Designing a Robotic Arm for Moving and Sorting Scraps at Pacific Can, Beijing, China

A Major Qualifying Project

submitted to the faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

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Abstract

In modern industry, innovation by automating processes provides companies with competitive advantages in speed, efficiency, and production value. This Major Qualifying Project studied the potential of a robotic, palletizing arm to help Pacific Can Company Ltd. replace their manpower-driven operation of moving and stacking unpainted and painted blocks of scrap metal. Focus areas of the project included work area design, block distinction, alarm systemization, as well as robotic arm and end of arm tool selection.

Authorship Statement

The project was completed by four WPI students, each member contributed in various degrees to all parts of this project. Yifan Shao and Fernando Gonzalez mainly concentrated on designing the work area, selecting the type of robot, and selecting the type of end of arm tooling. In contrast, William Farrar mainly concentrated on developing an innovative solution, stating objectives, and executing the methodology. Mohamad Alblaihess contributed on executing the methodology as well as selecting criteria methods, performing investment analysis, and reflecting on the project. During this project, all the members worked in correspondence with the BUCT members and contributed to different sections simultaneously. There were meetings arranged to ensure an excellent outcome by brainstorming ideas, creating presentations, and working on developing an effective solution for the problem.

Acknowledgements

The authors would like to thank *Pacific Can, Beijing* for sponsoring the project. Also, special thanks to Mr. Glenn Yee, Pacific Can's CEO, and Mr. Tian, Pacific Can Beijing facility technical engineer, for their kind and generous hosting of our team. It has been a great experience for all the members to learn, in-depth, the actual work of a factory; especially one that is so industrially large and renowned. The team obtained valuable knowledge and feedback from Pacific Can, its engineers, and all its employees. The managers never hesitated to provide us with their help and expectations!

We also would like to thank and greet Professor Jianyu Liang and Professor Amy Zeng for the exceptional effort that allowed this project to come to fruition. In addition, the Beijing Project Center allows our team the valuable opportunity to interact with a different and distinct culture such as China.

Finally, we would like to give Beijing University of Chemical Technology (BUCT) special thanks for being such a gracious host. The university and its students played a big role in helping our team complete this project. Thanks to the loyal and receptive BUCT members who played a significant role to complete this project, and for being valuable resources for the WPI members to learn from. Their tenderness allowed the team to have such a strong core unit, making it more possible for achieving our goals.

Executive Summary

In modern industry, innovative technologies are implemented every day; these breakthroughs help companies improve their processes' speed, efficiency, reduce their labor costs, and increase the capabilities of their facility. These benefits provide companies, such as Pacific Can Company Ltd., with incentives to invest in modern machines.

Pacific Can (Beijing) Ltd. is one of the six production facilities of Pacific Can Company. In 1991, Pacific Can Company Limited was founded in Hong Kong by Mr. Glenn Yee, a WPI alumnus, and a few of his former colleagues. Today, Pacific Can Company is one of the largest can manufacturing companies in China, producing around two billion cans a year.

The scope of this project aims to improve Pacific Can's scrap management system. The current process involves four workers moving large blocks of compressed aluminum cans from the compressor's exit to the loading area where they are transported for recycling. There are two different types of blocks, which are placed and stacked on different loading pallets, as their recycling process is different.

The objective of the company is to improve this section of their process by purchasing a robotic arm to replace the workers performing this arduous labor. In order to justify the purchase of the arm, it must meet certain criteria: it must be able to lift the heavy blocks from the exit chute to the loading area, it must be able to differentiate between painted and unpainted blocks and place them in their respective loading areas, it must be able to operate at the current and higher production rates, maximum movement freedom is preferred, it's end of arm tooling must be able to secure the blocks but is not limited to only that shape (if possible the arm should be as versatile as possible in case it can be used for further applications in the future), finally it needs to be cost effective.

In order to achieve this goal, the BUCT and WPI teams worked together to study commercially available options and their features. Through extensive research and work in the field at Pacific Can as well as responsive feedback and concerns expressed by Pacific Can engineers, the project team was able to pursue this problem with the necessary resources.

Once the purpose of the three BUCT student teams had been discovered, the project was broken up into three mains groups to accommodate the upcoming decisions. The three main groups became the mechanical, detection, and alarm groups. The mechanical group focused on the design of a new work area accommodating the upcoming changes, as well as the selection of the robotic arm and its end of arm tooling. The detection group focused on learning and simulating color distinction software in order to provide the robotic arm with the ability to differentiate unpainted and painted scrap blocks. Finally, the alarm group focused on safety alarm simulations in order to ensure the robotic arm would function properly, allow for safe human interaction, and lastly have the ability to notify workers when the robotic arm had finished stacking a pallet of blocks so that it could be processed for recycling.

The results of the project involved various successful alarm simulations for the robotic arm, performed live for the company. Similarly, the detection team was able to use a color extracting software called OpenCV to send appropriate signals to the robotic arm controlling software after successfully determining whether a scrap block was painted or unpainted. The mechanical team, after contacting many companies concerning robotic arm capabilities and necessary tooling, was able to find a robotic arm fulfilling the needs of the process. ABB's IRB 460 high-speed palletizing robot was selected for the project as it was able to carry a payload of

110kg, has a range of 7-feet, and is able to use integrated detection software to move and stack the blocks. The IRB 460 robot would utilize a FlexGripper Clamp as the appropriate end of arm tool, made to use pressure squeezing to pick up, move, and stack the blocks. The team used SolidWorks to recreate Pacific Cans work area and then used CREO to provide a simulated new work area design including conveyor belts to assist the robotic arm and the robotic arm itself. Additionally, a miniature IRB 460 robotic arm was used to simulate the operations and activities in sync with OpenCV. After finding success in all these aspects, a cost analysis of the robotic arm and work area was done. Finding that should Pacific Can take advantage of the opportunity now, in only 4 years their purchase would be refunded and breakeven. Consequently, in that15 year span the company would see a 308% return on investment.

We recommend Pacific Can take full advantage of this new process design as soon as possible. With the increase in labor wages in the coming years, the sooner the process is replaced the more money Pacific Can will save. The company should apply this new design to all six Pacific Can facilities in China in order to maximize the benefits of this investment. In doing so, we also recommend that the company use our arm and end of arm tool selections as well as contacting ABB as their supplier. We have had great success with ABB and its integration company, who are now well informed of the situation at Pacific Can, which will make the transition much easier.

