will be considered in optimizing the process. The previous 3-D model created by Ivenso will serve as the platform for determining and implementing any new modifications or designs. While increasing the efficiency of the automated process is the main goal, it is important to make sure that the sterility of the environment and the tools used are maintained throughout the process.

II. LITERATURE REVIEW

The research conducted for this system covers the study of a wide range of specific topics. Temperature measuring systems, robot and software selection, rules and regulations in the meat processing industry, and the study of harmful bacteria in the food industry are among some of the topics that were reviewed in order to effectively analyze the current system. The purpose of this section is to review over these topics and any previous research conducted on these topics to provide the knowledge and groundwork for which the research is based upon.

A. The Effect of E. coli and Other Related Harmful Bacteria

Each year, approximately 48 million people in the United States contract a foodborne illness due to contaminated food products [3]. A foodborne illness is an infection or irritation of the gastrointestinal tract. Common symptoms of food borne illnesses include, vomiting, diarrhea, abdominal pain, fever, and chills [4]. Raw food products including meat, poultry, fish, dairy products, and produce can often contain harmful bacteria that cause food borne illnesses when consumed. Raw products may become contaminated if the right measures are not taken in the handling in distribution of the products.

One of the most common types of bacteria found in raw meat products is Escherichia coli O157:H7. Escherichia coli O157:H7 is a strain of E. coli that causes disease upon consumption due to the Shiga toxin it produces [5]. In order to eliminate the bacteria, meat should be cooked to a specific internal temperature. Because the bacteria can spread by touch, it is important that all the surfaces and utensils the meat may come in contact with should be properly cleaned with hot water and a disinfecting solution. If the surfaces and utensils used in the handling of raw meats are not cleaned properly, the risk of cross-contamination (spread of bacteria from contaminated food to uncontaminated food) becomes present [4].

B. Previous Research

The discovery of a system that rids the use of manual processes to verify the internal temperatures of meats has been the topic of an ongoing research. In his thesis, “Assessment of Critical Food Processing Variable using Robotics”, Ryan Mascoe first developed the idea of using machine vision to aid a robot in selecting random meat samples from a conveyor belt to verify their internal temperatures [6]. The idea was to have cameras located outside the oven that would locate the meat samples exiting the oven and send signals to a nearby robot. The robot would then pick up random meat samples off the conveyor and move them to a location where a temperature probe would be inserted to evaluate the internal temperature of the selected meat patties. Chaitanya Sannathi contributed to the research of this system by conducting experiments pertaining to the heat dissipation of the system, the impact of cooking time with respect to the variation of internal temperature, and the assessment of the temperature probe’s optimal initial temperature. Using the previous research as a reference, Ikenna Ivenso was able to create a 3-D computer simulation illustrating the designed prototype.

C. The Role of the USDA’s Food Safety and Inspection Services

The Federal Safety and Inspection Services (FSIS) is the public health agency of the United States Department of Agriculture which is responsible for ensuring that meat and poultry products are safe, wholesome, and correctly labeled and packaged [7]. With the increasing concern of microbiological contamination in meat products, the FSIS created a system of regulations titled, *Pathogen Reduction: Hazard Analysis and Critical Control Point (HACCP) Systems*, designed to reduce the likelihood of harmful bacteria contaminating raw meat and poultry products [7]. The HACCP standards are summarized by seven principles [8]:

- Conduct a Hazard Analysis.
- Determine the Critical Control Points (A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level).
- Establish critical limit(s) (A criterion which separates acceptability from unacceptability).
- Establish a system to monitor control of the CCPs.
- Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.
- Establish procedures for verification to confirm that the HACCP system is working effectively.
- Establish documentation concerning all procedures and records appropriate to these principles and their application.

In addition to the establishment the HAACP, the FSIS also determined the minimum internal temperatures in which raw products should be cooked at in order to eliminate any harmful bacteria the product may contain. The minimum internal temperatures requirements for certain raw products are shown below in Figure 2.1 [9].

Product	Minimum Internal Temperature & Rest Time
Beef, Pork, Veal & Lamb Steaks, chops, roasts	145 °F (62.8 °C) and allow to rest for at least 3 minutes
Ground meats	160 °F (71.1 °C)
Ham, fresh or smoked (uncooked)	145 °F (60 °C) and allow to rest for at least 3 minutes
Fully Cooked Ham (to reheat)	Reheat cooked hams packaged in USDA-inspected plants to 140 °F (60 °C) and all others to 165 °F (73.9 °C).

Product	Minimum Internal Temperature
All Poultry (breasts, whole bird, legs, thighs, and wings, ground poultry, and stuffing)	165 °F (73.9 °C)
Eggs	160 °F (71.1 °C)
Fish & Shellfish	145 °F (62.8 °C)
Leftovers	165 °F (73.9 °C)
Casseroles	165 °F (73.9 °C)

Figure 2.1**:** The Safe Minimum Internal Temperature Requirements for Various Raw Products

D. Selecting the Temperature Measuring Device

There are several different thermometer devices that can be used to measure the internal temperature of meat products. Some of the thermometer types include: thermocouples, thermistors, oven cord thermometers, bimetallic-coil thermometers, and single-use thermometers [10]. A thermocouple consists of two dissimilar metals joined together at the tip of an outer sheath. As thermocouple is heated or cooled, the junction between the metals produces a voltage that can be correlated to temperature values [11]. Thermocouples are often used in the food processing industry because of their fast response time and accuracy. Also, thermocouples can be easily calibrated for accuracy and are designed to be used at the end of the cooking period, not during [10]. Therefore, the use of a thermocouple was selected to measure the internal temperature of meat patties because its specifications meet the desired objectives of the system. There are several different types of thermocouple. Each type is designed for specific applications and suited for certain temperature ranges. The K-type thermocouple was selected because of its low cost, accuracy, reliability, and wide temperature range (–454°F-2300°F) [12].

E. Measuring the Internal Temperature

The USDA requires that the temperature of a selected meat product should be measured after a period of ten seconds [13]. In previous research, a series of experiments were conducted to test the validity of the previous statement and to determine the optimal initial temperature of the probe prior to testing. One experiment consisted of recording the internal meat temperatures after varying time periods. The result showed that the maximum temperature of the cooked patty was recorded when the delay time is ten seconds [14]. Therefore, the requirement stated by the USDA is correct and the temperature of all tested meat samples should be recorded after duration of ten seconds. The experiment conducted in order to determine the optimal initial temperature of the probe consisted of recording the internal temperatures of meat at varying probe temperatures. After several tests, it was concluded that portion of the temperature probe used for testing should be maintained somewhere between 97 and 102 degrees Fahrenheit in order to obtained the best temperature results consistently with a range of less than two degrees (from highest to lowest) [14].

F. Robot and Software Selection

The four axis inverted SCARA s800 robot was previously selected for its design, cycle speed, and compatibility with the system's work space. Also, the robot's inverted design allows the robot to be connecting to an overhanging rail for it to move along. The movement along the rail enables it to be moved and locked in place over the conveyor when carrying out cooked meat samples handling, or to be moved out from over the conveyor for cleaning and maintenance [15]. Because the optimization techniques for the model system proposed in this thesis require a robot with the same compatibilities, the robot was also chosen for this research.

The robot modeling program, *WorkSpace 5*, was the selected software for both previous research and this research. This modeling program was chosen for the basis of my research so that a simulation utilizing the system design and modifications put forth in this thesis can be compared to the previously created simulation at some point in the future. *Workspace 5* was previously chosen as the program of choice for its ability to accurately create and customize CAD objects and for its ability to manipulate the properties of robot manipulators, mechanisms, and other components. It also was chosen for its easy to use programming interface and its ability to predict the cycle time and throughput of a completed simulation [15].

III. EVALUATION OF PREVIOUS PROTOTYPE

As stated earlier, Ivenso previously developed a 3-D simulation for the automated temperature probing of meat patties along a production line. The simulation design contained a conveyor belt containing several rows of meat samples, a model of the Adept Cobra s800 SCARA robot with an overhead mounting system, a machine vision system containing 4 cameras, a probing station, a washing station, and a disposal bin. The first set of cameras, located above the oven exit, is used to monitor the speed and position of the meat samples. The robot manipulator, containing a suction device as the end-effector, is used to pick up the formed meat patties off the moving conveyor belt and transfer them to the probing station. The probing station consists of a platform containing a temperature probe and is located within close proximity of the conveyor belt. The second set of cameras makes sure that the selected meat sample is properly aligned on the probing platform to obtain an accurate reading. The washing station is used to clean the end-effector of the robot between each sample selection to prevent the build-up of grease that may inhibit the functionality of the suction device. Lastly, the disposal bin is used for the disposal of samples after probing. The layout of Ivenso's simulation model is shown below:

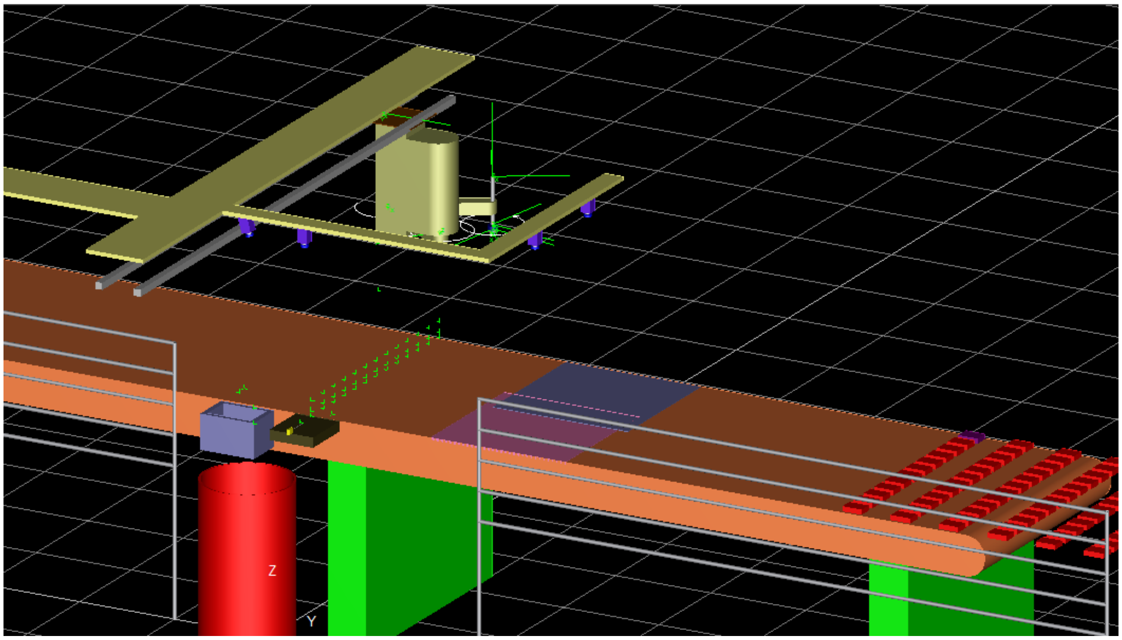


Figure 3.1: A Screenshot Depicting Ivenso's Previously Created Simulation

A. Process Flow

The process steps for the automated system depicted in Ivenso's simulation model are shown below in Figure 3.2:

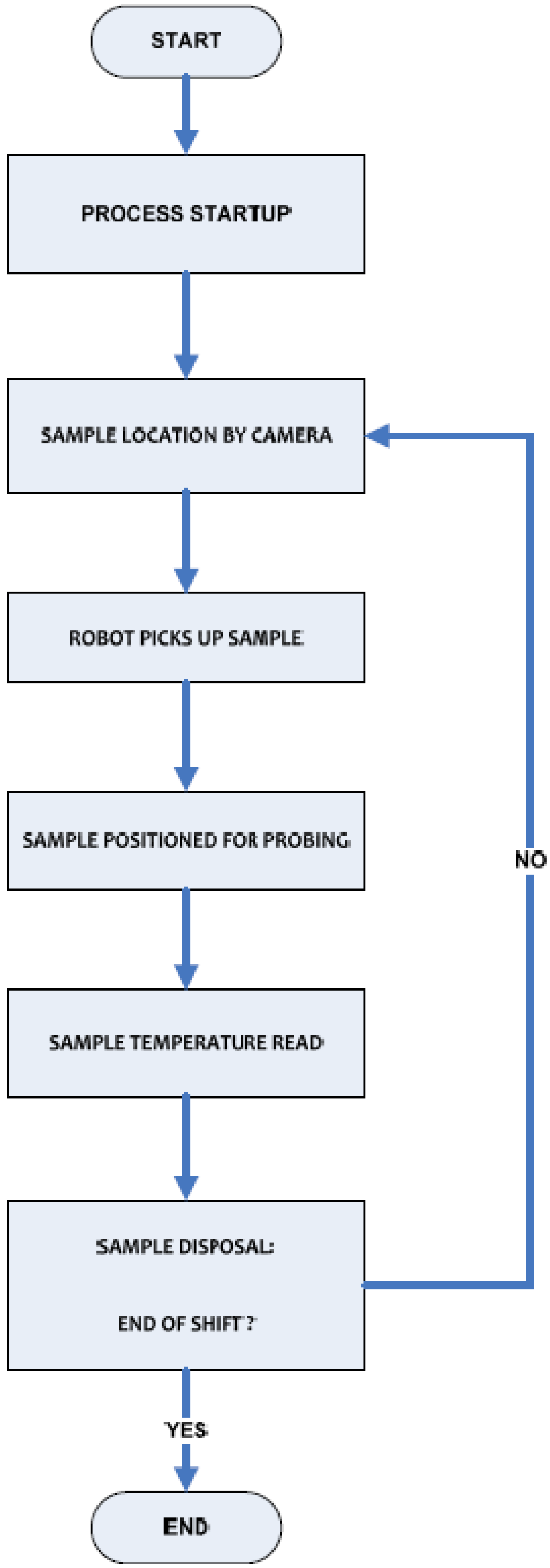


Figure 3.2: Block Diagram Depicting the Steps of Ivenso's Prototype Simulation Model [15]

1. **Process Startup [15]:** This step was used to initialize and reference all motion variables for the system. The robot also moves from its inactive position outside the production line to its initial position located above the center of the production line.
2. **Sample Location By Camera [15]:** The set of cameras located on the mounting system perpendicular to conveyor belt are supposed to determine the speed of the moving conveyor and select a random meat sample for testing. The information will then be sent to a process controller that in turn relays the information to the robot.
3. **Robot Picks Up Sample [15]:** After receiving the data from the process controller, the robot locates and picks up the chosen meat sample with the suction tool located at the end effector.
4. **Sample Positioned for Probing [15]:** The robot carries the meat sample to the nearby probing platform. Here, the second set cameras determine the portion of the meat sample where the temperature probe will be inserted in and relays the information to the robot.
5. **Sample Temperature Read [15]:** Once the meat sample is placed on the temperature probe, the robot manipulator moves to the nearby washing station where the end effector is cleaned for the required temperature measuring duration (10 seconds).
6. **Sample Disposal [15]:** After the required 10 second temperature reading is completed, the robot removes the meat sample from the probing platform and disposes the sample in the nearby bin.

B. Analyzing Optimization Options

The purpose of optimization is to make something as fully perfect, functional, or effective as possible [16]. In optimizing the verification of the internal temperature process for formed meat samples along a production line, the main goal is to increase the number of temperature readings taken during a shift while minimizing costs and wasteful testing. Increasing the number of formed meat samples tested does not only reduce the possibility of undercooked meat, but also reduces the amount of samples that need to be sent back through the oven. As more meat patties are probed for the purpose of verifying their internal temperature, the gap between the current and previously tested meat patty decreases. As the gap decreases, the number of meat patties that must be sent back through the oven decreases. Sending meat patties back through the oven is a waste of time and money. For the context of this research, I wanted develop a way of optimizing the system using a single robot like the previous simulation. Even though adding a second robot to the system would increase the number of conducted temperature measurements for meat patties, the costs would be greatly increased.