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1. Introduction

Pacific Can (Beijing) Ltd. is one of the six production facilities of Pacific Can Company. In 1991, Pacific Can Company Limited was founded in Hong Kong by Mr. Glenn Yee, a WPI alumnus, and a few of his former colleagues. It was built in 1995 with designed production of 1,000,000,000 cans per year. During the past twenty years, the company experienced substantial development in mainland China. From its founding up until 2014, Pacific Can Company Limited has now reached a total production rate of over 6,500,000,000 Aluminum cans per year. Since then, the facility has been upgraded and is capable of making 2,000,000,000 cans per year (Pacific Can China Holding Limited, 2011). It has become one of the major suppliers of domestic and international beverage brands such as Coca Cola, Pepsi and Tsingtao Brewery (one of the biggest beer beverage brands in mainland China). During this MQP, the focus will only be on Pacific Can Ltd, Beijing Facility.

Pacific Can is one of the leaders in can manufacturing in China. Throughout the last two decades, Pacific Can has established a renowned name in can manufacturing. There are various types of beverages that Pacific Can is packaging every day. These include: beer, tea, soda, and juice. In recent years, Pacific Can is claiming that they pushed their operating capacity to its highest; and are now considered one of the main suppliers in China to support both the domestic and international demand in maintaining a satisfactory level in manufacturing cans. There are six operational production facilities of Pacific Can over China; meanwhile, the company is seeking more expansion in the region as the demand level is uprising sharply.

What makes Pacific Can a unique and leading company in can production is its uniquely designed product the 2-piece aluminum can, which is called the Slick2oo. The introduction of Slick2oo was in 2009 when Pacific Can first introduced its innovative can design. It led the company to replace the old design, the 3-piece aluminum can, for the 2-piece aluminum can (See Figure 1.A). The introduction of 2-piece aluminum can has given the company many benefits; such as one filling line can accommodate multiple different can sizes. Therefore, it has led to reduce many of the costs beverage companies used to pay for using the old design. Nevertheless, the replacement of 3-piece aluminum cans to 2-piece aluminum cans has contributed vastly to producing safer and healthier cans, as the new design omits any leakage that might occur or rust that may develop.

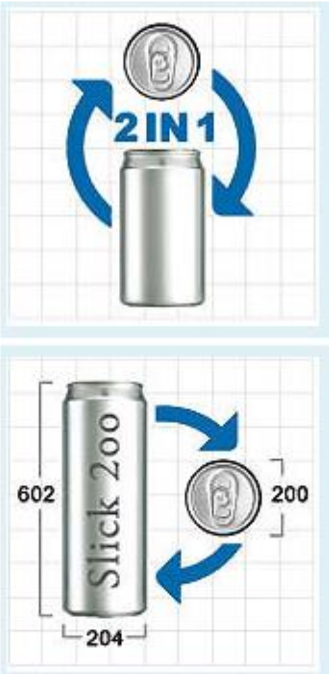


Figure 1.A 2-piece aluminum can design

On the contrary, the mission of Pacific Can is not only about the expansion of can producing. It is also about contributing to the environment by being a part of the sustainability of aluminum beverage cans. The three main characters that reflect Pacific Can are *Integrity, Professionalism, and Quality*. In addition, the type of cans Pacific Can is producing use a fitting size, and a lightweight material that raises the consumers desire to buy their product. Moreover, the aluminum cans can be recycled infinitely, which aids the necessity of improving the process of aluminum recycling (Pacific Can China Holding Limited, 2011).

1.1 Problem Statement

The factory in Beijing expressed their interest in improving their current system associated with moving and stacking compressed blocks of scrap metal. Due to the large production rate, the process of sorting and organizing the compressed metal scrap blocks becomes challenging and severe. Currently, the metal scrap blocks exit from two funneled chutes separating the painted metal scraps from the unpainted ones (See Figure 1.1.A). The dimensions of these chutes vary and thus do the sizes of the blocks produced. The average width and height for the colored and non-colored compressed scrap block are averaged around 31-cm by 31.5-cm and 31-cm by 19.5-cm respectively. Only the length of these blocks can be manually controlled based on the batch entered in the two funneled machines. After these blocks are produced the workers must carry and stack unpainted and painted blocks on 45-inch by 55-inch pallets, respectively. These pallets can contain around 60 blocks and weigh around 1100kg when full. The problem arises because the compressed scrap blocks are quite heavy, as each block may weigh approximately 25 kilograms. The blocks come out with a frequency of 90±9s and 120±10s for the blank and colored blocks, respectively. This workload is distributed amongst only four workers and thus is very taxing work. One of the issues is the labor force used to move and sort those blocks faces difficulties in completing the mission because of the heavy weight and the nature of the sharpness of the metal blocks. Assuming large growth in future production; moving and stacking these blocks will become an increasingly difficult task requiring more and more workers.

Figure 1.1.A Metal scrap exit chutes

The factory in Beijing aims to replace the current system that uses four workers in completing this process with a mechanical robotic arm. The arm hopes to have characteristics such as the ability to sort, move, and stack the cans. Additionally, it hopes to accomplish faster performance and efficiency in completing the task. Consistency is also important in the decision making process ahead. The robotic arm should be able to operate without human interaction and be able to work 24/7.

1.2 Objectives

The main objective in completing this project is to select a robot that will aid Pacific Can in the process of sorting and stacking the compressed can scrap blocks. In order to achieve this goal, a group from Worcester Polytechnic Institute and Beijing University of Chemical Technology (BUCT) students will work together in the process of selecting the robot. The group is fairly large and interdisciplinary as it consists of three mechanical engineers, six automation majors, and one industrial engineer. The group will need all these skills to help achieve the integration of this robotic arm into Pacific Can.

There are three main tasks that need to be achieved in order to build the robot: (1) the robotic arm and end of arm tool (EOAT), (2) the metal scrap recognition, and (3) the safety protection system. Those tasks are divided to the subgroups as each subgroup would handle one task. After each dividend complete the task assigned, the work would be combined to accomplish the end goal. It is essential to obtain a high level of work among the three subgroups for the sake of building the robot accurately. The task is considered a very complex job, but the team truly believes they can surpass this obstacle and eventually integrate a robot that would complete the assigned task. Nevertheless, it is satisfying that the management of Pacific Can would bestow the student of BUCT and WPI the trust of completing such an important task.

Innovative Objectives

1. The team will analyze the properties and effectiveness of different end of arm tooling for the robotic arm. Eventually the team will select an EOAT capable of carrying aluminum blocks the most effectively.
2. The team will explore new mechanisms to carry and stack the aluminum blocks not including the use of robotic arms.
3. The team will weigh the advantages of different robot arm designs, and eventually decide on one that best suits the situation.
4. The team will research modular design, so that the robotic arm can be easily upgraded to meet the changing production needs.
5. The robotic arm will be valuable to the company not only for moving and stacking, but with have flexible viability completing other tasks as well.
6. Equipping the arm with barcode scanner, storage facilities and warehouses can use this robot to sort boxes and stack them on the right shelf
7. With proper alterations in programming and hardware, the arm can be used to sort and stack the boxes of aluminum cans produced from the production line in Pacific Can factory.
8. If the team can design a moving platform for the arm, and with proper alterations in programming and hardware, it can replace the human operated fork-lifer cart. As a result, the whole process of pick up aluminum waste block and carrying to truck can be fully automated, saving even more human labor.

2. Literature Review

The chapter presents a background on the importance of aluminum can recycling, the importance of creativity and entrepreneurship in business, and the different technologies used in designing a mechanical arm.

2.1 Innovation and Entrepreneurship

Creativity is the ability to turn anything to something valuable. Creativity is intangible; some people are more creative than the others. Meanwhile, there are no real measurements or framework that can define creativity in people. There are many creative people in history; some are famous like Steve Jobs who gave the world such an iconic gift, a brand that can be found in any house nowadays. Some only been noticed by the environment they are surrounded by like Jack Welch, GE's CEO, who first introduced Six Sigma theory and application. What creative and innovative people share is whichever part has been introduced, it made such a significant difference in people's life at easing and yielding it.

Entrepreneurship is a phenomenon that is correlated to the ability of identifying new ventures and creating them. It is the behavior of solving a problem, diminishing an unseen one, or proposing an alternative solution that would improve a process. William Baumol wrote, "The entrepreneur is one of the most intriguing and at the same time most elusive characters in the cast that constitutes the subject of economic analysis." Thus, entrepreneurship is related to the individual or people who are able to create economic benefits and gain them (Minniti, 2007). Although the field of entrepreneurship research is considered recent, less than 50 years old, it is believed that it has been out ages ago. However, the importance of entrepreneurship is being realized and noticed as our economics is fairly formalized and system oriented. It is argued that entrepreneurs have risen away from the attraction of researchers or the connection of the institute disciplines (Astrom, Harirchi & Landstrom, 2012).

Meanwhile, entrepreneurship about coming up with an idea and eventually creates values for organizations from the idea. Entrepreneurial mindset includes curiosity, connections and creating values. For new discovering, it requires curiosity to start. Once discovery were made, a person need to pursuit and integrate knowledge and discoveries to get innovative solutions. Eventually, a person can use innovative solution to meet the demand and eventually create values (KEEN,n.d.). The team thought of four basic ideas about how to use this project to create values for the company and industries.

Entrepreneurship is very important in today’s market life. In entrepreneurship, you provide such a new idea that can be implemented then turned into a project that provide a net present value. Not only entrepreneurship gives attention to making value in the material form; it also becomes involved in accomplishing a remark at people’s life. The larger the effect you mark in an environment, the more valuable your idea becomes. In recent years, a Spanish entrepreneur developed a strawberry harvesting machine, the necessity of developing that machine was critical. The farm was losing approximately two million dollars for the inability of finding workers that can harvest the crop. Meanwhile, the robot has a substantial performance as it made the farm obtain two employees instead of twelve. The robot technicality depends on high powered computing and vision sensing technology (Blostein, 2015). Even though if building a robot is a complex job, lining up the bases that the robot depends on requires intuitive ideas.

Innovation is a new or more effective solution for satisfying new requirements or existing need. However, innovation is different form invention, as innovation is using a better idea or method, and invention is more focused on creating new idea or methods. The team came up with four ideas about innovation and how to be innovative in this project.

In the business and technology world innovation and entrepreneurship are two largely growing practices working, in some situations, together. For years, Worcester Polytechnic Institute has combined science and technology study through Major Qualifying Projects and Interactive Qualifying Projects alike. In our project, we hope to not only be able to use real world science and technological application but also innovative and entrepreneurial application. In doing so our project will not only solve a problem specific to a unique situation, but may be able to also find use in other areas as well. In doing so, we will analyze the innovative qualities our project may have and also entertain the entrepreneurial possibilities a project like this could hold.

In doing extensive research I found that Judy Estrin might have classified innovation the best. She breaks innovation down into three different types: incremental innovation, breakthrough innovation, and orthogonal innovation. Incremental innovation would be an advancement in a technology that essentially stays the same idea such as Windows 7 moving on to become Windows 8. Breakthrough innovation is something like creating the internet or the telephone. Finally, orthogonal innovation is innovation that repackages a technology in a new advanced way such as the MP3 player becoming the iPod (Estrin, 2008).

Our project falls under orthogonal innovation; we are taking a process that has been done a certain way for many years and executing the same process in a new repackaged way. By replacing this system, currently using manual labor, with a mechanical arm that will increase the efficiency, speed, and save money we are innovating the process.

Companies all over the world have seen changes in small parts of a business like this before and eventually all converted to the new technology. This can be seen in small things like record keeping. At one point, record keeping was all done via pen and paper. Now there are few businesses left that have not converted all documents into digital, computer copies. This upgrade could not only be a potentially huge upgrade for Pacific Can Company's scrap stacking and moving process, but many other can manufacturing companies as well.

Innovating trending is a large part of big companies. Every time Apple produces a new IPhone with a new piece of technology attached Samsung is very quick to follow. For example, Apple created smart phones with 64-bit technology and Samsung immediately answered by doing the same with their phones (Curtis, 2013). This kind of innovative trending and following between companies is a huge part of the business world. Just as Amazon has come out with the new Amazon Prime, Google has released Google Express to be able to compete (Lutz, 2014). You tend to see these imitation innovation products consistently between lots of companies such as Apple-Samsung, UPS-FedEx, Coke-Pepsi, Pizza Hut-Dominoes, etc. These are big companies trying to stay in the game with the newest and most successful technologies. These all come from innovating processes or products. If a large, renowned company such as Pacific Can switches to a mechanical arm to handle their stacking process and sees great success other companies will soon follow.