The first aspect of the current system I wanted optimize was the disposal process for meat patties samples after they were removed from the temperature probe. In the previously constructed simulation, an average of twelve meat patty samples are probed and disposed of in a 5 minute time period. In previous research, it does not specify where the meat samples are sent to once they are dropped into the disposal bin. It can be assumed that the discarded patties are either thrown away or sent back through the oven. Either way, both options prove to be inefficient. If it is determined that the selected meat patty sample meets the required minimum internal temperature, then it would be a waste to throw the sample away or send it back it through the oven. If it is determined that the selected meat patty is under cooked, then it should be sent back through the oven to ensure the elimination of any harmful bacteria it may contain, but it should not be thrown away. Therefore, I proposed the idea of having two separate disposal bins. One bin will be used for the collection of meat patty samples that meet the minimum required internal temperature and are ready to move onto the next step in the meat packaging process. The other bin will be used for the collection of samples that do not meet the required minimum internal temperature. These patties will be sent back through the oven to ensure the elimination of any harmful bacteria.

The second aspect of the system I wanted to focus on was increasing the number of samples tested with respect to time. Figure 3.3 shows the approximate time it took the robot manipulator to verify the internal temperature of each selected meat patty in the previously constructed simulation.

Sample #	Time (s)
1	23.5
2	24.6
3	24.4
4	24.6
5	23.7
6	24.6
7	24.2
8	23.9
9	23.8
10	23.2
11	23
Average	24.0

Figure 3.3: Approximate Testing Duration for the Meat Patty Samples Tested in the Previously Constructed Simulation

The time values were measured from the point when the robot picks up the meat patty sample off the conveyor to when the robot manipulator returns to its initial position. The process time for each meat patty sample is different because the patties are located at different positions along the conveyor belt.

An average time of twenty-four seconds to test a single meat patty seems considerably long knowing that it only takes ten seconds to measure the patty’s internal temperature. Therefore, I started to formulate a system where the probing platform would contain two probes instead of one. After the robot manipulator places a sample on one of the two probes, it could return the conveyor to select, pick up, and place another meat patty sample on the other probe before the temperature measuring period for the first patty was completed. The washing of the end effector would still take place but it would occur after three or so patty selections instead of one.

Even though the two bin system and multiple probe idea seemed to be an efficient solution, the risk of contamination was not properly evaluated. If it is determined that a selected meat patty is undercooked following the probing procedure, one must assume that the meat contains harmful bacteria. Therefore, when using the two bin system for the disposal of meats, the probing platform, as well the temperature probe itself, must be thoroughly cleaned after each undercooked meat sample is tested. Otherwise, meat samples that meet the required internal temperature may become contaminated if the previously probed patty was determined to be undercooked. Developing a device that cleans the probing platform and the stationary thermocouple after every temperature measurement could prove to be difficult as well as costly. The multiple probe idea could be utilized using a single disposal bin system, but that would still leave the issue concerning the amount of wastes produced.

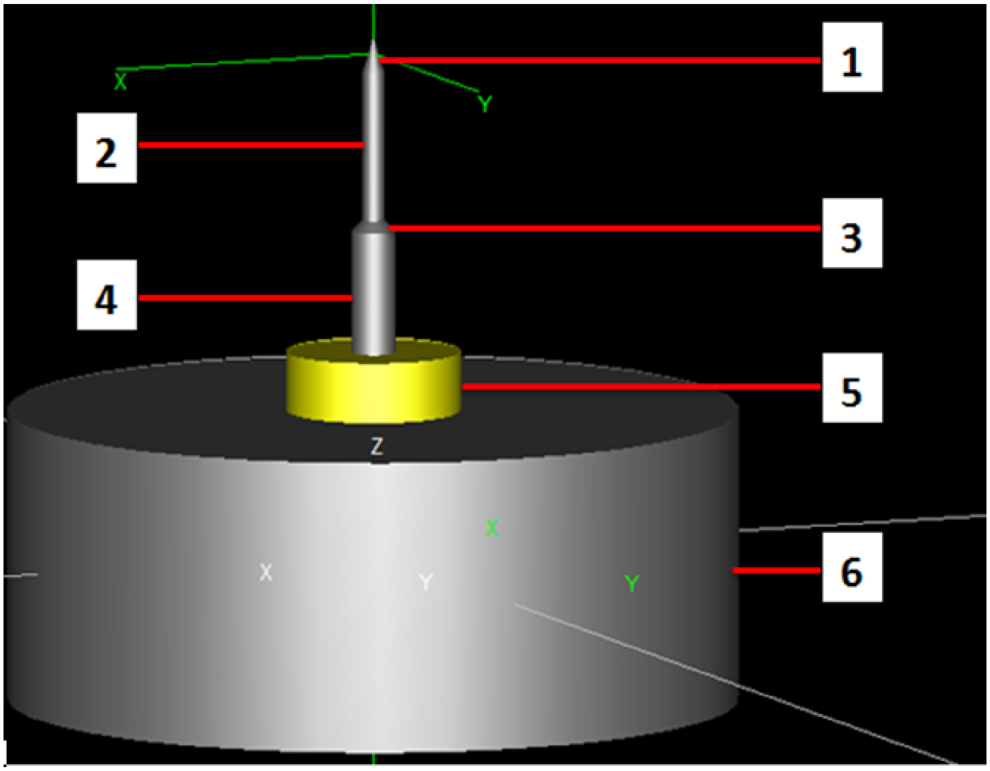
IV. SYSTEM DEVELOPMENT

The previous research and constructed simulation has provided much insight in determining how to optimize the automated system of verifying the internal temperatures of meat patties. Using Ivenso's constructed simulation as a reference, it appears that optimizing the current disposal process as well as the testing duration for formed meat samples could increase the overall efficiency of the system significantly. As I learned, it is important that the creation of any new designs or modifications for optimization purposes maintain the sterility of the environment. It is also important to minimize the cost of the system as much as possible while maintaining the safety and efficiency of the process.

Using what I learned from my previous ideas and the errors associated with them, I determined that it would be much easier if there was a way to measure the internal temperatures of the meat patties while they were on the conveyor belt. When the patties are removed from the conveyor belt for testing, it leaves the problem of deciding where to send them after. Also, adding more surfaces for the meat patties to come in contact with throughout the process, such as a probing station, increases the maintenance required to keep the surfaces sanitized. Therefore, I designed a probing tool that attaches to the end effector of the robot manipulator for the purpose of measuring the internal temperatures of the meat patty samples along the conveyor belt.

A. Temperature Probe Tool Design

The tool contains a steel base that connects the end effector of the robot manipulator to the thermocouple. A K-type thermocouple was selected based on the research discussed earlier in the Literature Review. The thermocouple has a stainless steel sheath made up of two sections with different diameters. The thinner section is the actual portion of the thermocouple that is inserted into the meat patty samples. The length of this section was calculated so the conic shaped tip would reach the exact center of the formed meat patty. The diameter of the section being inserted into the selected meat sample is the recommended diameter for the fast-response measuring of burgers, steaks, and other thin meat portions [17]. The larger section attaches to the thermocouple base and is used for reinforcement to prevent the thinner section from breaking while inserted in the selected meat patty. The thermocouple should be wired properly so that all the measured data is sent directly to the database management system (DBMS) so it can be processed and stored. All of the parts were created using the inbuilt CAD capabilities provided in *Workspace 5*. The completed design and the dimensions of each part are shown below in Figure 4.1:



Part #	Shape	Length (mm)	Diameter 1 (mm)	Diameter 2 (mm)
1	Cone	2.486	1.524	0
2	Cylinder	10.214	1.524	N/A
3	Cone	0.771	3.048	1.524
4	Cylinder	8.529	3.048	N/A
5	Cylinder	8	12	N/A
6	Cylinder	20	50	N/A

Figure 4.1: Temperature Probing Tool Design and Part Descriptions

B. Work Cell Shell Modifications

As mentioned earlier, Ivenso's previously created work cell shell was used as a platform for implementing any new designs and modifications. Because his design contained some of the necessary components such as the conveyor line, robot manipulator, overhead mounting system, and meat patties, there was no need to create a new shell entirely from scratch. The rotational gripper located at the end effector of the robot manipulator was detached and replaced by the newly created probing tool. The probing station, disposal bin, and the set of machine vision cameras located above the probing station were eliminated from the shell. Another washing station was created on the opposite side of the conveyor directly across from the original using the program’s inbuilt CAD capabilities.

C. Process Flow

In summary, a set of machine vision cameras located on the mounting rack above the production line will detect the speed of the conveyor and the positions of the moving meat patties. The cameras will relay the information to the robot manipulator which is also located on the mounting rack above the production line. Using the information provided by the cameras, the robot will select a meat patty sample and insert the probe (located at the end effector) into the selected meat patty. With the probe inserted in the sample, the arm of the robot manipulator will then follow the sample as it moves along the conveyor for the required temperature reading duration (10 seconds). After the internal temperature of the selected meat patty is determined, the robot manipulator will remove the probe from the sample and travel to the nearby washing station. After the end effector is washed, the robot will return to its initial position where the process of testing a new meat patty sample will begin. The process flow diagram is shown below in Figure 4.2 followed by a detailed description for each step of the process.

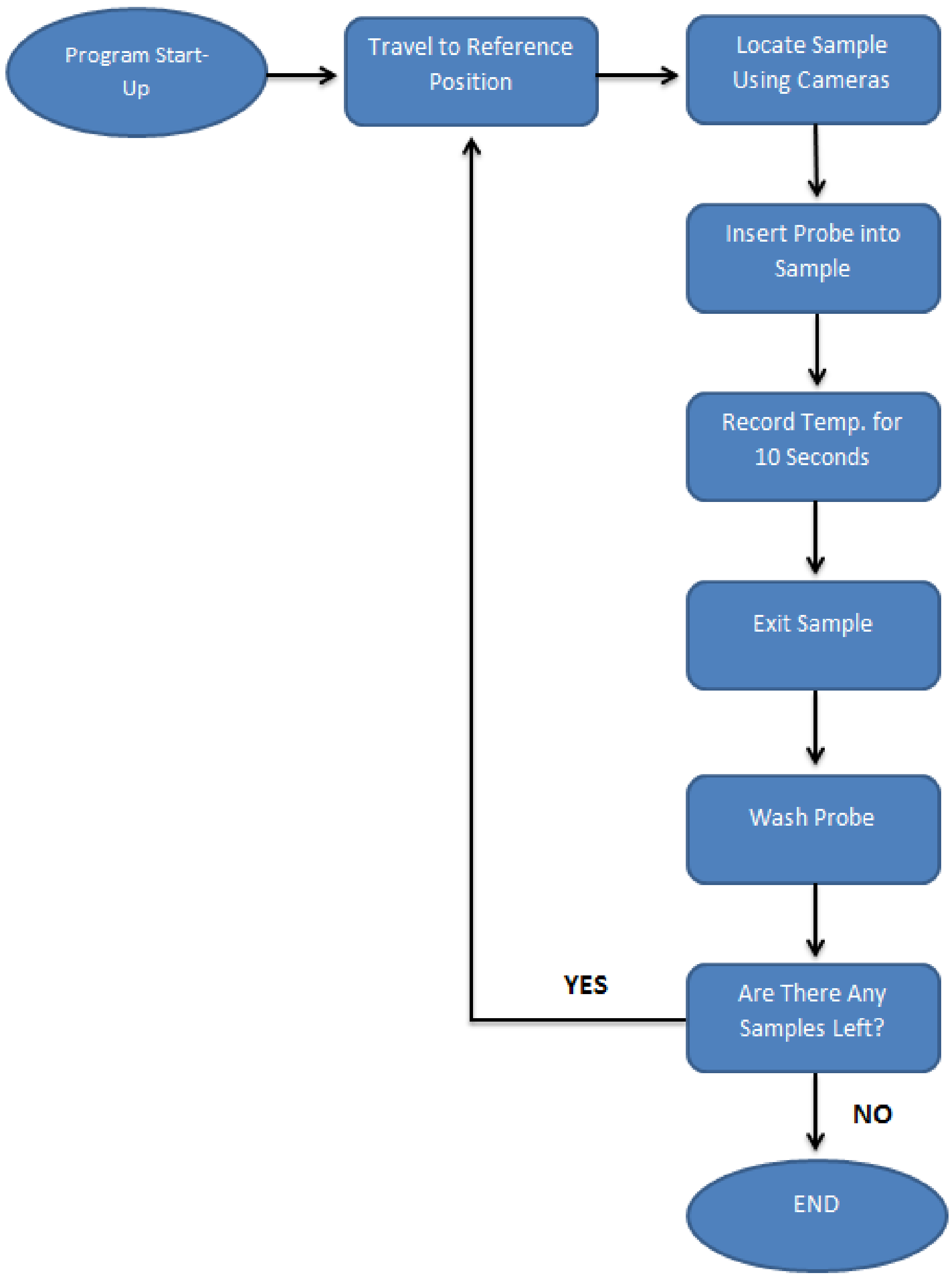


Figure 4.2: Process Flow for the Automated System of Verifying the Internal Temperature of Meat Patties Using the Newly Designed Probing Tool

1. **Program Start-Up**: During this step, the robot along with the machine vision cameras are activated and prepared for operation. All moving variables and components are calibrated and tested to ensure the shift is prepared to begin. Once the initial procedures

are completed, the conveyor will start sending the previously formed meat patties through the oven.

2. **Travel to Reference Position:** The reference position is the position where the robot will insert the temperature probe into the selected meat sample. All of the meat patties will be selected and probed from this position. The reference position for the robot is the point along the above mounting rail at the midpoint of the conveyor belt. During this step, the robot will travel from its inactive position outside the conveyor belt along the rail until it reaches the reference position.

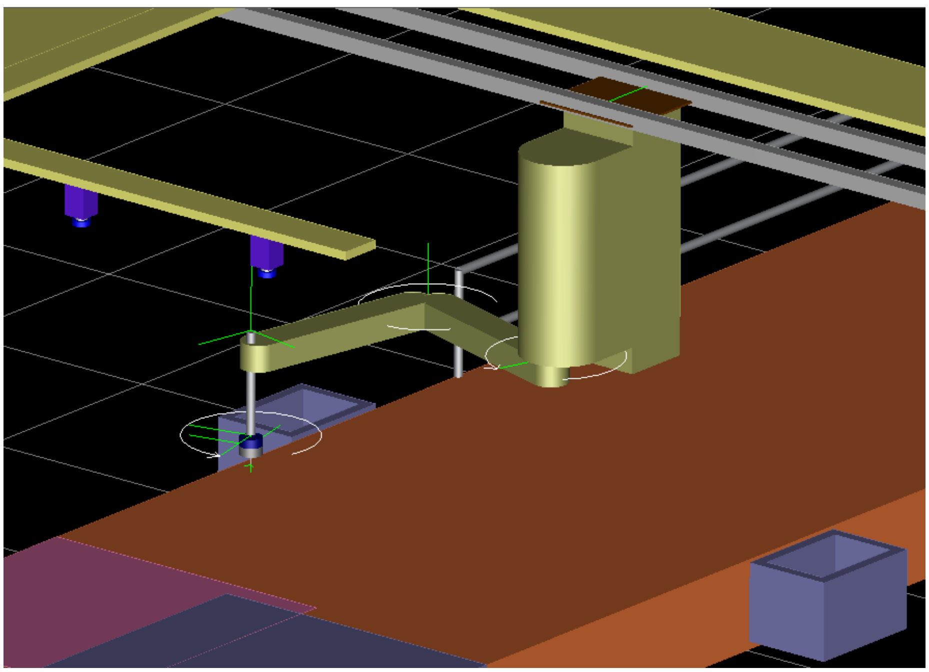


Figure 4.3: Robot Manipulator at the Reference Position

3. **Locate Sample Using Cameras:** A set of machine vision cameras connected to a process controller will be located on the mounting rack above the conveyor belt. Because the meat patties traveling along the conveyor are arranged twelve to a row, the cameras are

positioned so that each camera is capable of monitoring at least six lanes of meat patties [15]. Throughout the shift, the cameras will detect the speed, position, and center of the meat patties as they travel along the conveyor. These signals are sent to the process controller which will use the information to randomly select a meat sample for testing. The process controller will then relay this information to the robot manipulator.