From an entrepreneurial side the mechanical arm also holds great promise. An arm able to detect, move, and stack has the versatility to be used in many areas, performing many tasks. This gives it a wide market as a product. Someone starting a company based on mechanical arms has the ability to manufacture these arms with small tweaks to be able to serve multiple different markets and purposes. Especially when considering the option of interchangeable mechanical hands able to fit many different tasks.

Once the mechanical arm has proven its use through replacing a company process and saving money in the long run, the mechanical arm market has a large possibility of taking off. When you look around, probably everything you see has been manufactured and not handmade. The change made to manufacture all those things was replacing a human process of manual labor with a machine capable of completing the same tasks faster and more accurately. The first breakthrough in that market was probably the Ford assembly line, but it only took one great success for other companies to see the value in its innovation (Anandan, 2014). The same change is to come with industrial robotic arms.

The Global Industrial Robotics Market is expected to have a Compound Annual Growth Rate of 6.42% from 2013-2018 (Technavio, 2014). Additionally, Transparency Market Research expects this market to have grown its market value to $44.48 billion by 2020 (Modern Material Handling Staff, 2015). The time for industrial robots to replace most processes in companies has come, so it is the perfect time to get into the market of robotic arms.

2.2 Reuse, Reduce, and Recycle

Aluminum is one of the finest materials that contributed abundantly in industry. Aluminum has important characteristics that allow it to be used in different industry sectors; and one of its important usages is in can production industry. Therefore, the production for aluminum to form different products runs continuously. Recycling the aluminum would help in saving 95% percent of the energy needed to produce aluminum from the beginning (Admin, 2008). In addition, by recycling the aluminum, the company would be able to reduce the amount of aluminum needed to remake the cans. Thus, the company contributes to the environment by reusing its waste and minimizes it.

Building the robot would contribute to the process of reusing, reducing, and recycling in multiple ways. If building the robot would fasten the process of sorting and stacking the aluminum scraps, the facility would be able to attain higher level of aluminum recycling. Thus, it would be an example to other cans facilities to the process of recycling aluminum. In addition, the robot itself would achieve the ability to reuse the human resource units in other suitable jobs that shall not be as difficult as involving in the process of sorting and stacking the 25 kg aluminum scrap.

2.3 Current Technologies

The Pacific Can Ltd. wishes to use a robotic arm to carry aluminum waste block generated during the production process. The original solution came from the company was using manpower, however, this method is expensive and ineffective.

An industrial robot, by definition, is an automatically controlled, reprogrammable, multipurpose manipulator. Application of industrial robots includes packaging, wielding, painting and palletizing. The advantage of a robotic arm comparing to manpower is its high endurance of long time operation, its efficiency of working and precision of each action. The most common robotic configurations include articulate robots, SCARA robots and Cartesian robots.

The earliest industrial robot meets the definition was created by Griffith P Taylor and published in Meccano Magazine in 1938 (Meccano Magazine, 1938). This robot can stack wooden block in patterns pre-programmed into the robot. The first robotic patent was applied by George Devol in 1954 was eventually granted in 1961. A company called “Unimation” founded by George Devol and Joseph Engelberger was the first company, which produce industrial robots. European and Japanese companies such as ABB Robotics and KUKA Robotics entered the market. The interest in Robotics increased in late 1970s and reached its peak in 1980s. Nowadays, most market has been taken over by Japanese corporations.

Theory and Practice of Robots:

Design principles

Industrial robots can be categorized by their operation modes, control systems, end of arm tooling, interactive mechanisms and arm geometry (Thomasnet, n.d.). These machines are the crucial part of automatic production in manufacturing and they can be used for purposes with wide varieties. With proper programming and end of arm tooling, an industrial robot can repeat complex motions and activities with no compromise in accuracy and efficiency. Even more, it’s possible to mound multiple end of arm tooling on a same industrial robot, making it capable of achieve multiple functions at a time. However, this method is not common among the industrial robots. More commonly, each robot focuses only on one single task.

The common ways to power the arm include electric motors, hydraulic drives and pneumatic actuators (Thomasnet, n.d.). As the most common way of powering the industrial robot, electric motors posses advantages such as efficient power sourcing and simple design characteristics. On the other hand, hydraulic drives are often used for heavy load work in volatile gas or hazardous surroundings. Because in such environment, electricity can easily set off an explosion by igniting the gas, making electric motors unsuitable for this kind of environment. However, the hydraulic drives have higher requirements for maintenances and risk of oil leakage due to its more complex system design (Thomasnet, n.d.). Pneumatic actuators are widely used in powering the mechanism to interact with external objects. For an example, pneumatic actuators can be used to drive end of arm tooling of a robotic arm.

The range of the robotic arm motion is often defined by Degrees of Freedom. In mechanical engineering, DOF is the number of parameters needed to define some object's configuration. More DOF means more flexibility, and inevitably more complex arm design and programming.

Each robotic arm is controlled by operating system running on a digital computer. The computer will manipulate the robotic arm accordingly to its programming. Nevertheless, this is the crucial part of the industrial robotic arm. Without the operating system and controlling module, a robotic arm is incapable of being intelligent and automated. For each specific motion, the arm has to be designed carefully, with only capability of doing one set of motion. However, with sophisticated programming, the robotic arm can use its advantage of flexibility and perform tasks as ordered. To perform its action, the industrial robot can operate purely under the command of operating system. Also, manpower can be used to carefully and accurately guide the arm through a cycle of task, allowing the computer to memorize the action and repeat such actions.

2.3.1 Current Status of Industrial Robotics in China

The Industrial Robotics market has seen exponential growth since the year 2000, with annual sales reaching record 180000 units a year. The main producer for these robots is Japan who holds 60% of production, as far as consumers the US, China, Germany, South Korea, and Japan hold 70% of the demand share.