4. **Insert Probe Into Sample:** Using the information received from the process controller, the robot manipulator will insert the probe (located at its end effector) into the center of the selected meat patty. At this point, the database management system (DBMS) will start collecting the data taken from the temperature probe.

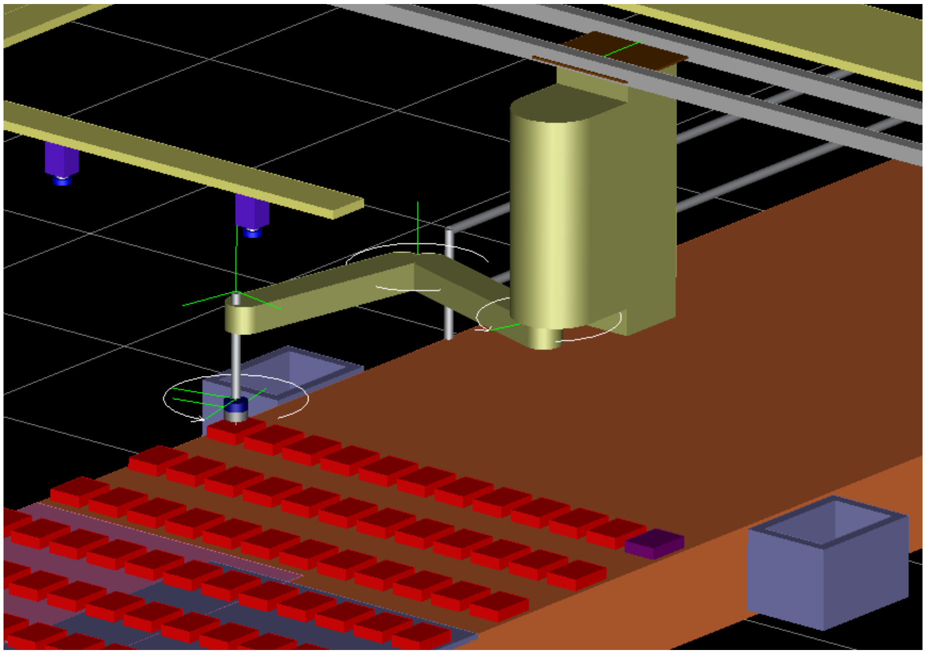


Figure 4.4: Screen Shot Depicting the Process of Inserting the Temperature Probe into a Selected Sample

5. **Record Temperature for 10 Seconds**: With the probe inserted into the selected meat patty, the robot manipulator will follow the patty as it moves along the conveyor for the

required temperature measuring time of ten seconds. The data recorded during this step is continually being sent to the DBMS where it is evaluated and stored.

6. **Wash Probe**: After the internal temperature of selected meat patty has been determined, the robot manipulator will remove the probe from the sample and travel to one of the two washing stations. The two washing stations are located across from each other on both sides of the conveyor belt. As displayed in Figure 4.5, if the selected meat patty is located in lanes 1-6, the robot manipulator will travel to Washing Station A. If the selected meat patty is located in lanes 7-12, the robot manipulator will report to Washing Station B. The washing stations will contain a nozzle that will spray hot water along with a disinfectant solution for the purpose of eliminating grease build-up and any harmful bacteria that may have been present if the previously tested meat patty was undercooked.

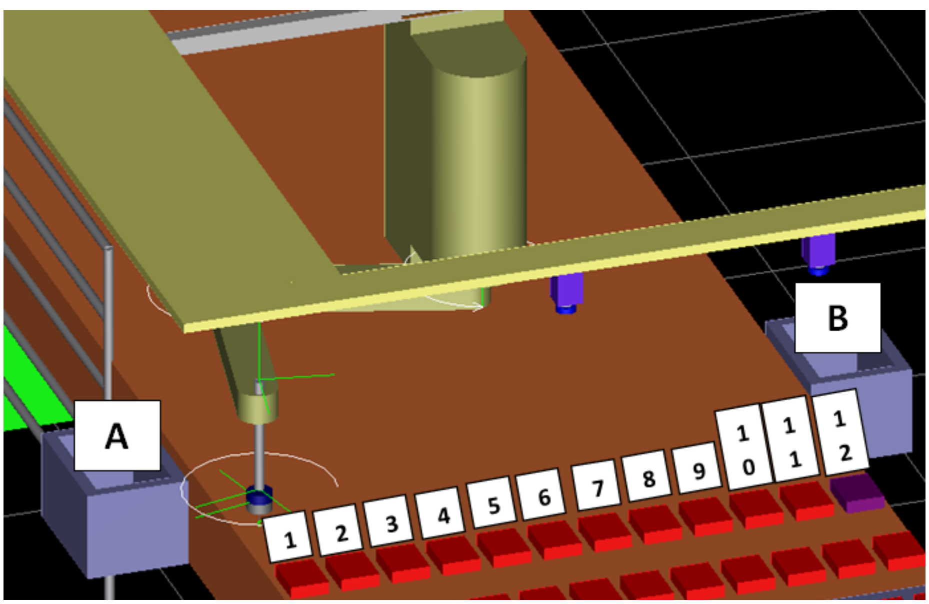


Figure 4.5: The Labeling of Each Lane and Washing Station

7. **Are There Any Samples Left?:** Once the temperature probe has been washed, the process controller will relay information to the robot regarding the testing of a new meat patty sample or if there are no tests remaining. If there are more samples left for testing, the robot will travel to the reference position. If there are no remaining meat patties, the robot will travel along the overhead mounting rail back to its inactive position and all systems will be shut down.

D. Sample Return Process

When it is determined that the internal temperature of a selected meat sample does not meet the minimum temperature requirement, it is important that the meat samples in the section are sent back through the oven and the conveyor is slowed down to increase cooking time. It is important that the return process sends all of the possibly undercooked samples back through the oven while refraining from sending meat samples that have met the required minimum internal temperature. As discussed earlier, the process of sending samples that have met the internal temperature requirements back through the oven is unnecessary and a waste of time and money. Therefore, a process was developed to meet the desired objectives and rid the previous process of returning the entire batch.

At the start of a shift, each horizontal row containing twelve meat patties will be numbered as they pass under the machine vision cameras. When an undercooked sample is determined, the DBMS will determine number of rows between the current row containing the undercooked sample and the row containing the last verified sample. The DBMS will also determine the number of rows between the current row and the row containing the next sample tested. At this point, a mechanism will transfer the samples found in the determined rows to a nearby conveyor that will return the samples back to the oven. The mechanism design as well as the conveyor setup for sending the undercooked meat patty samples back to the oven has not been designed yet but would be a good topic for further research.

E. System Evaluation and Further Implementations

In order for the newly developed system to be carried out effectively, two assumptions were made in the design process. The first assumption made was that the meat patties are cooked uniformly through the oven. In other words, the meat patties on the end lanes should be receiving the same amount of heat as those located in the center. The second assumption made was that the meat patties were formed in a way so that the thickest portion is located in the center. It is important that the meat samples are formed this way because the minimum required internal temperature only ensures the elimination of harmful bacteria when measured at thickest portion of the meat sample.

The newly designed system fulfills the previously set optimization goals and also minimizes the equipment costs. As discussed previously, the use of a disposal bin to collect meat patties after measuring their internal temperature and a return process that consists of sending the entire batch back through the oven with the detection of an undercooked sample leads to unnecessary wastes. Also, the use of probing platform to measure the internal temperatures of the meat samples leads to an inefficient testing duration for each sample. Attaching a temperature probe tool to the end effector of the robot manipulator allows the internal temperatures of the meat patty samples to be verified as they move along the conveyor. The testing duration for each meat sample tested using the tool will be reduced because the time spent picking up each sample off the conveyor and moving them to the probing platform is eliminated. Also, because no samples are removed off the conveyor after the measuring period, the disposal of meats that meet the required minimum internal temperature is avoided. The proposed disposal process will clearly result in a fewer amount of meat patties being sent back through the oven because only those that are undercooked or have the possibility of being undercooked are sent back rather than the entire batch.

The use of two washing stations was proposed in hopes of reducing the testing duration for each sample even more. However, once the simulation is created, if it is determined that the cost of adding an extra washing station exceeds the amount of time reduced, then only washing station should be used. Also, the temperature of the water used to wash the temperature probe should be calculated so that the temperature of the probe leaving the washing station is as close to the optimum initial temperature determined in previous research (approximately 100°F).

One possible con for the designed system is the speed of the conveyor belt. The speed of the conveyor belt will have to be slower so that the arm of the robot manipulator can follow the sample along the conveyor belt without exceeding the joint limit. Therefore, I designed a further implementation that would speed up the conveyor while still maintaining the system process. The idea consists of creating separate rail mechanism that runs parallel to the conveyor belt. The rail setup in which the robot moves along would connect to the newly created rail mechanism so that it could move horizontally with the conveyor belt. Therefore, once the robot manipulator inserts the probe into the selected meat patty, the robot will be able to follow the meat patty for testing duration at whatever speed the conveyor is set at. A design of the proposed implementation is shown below in Figure 4.6.

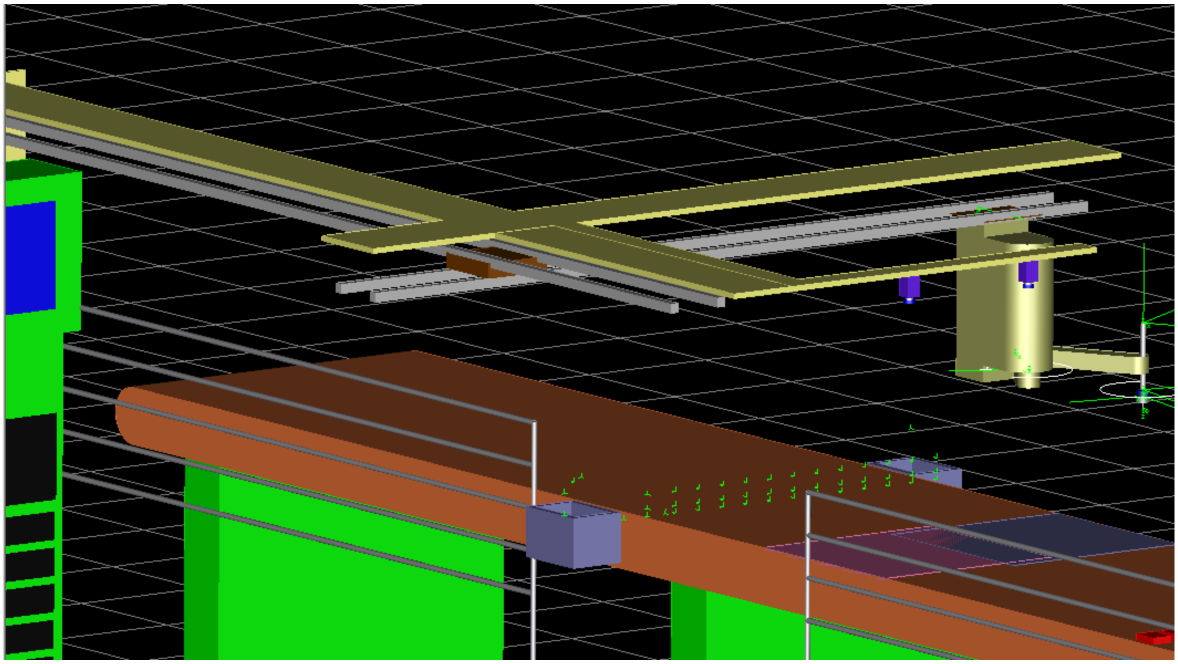


Figure 4.6: The Proposed Implementation of an Additional Rail Mechanism

Even though this implementation would increase the amount samples that could be tested over a period a time, the cost of adding the additional rail mechanism may outweigh the benefits. Therefore, a simulation should be created for both the original newly designed system and the system implementing the additional rail mechanism in order to see which process proves to be the most beneficial.

V. CONCLUSION

From analyzing the previously constructed simulation, it was determined that the current system utilized certain methods that could be easily modified in order to make the process more efficient. It was observed that the use of disposal bin to return all tested samples back through the oven leads to unnecessary additional cooking for samples that satisfied the minimum required internal temperature. The amount of time it took to test each sample in the previous constructed simulation was also observed. Using the previous observations as a platform for increasing the efficiency of the system, a new system process was designed. The newly designed system eliminates the need for a disposal bin resulting in a reduced amount of wasteful testing. The new system also reduces the testing duration for each selected sample by eliminating the time it took to transport the selected meat patty to and from the probing platform. Also, the proposed return process for undercooked samples and the additional implementation of a second rail mechanism should lead to an even more increased efficiency. Overall, the newly developed system and further modifications should contribute in optimizing the automated temperature measuring system for formed meat products.

VI. FUTURE RESEARCH

The main goal for further research should be to create a running simulation for the newly designed system and processes put forth in this thesis. A simulation for the system incorporating the additional rail mechanism should also be created so that the two processes can be analyzed and compared based on the results produced. Another goal for further research should be to design a second conveyor system for returning undercooked meat patties as described in the newly proposed return process.