The economic development of China during past 30 years is a legend. China has become "The World's Factory". This accomplishment is achieved by cheap labor price of Chinese workers who work in those factories. The unbeatable low price gives Chinese product incomparable competitiveness in world market. However, the human labor force is rising, and China may lose the price advantage eventually. The factories owners in China now are looking into a new work force: robots, which is cheap and efficient. Comparing to human, robots don't eat nor rest, they don't get distracted and they are easy to manage. Such features are drawing the attention and interest of Chinese enterprises. According to Yingqun Chen, China has surpassed Japan and become world's largest and fastest growing robot market. The number of robots sold in past five years is increasing at average rate of 36 percent per year (Chen, 2014). Nonetheless, giant manufacturers such as Foxconn, Hair and Midea announced plans to purchase enormous amount of industrial robots to replace human labor one after another. There's no doubt that demand for industrial robots in Chinese market in next decade will remain high. On the other hand, the market is dominated by foreign enterprises such as ABB and KUKA. 28,000 out of 37,000 robots sold in China in 2013 were made by foreign manufacturers, according to Yingqun Chen (Chen, 2014). In the near future, with certainty, international corporations will try to get into the booming Chinese robot market in order to get a share of the cake. Many domestic robot companies will spring up, and there's hope to see another giant manufacturer like Foxconn rise in the robot market.

With this transform in major labor force, the social impact come with it cannot be underestimated. Assume most of the factories in China replace workers with robots; a great number of populations will face unemployment. Those people who work in factories nowadays are usually young people with relatively minimum education. They earn their money by doing repetitive and minimum skill required jobs. Once robots take their jobs away, these people cannot find new jobs because of their lack of education and skill. It will be a great social problem awaiting Chinese government to solve. However, jobs do not simply vanish, they just transformed into other new jobs. In the growing robot market, there will be significant rise in demands for human labor such as robotic engineers, workers who assemble the robots and engineers who program the robots.

China currently holds 1/5 of the worlds demand for industrial robots, the industry sprouted in 2003 and has grown rapidly, it is expected for the demand to triple in the next 3 years to an impressive 100000 units expected to be purchased in 2017. Clearly industrial china is moving in the direction of automation, these robots are expected to increase output and worker productivity.

Regardless of this growth china still compares poorly within the technologically advanced nations in this industry; in china there is an average of 30 robots per 10000 workers, the global average is 62. Therefore there is a lot of catching up to do in order to move away from the currently labor intensive industrial plan to a more automated industry, this opens up opportunities for companies with innovative strategies to get ahead of the competition and improve efficiency with these modern tools.

2.3.2 Robotic Arm Expectations

For the robotic arm, we expect to see applications of linkage and gear systems to realize at least 3 degrees of freedom in 3D dimension. Also, we will expect using of electric motors to power the robotic arm and realize rotation of the arm. Linkage systems can be used to transfer rotational motion from the electric motor into specific motions we want, the gear systems can help achieve the motion we want as well.

End of Arm Tooling, often being referred as EOT, is one of the most important peripheral of robotic arm. Common types are welding devices, spray guns and grippers. The students from BUCT considered grippers such as vacuum gripper, flip type gripper, fork type gripper and bag type gripper. They believe a vacuum gripper will be the most ideal type, however, due to the uneven surface of the aluminum block, vacuum is not a viable solution. Considering the four types listed above, they think fork type gripper is the most promising type of EOT for this project.

The company wanted use only one robotic arm to stack two different kind of aluminum block, so a detection system is needed for the arm in order to distinguish two types of block and put them in the right stack. There's already sophisticated color detection module on the market that can process the color of the object using its camera and transfer it into signals.

2.3.3 Arm Options

In the past few decades the robotic arm industry has experienced exponential growth, this has made it possible for vast research and development to occur; and now there exists a large variety of different

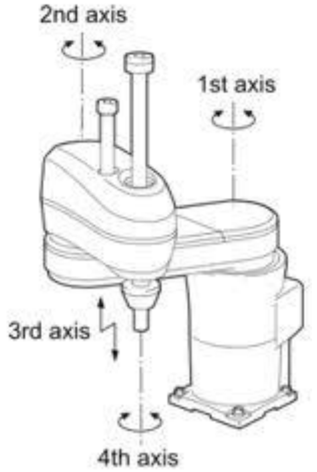


Figure 2.3.3.A 4 Axis Robot

robot arm types.

Some of the most common arm types include:

- 4 Axis Robot: this type of industrial robot can fully position its tool in any desired position and orientation, the use of 4 axis allows for fairly good versatility movement (See Figure 2.3.3.A).
- Cartesian Robot: this industrial robot operates under three principal axes of control, these are linear and thus no rotation. All axes of control are perpendicular (See Figure 2.3.3.B).

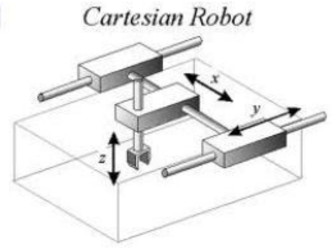


Figure 2.3.3.B Cartesian Robot

- SCARA Robot: this industrial robot is also known as the Selective Compliance Assembly Robot Arm, this robotic arm is designed for working with holes in the XY axis, this advantageous for multiple assembly operations but not necessarily for material handling (See Figure 2.3.3.C).

Figure 2.3.3.C SCARA Robot

- 6 Axis Robot: this type of industrial robot can fully position its tool in any desired position and orientation, the use of 6 axis allows for high versatility of movement (See Figure 2.3.3.D).
- Redundant robots: this type of industrial robot is very similar to the 6 axis robot, it too can position its end tool in any position or orientation, nevertheless it can do it in several postures, making it the most versatile in terms of motion (See Figure 2.3.3.E).

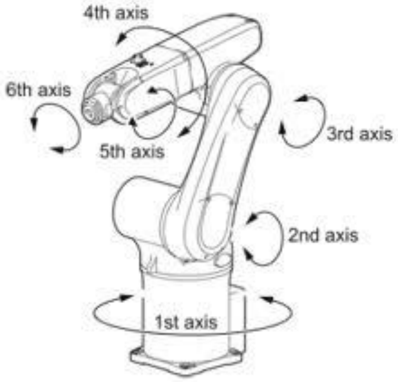


Figure 2.3.3.D 6 Axis Robot

- Dual Arm Robot: this type of industrial robot allows for two arms that can work together in the same work space performing complicated operations (See Figure 2.3.3.F).

Figure 2.3.3.E Redundant Robot

Figure 2.3.3.F Dual Arm Robot

2.3.4 KUKA & ABB Robotic Arm

- **KUKA KR 40 PA**

Figure 2.3.4.A KR 40 PA Robot

KR 40 PA is a four-axis industrial robot developed by KUKA especially for tasks such as palletizing, handling and depalletizing (See Figure 2.3.4.A). The maximum payload on the wrist of the robot is 40 kg, plus a maximum supplementary load of 20 kg. All main bodies of the robotic arm are made of cast light alloy and designed to optimize cost-effective and high torsional and flexural rigidity. As a result, the robot has a high natural frequency and is thus characterized by good dynamic performance with high resistance to vibration. The arm itself is hollow structure to reduce its weight while still ensuring high strength. The joints and gears are all covered and free from backlash. The axes are drove by brushless AC servomotors of plug-in design, which are in no need of maintenance during its life cycle and capable of preventing damages from overload. According to KUKA, the main axes are lifetime-lubricated, only requiring oil change after 20,000 operating hours. It only requires very small floor space for mounting. The lifespan of a KR 40 PA industrial robot is about 10 to 15 years, like all other KUKA robots. (KUKA Roboter GmbH, 2005)

The robot comes with a controller whose control and power electronics are integrated into a operational cabinet. The controller is easy to use and meets the safety standards of EU machinery directive and relevant standards. The power supply and signal wires are already combined into the cable between the control cabinet and the robot. The cables are plug-in style, as well as the energy and fluid supply line for the operation of end effectors. These lines are fixed inside the main axis A1 of the robot permanently. (KUKA Roboter GmbH, 2005)

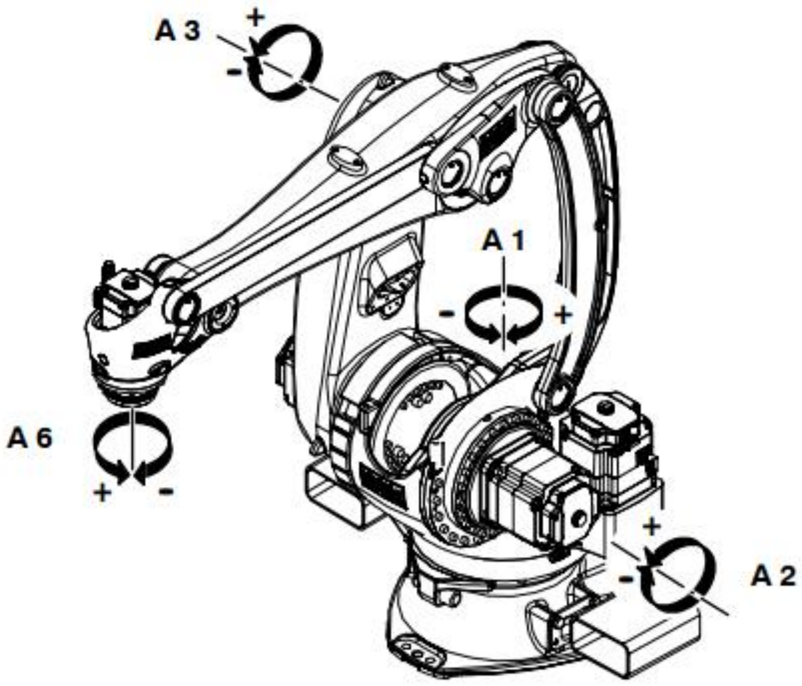


Figure 2.3.4.B KR 40 PA possible movements

The robot consists of a fixed base frame, along with a rotating column, link arm and wrist. The wrist is provided with a mounting flange for attaching the end of arm tooling. The possible movements the robotic arm can perform can be seen in Figure 2.3.4.B. Moreover, the positions of A1, A3 and A6 axis are sensed by an absolute position sensing system with sensors on each axis. Each axis is powered by a transistor-controlled low-inertia AC servomotor. The range of A1 axis is from positive 155 degrees to negative 155 degree, which is 310 degrees in total while the maximum range of the arm is 2091 mm. The repeatability is around 0.05 mm. It It weighs 695 kg alone, excluding the controller cabinet, end of arm tooling and any other attachments on the arm. The envelope of the working volume is around 12.6 cubic meter. Its protection level is IP 65, which is dust tight and resistant to water jets. (KUKA Roboter GmbH, 2005)

Quoted from the sales contact from KUKA, the rough price for the arm is around 240,000 RMB to 250,000 RMB. The price quote excludes any external equipment such as end of arm tooling and visual detection systems. The first year of purchasing is under warranty provided by the manufacturer. The maintenance cycle for the robot is every 2 to 3 years and 5,000 to 8,000 RMB. For the integration, the sales contact actually recommended a professor from BUCT, Professor Zhang Beike.

- **KUKA KR 30-3**

Figure 2.3.4.C KUKA 30-3 robot

KUKA KR 30-3 is a six-axis industrial robot manufactured by KUKA with the main applications of handling, assembling, machining, etc. (See Figure 2.3.4.C). The rated maximum payload of this robot is 30 kg. Similar to KR 40 PA, the main bodies of the robot are made of cast light alloy specially designed to optimize dynamic performance and resistance to vibration. All axes are powered by AC servomotors that don’t require maintenance and offer reliable protection against overload. All the components are designed to be simple and straightforward. The numbers of components are minimized as well. The whole unit can be quickly replaced by another robot without any major programming. The major axes are lifetime-lubricated as well, requiring a necessary oil change after 20,000 operation hours by the earliest. The robot is designed to occupy minimum space on its base and being able to reach objects that are close to itself. In comparison to KR 40 PA, it can also realize overhead movement and movement in two more axis. Each robot is equipped with controller cabinet that integrates control and power electronics. The robot meets the safety requirements specified in EU machinery directive and relevant standards. The power supply and communication wires were integrated into the cables that connect the robot and the controller. (KUKA Roboter GmbH, 2003)

The design of this robot is more complicated than that of the KR 40 PA. It includes a fixed base frame, rotating column, link arm, arm and wrist (See Figure 2.3.4.D). On the wrist, a mounting flange is provided for attaching end of arm tooling. The possible movements are shown in Figure 2.3.4.D The positions of the axes can be detected by means of a cyclically absolute position sensing system featuring a resolver for each axis. Each axis is powered by a transistor-controlled, low-inertia AC servomotor while the brake and resolvers are space-efficiently integrated in to the motor unit. (KUKA Roboter GmbH, 2003)