VII. APPENDIX

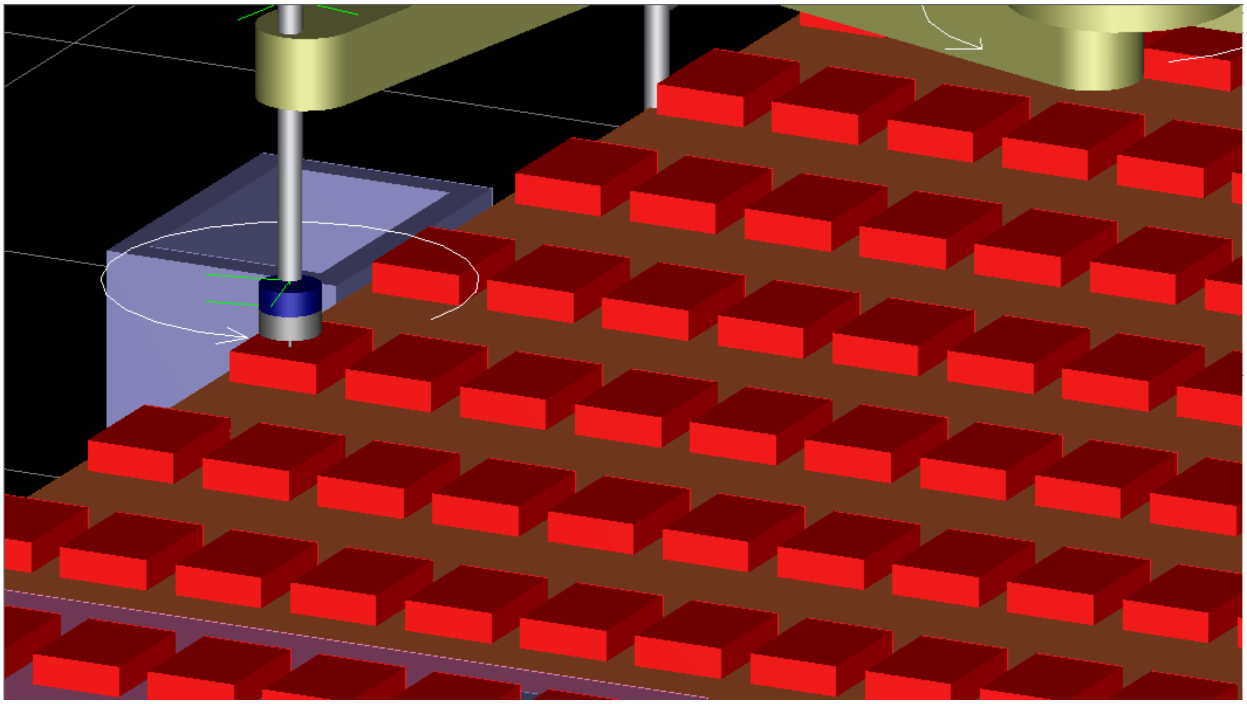


Figure A.1: Close-Up of the Probe Inserting the Selected Meat Patty

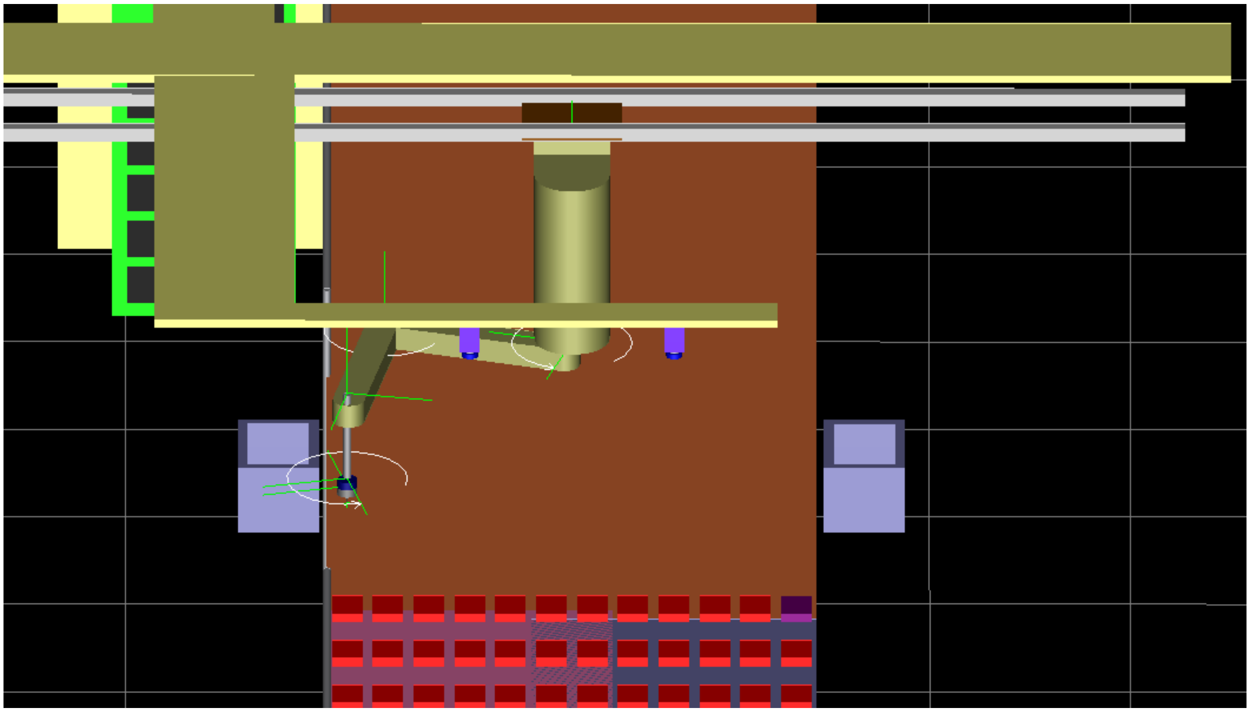


Figure A.2: The Robot Manipulator in Reference Position

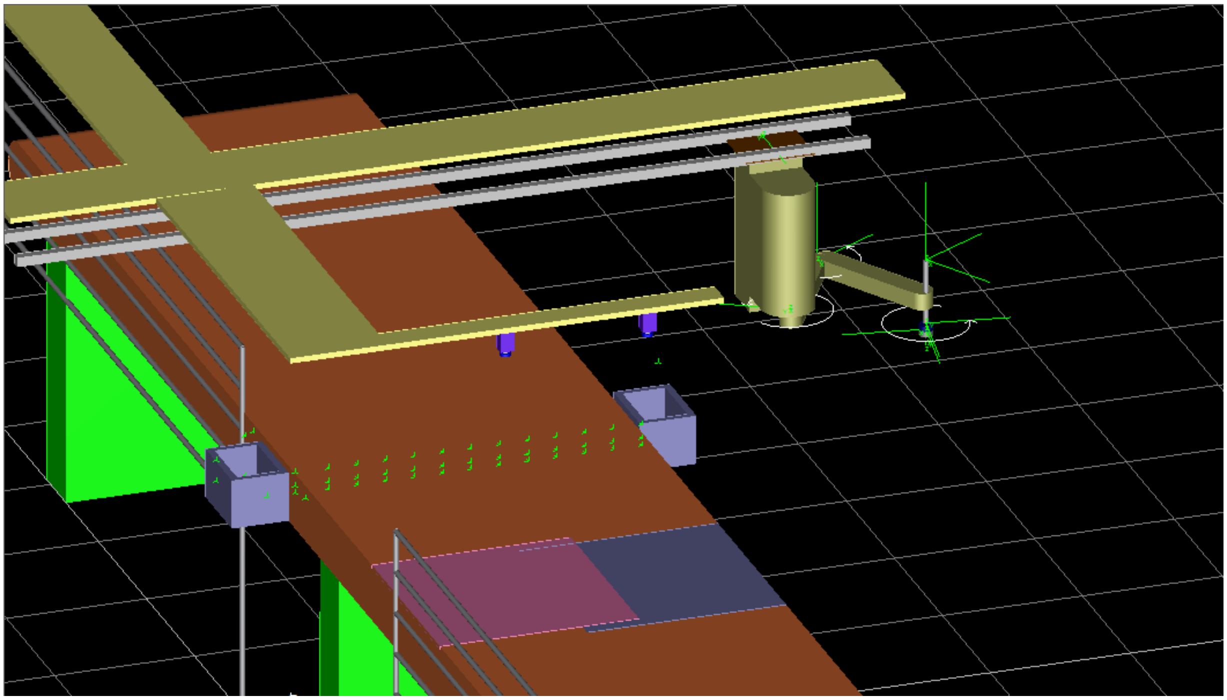


Figure A.3: The Robot Manipulator in the Inactive Position Outside the Production Line