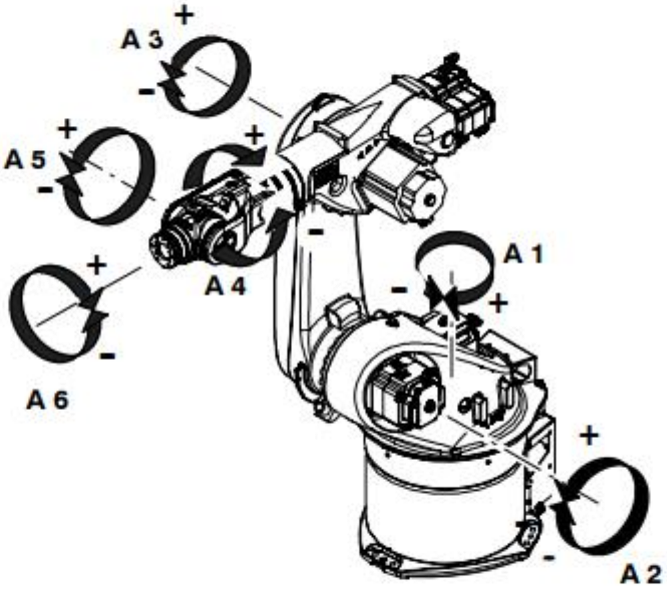


Figure 2.3.4.D KR 30-3 possible movement

The maximum total load of the robot is 65 kg while the maximum payload is only 30 kg. The weight of the robot itself is approximately 665 kg and the mounting of the robot can be variable, not only limited to the floor. The possible moving angle range for A1, which is the base, is from positive 185 degrees to negative 185 degrees. Because of its special structural design, it can achieve about 27.2 cubic meter of working envelope volume. Its protection level is IP 64. By the definition from International Electronics Committee, IP 64 means dust tight and protection against water splash. Its protection level is one of the lowest among the candidates.

The sales contact from KUKA didn't recommend this robotic arm because its payload is only 30 kg. Since the weight of the end of arm tooling is counted toward the payload, there's a great risk that the robot cannot complete the task because the block plus the end of arm tooling will exceed the payload. The price of the robot, according to the sales contact, is 300,000 RMB, excluding any integration fee, end of arm tooling or any visual detection module. The maintenance fee of this robot is like any other KUKA robot, which is 5,000-8,000 RMB for every 2 to 3 years.

- **KUKA KR 60-3**

As a supplement, the sales contact from KUKA recommended KR 60-3 as a candidate, which has similar structure and design as KR 30-3. The major differences between the two series are range and payload. KR 60-3 can offer three level of payload in the wrist, which are 30, 45 and 60 kg. The weight of the robot is 665 kg, which is surprisingly the same as that of KR 30-3, despite the fact that they offer different payloads. The range of motion in A1 axis is the same between the two, except KR 60-3 is a bit slower in its angular speed. The reach ranges are 2033, 2230 and 2429 mm respectively for payloads of 60, 45 and 30 kg. Its working envelope volume is the same as KR 30-3, which is 27.2 cubic meter. (KUKA Roboter GmbH, 2003)

According to KUKA sales contact, the price of KR 60-3 is slightly higher than that of KR 30-3, which is 320,000 RMB, excluding any cost of detection system, integration fee and end of arm tooling cost. Its maintenance cost is 5,000 to 8,000 RMB for every 2 to 3 years.

- **ABB IRB 460**

Figure 2.3.4.E IRB 460 robot

ABB IRB 460 is a 4-axis compact industrial robot specially optimized for palletizing operations in the factory (See figure 2.3.4.E). The common industrial robots have 6 axis, giving them more flexibility over 4 axis ones. However, the advantages of 4 axis design are very prominent in jobs such as palletizing. In comparison to same priced 6 axis robots, IRB 460 can maintain its price at relative low range because of its simpler design. Benefiting from its lower complexity design, IRB 460 is also able to finish a standard cycle faster while yielding more payload. According to ABB, as one of the fastest palletizing robot, IRB 460 is capable of completing 2190 well defined cycles within one hour with 60 kg of load and 2040 same cycles within one hour with 110 kg of load on it. By the calculation, the longest cycle time of the robot is only approximately 1.76 seconds, which is way faster than the production rate of the blocks. The arm itself weighs 925 kg and has 110 kg of maximum payload. The reach range of the robot is 2400mm while the repeatability is 0.2mm (See Figure 2.3.4.F). It can only be mounted to the floor. Its base takes about 1007mm x 720mm of space, which totally satisfies the requirement of the team’s room layout print. The team had consulted the sales contact and integration companies about the price of the robot and integration. As the feedback in the emails stated, the robotic arm itself costs around 310,000 RMB while the total price of integration of the robot is a little bit over 100,000 RMB including all taxes. The price quotation above includes the robot itself, the basement of the robot, the end of arm tooling, installation fee, calibration fee, controlling unit, robot demonstrator and connecting cables. The sales contact claimed that the robot doesn’t required maintenance for up to five years. When maintenance is necessary, the average price will be 2,000 RMB per day, excluding the cost of replacement parts and materials. Its power consumption is only about 3.67 kW and can work in conditions of 200-600V and 50-60Hz, according to the data from ABB. (ABB Group, 2011a)

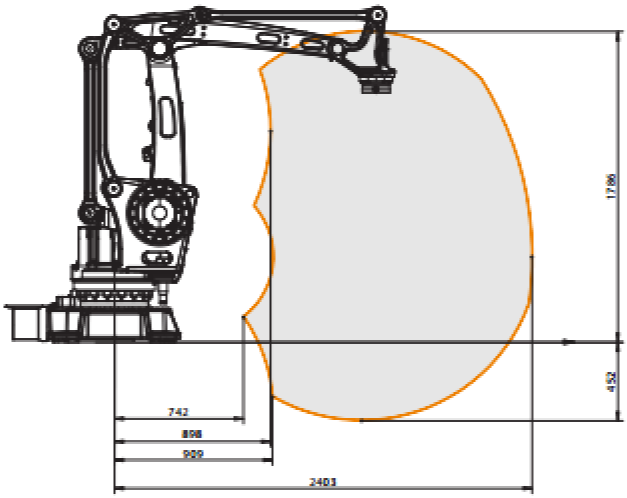


Figure 2.3.4.F IRB 460 range

As the data sheet the team acquired from ABB stated, the protection level of IRB 460 meets the requirement of IP67 standard. IP is the short abbreviation of “Ingress Protection Rating”. It’s an international standard of classifying and rating of degree of protection against foreign intrusion such as dust, water and etc. by utilizing mechanical casings and electrical enclosures. The first digit after the character represents the level of protection against access to hazardous parts and the ingress of solid foreign objects, while the second digit after the character stands for the level of protection against harmful ingress of water. As a result, the IP67 refers dust tight and immersion up to 1m. It can be further interpreted as no ingress of dust, complete protection against contact and withstand 30 minutes in water for up to 1 meter of submersion. The more detailed definition was published by IEC. The safety mechanisms that come with the robot are double circuits with supervision, emergency stop and safety functions and three-position enable device.