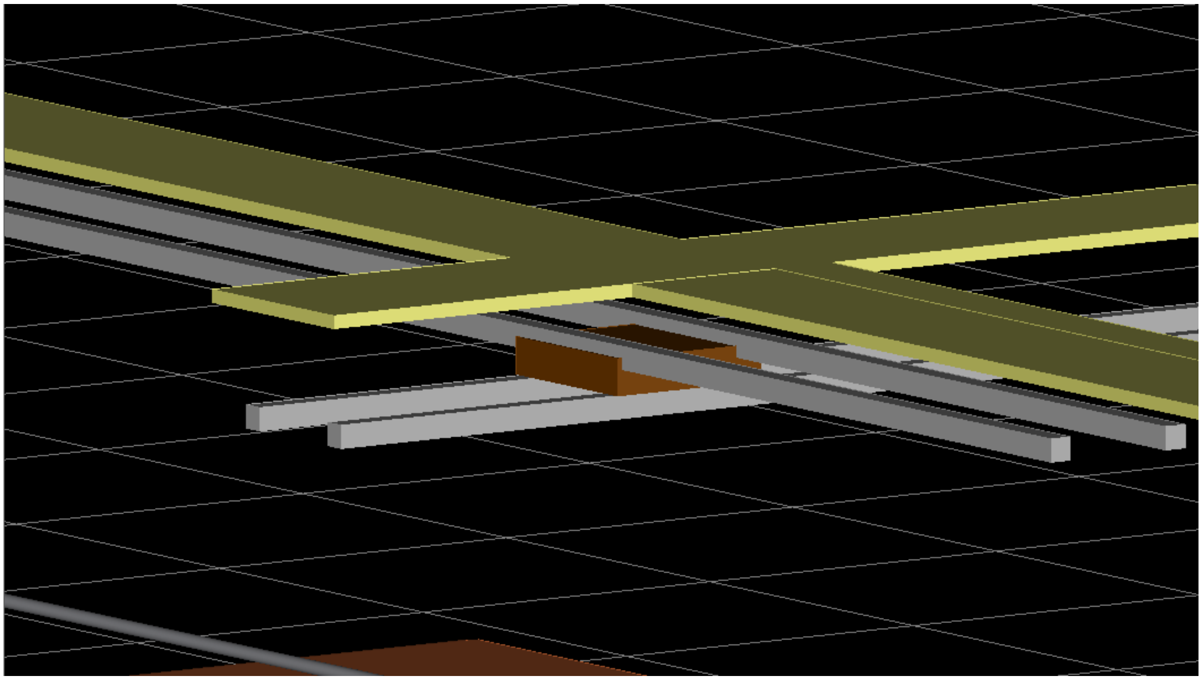


Figure A.4: Close-Up the Additional Rail Mechanism Connection

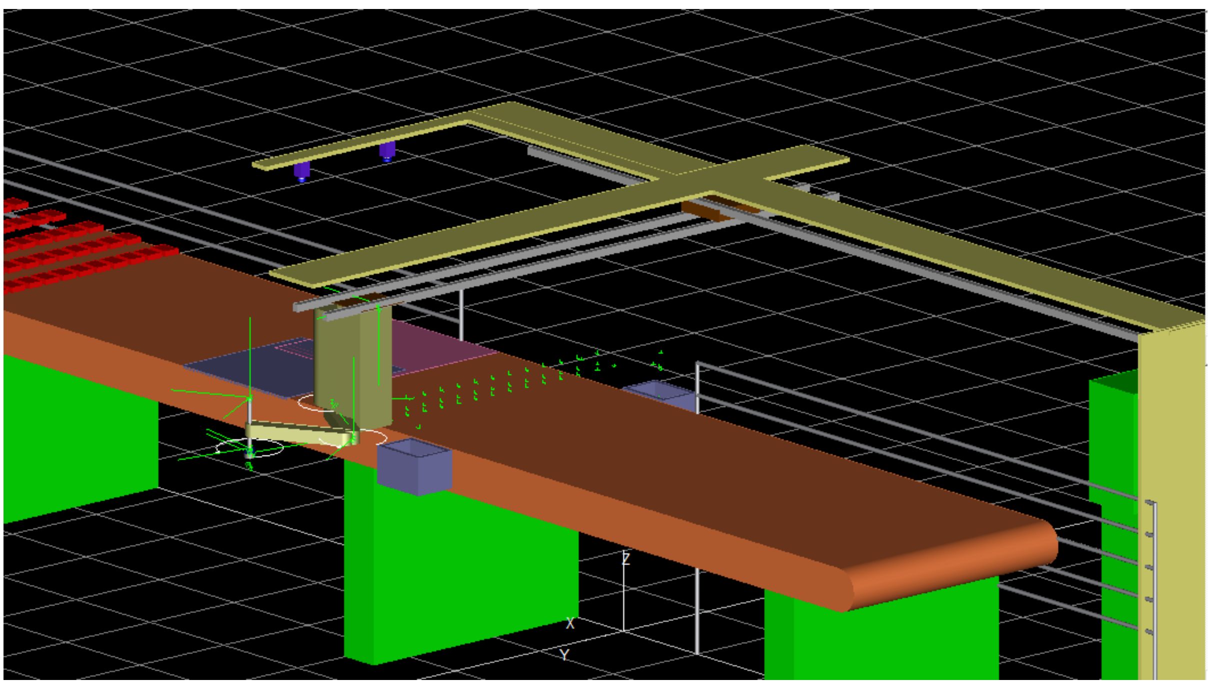


Figure A.5: Newly Designed System Using the Additional Rail Mechanism

REFERENCES

1. NSW Food Authority. (2011). “What are the health risks associated with poultry and red meat?” Retrieved April 7, 2013 from http://www.foodauthority.nsw.gov.au/consumers/keeping-food-safe/special-care-foods/poultry-and-red-meat/
2. WebMD. (2013). “Food Poisoning”. Retrieved April 7, 2013 from http://www.emedicinehealth.com/food_poisoning/article_em.htm.
3. Medline Plus (2013). “Foodborne Illness”. Retrieved April 20, 2013 from http://www.nlm.nih.gov/medlineplus/foodborneillness.html.
4. National Digestive Diseases Information Clearinghouse. (2012). “Foodborne Illnesses”. Retrieved April 20, 2013 from http://digestive.niddk.nih.gov/ddiseases/pubs/bacteria/.
5. United States Department of Agriculture Food Safety and Inspection Service. (2012). “Fact Sheets: Food Borne Illness and Disease”. Retrieved April 20, 2013 from http://www.fsis.usda.gov/factsheets/e_coli/index.asp.
6. Mascoe, Ryan M. (2003). Assessment of a Critical Food Processing Variable Using Robotics, MSIE Thesis, University Of Arkansas.
7. United States Department of Agriculture Food Safety and Inspection Service. (2012). “Fact Sheets: Production and Inspection”. Retrieved April 20, 2013 from http://www.fsis.usda.gov/factsheets/inspection_&_grading/index.asp.
8. FAO Corporate Document Repository. “Hazard Analysis and Critical Control Point (HACCP) System and Guidelines for its Application”. Retrieved April 18, 2013 from http://www.fao.org/docrep/005/Y1579E/y1579e03.htm.

9. United States Department of Agriculture Food Safety and Inspection Service. (2012). "Fact Sheets: Safe Food Handling". Retrieved April 20, 2013 from http://www.fsis.usda.gov/factsheets/Safe_Minimum_Internal_Temperature_Chart/index.asp.
10. United States Department of Agriculture Food Safety and Inspection Service. (2012). "Fact Sheets: Appliances and Thermometers". Retrieved April 20, 2013 from http://www.fsis.usda.gov/factsheets/Kitchen_Thermometers/index.asp.
11. Omega Engineering Technical Reference. (2013). "Thermocouples-An Introduction". Retrieved April 20, 2013 from http://www.omega.com/prodinfo/thermocouples.html.
12. Thermocouple Info. (2011). "Types of Thermocouple" Retrieved April 20, 2013 from http://thermocoupleinfo.com/thermocouple-types.htm.
13. Food Safety and Inspection Service, United States Department of Agriculture. http://www.fsis.usda.gov/oa/pubs/tempfood.html
14. Sannathi, Chaitanya. (2006). A Decision Support System for Controlling a Critical Variable: Internal Temperature, MSIE Thesis, University Of Arkansas.
15. Ivenso, Ikenna. (2011). Three Dimensional Simulation of an Automated Temperature Measurement System for Formed Meat Products, MSIE Thesis, University Of Arkansas.
16. Merriam-Webster. (2013). "Optimization". Retrieved April 16, 2013.
17. ThermoWorks. (2013). "Thermocouple Probes: Type K Penetration Probes". Retrieved April 16, 2013 from http://www.thermoworks.com/products/probe/tc_penetration.html.