Additionally, a PalletPack 460 Palletizing Function Package is also available for purchase along with the robot. The package includes the robot itself, end of arm tooling, PLC safety control, graphical HMI and PLC Cell Control. One of the benefits of buying PalletPack 460 is that PLC programmers can program the robot with little or no knowledge of ABB RAPID programming, allowing the user to reprogram the robot in order to satisfy the specific requirements of the client and adapt the changing work environment and application (Bengtsson, 2012).

- **ABB IRB 4600**

Figure 2.3.4.G ABB 4600 robot

As a 6-axis robot developed for general applications, the IRB 4600 can be integrated with many sorts of end of arm tooling for wide range of applications such as cutting, derubbing, cleaning, dispensing, material handling, palletizing and packaging and etc. (See Figure 2.3.4.G) Its highlighted features are fast acceleration and top speed, accuracy and versatility. Its design was optimized for space, production speed and production quality. Its position repeatability ranges from 0.05mm to 0.06mm, while its route repeatability goes from 0.13 to 0.46 mm. According to the ABB manual, the accuracy of IRB 4600 is in the top of its class, great for improving process speed and lowering scrap rates. This feature is especially useful in applications such as materials handling, dispensing, machining, measuring and etc. Also, its low weight is beneficial due to its optimized design allowing the robot to be one of the fastest one in the industry. As it was introduced in the ABB manual, it can cut the cycle times of the industry by 25%. This feature can come in handy when the factory increases its production rate since the scrap production rate will go up along with the can production rate. The client doesn't have to worry about the robot not being able to catch up with the rate since its speed is far above current requirement. Last but not least, its 6-axis design and compatibility with most ABB end of arm tooling makes it almost suitable for every robotic application. With new end of arm tooling and reprogramming, it can switch to another job very smoothly. So if the client no longer needs the robotic arm to pallet the aluminum blocks or wants to replace the robotic arm with newer model, the IRB 4600 can still create values for the client in other work stations. (ABB Group, 2012)

There are four variants of IRB 4600, and they are IRB 4600-60/2.05, IRB 4600-45/2.05, IRB 4600-40/2.55 and IRB 4600-20/2.51. The major differences between the models are the payloads and their reach range. The payloads are 60 kg, 45 kg, 40 kg and 20 kg respectively, while their reaches are 2.05m, 2.05m, 2.55m and 2.51m respectively. Because of the compact design, the base area of IRB 4600 is only 512mm x 676mm, and its weight is only 412 kg to 435 kg, which is less than half the weight of IRB 460. Nevertheless, the second benefit is that it can be mounted not only to the floor, but also on shelf, inverted or tilted. This property makes it more flexible for the team to decide the room layout since it can be mounted not only on the floor. One of the scenarios is that the robot is mounted to the wall so that the robot can have much less cycle time and moving while carry and stack the blocks, in contrast to the scenario that the arm is located on the floor. (ABB Group, 2012)

According to the price quote the team received from the sales contact, the IRB 4600 industrial robot costs around 340,000 RMB, excluding any integration fee. Its maintenance is similar to IRB 460 since all ABB robots don’t need any servicing in the first five years and afterwards the charge will be 2,000 RMB per day, excluding any charge for the replacement parts and materials. Its protection level is the same as the IRB 460, which is IP67. The Foundry Plus package can be purchased to enhance the protection level of the robot even further. With this package, the robot can go through high pressure steam and water washing.

- **ABB IRB 4400**

Figure 2.3.4.H ABB IRB 4400 robot

ABB IRB 4400 is also a compact, fast conventional robot for medium to heavy handling, similar to IRB 4600 (See Figure 2.3.4.H). It has 6-axis and capability to realize versatile applications using different end of arm tooling and programming. It can be installed for applications such as cutting and derubbing, grinding and polishing, material handling and etc. Its rigid, robust built makes it very reliable and needs minimum numbers of routine maintenance. Another feature of the arm is its extensive communication capability. It can communicate with external hardware with serial links, network interfaces, PLC, remote I/O and field bus interfaces. According to the data sheet provided by ABB, its reach is 1.96m while its maximum payload is up to 60kg. Its position repeatability is 0.19mm while its path repeatability is about 0.56mm, which is less accurate than the IRB 4600. The weight of the arm is 1040 kg, making it the heaviest one among the three ABB candidates. Its base size is medium, which is 920 x 640 mm. Unlike IRB 4600, it can only be fixed on the floor. However, it still has versatility in its application due to its design. Like IRB 4600, it can still be used in other work post and continue t create value while it’s replaced by other methods on the palletizing job. Figure 2.3.4.I introduces the dimensions and load diagram of the robot. (ABB Group, 2010)

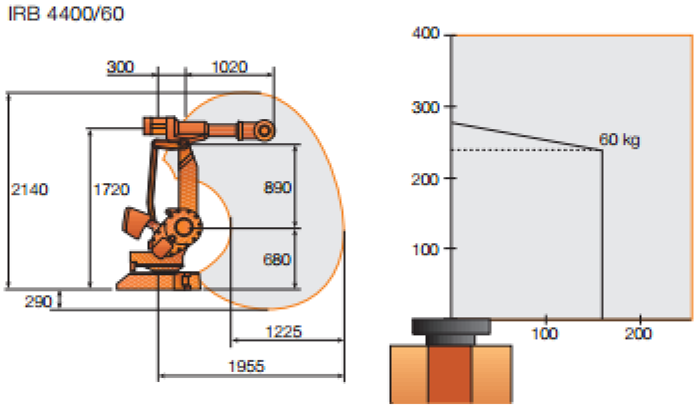


Figure 2.3.4.I ABB IRB 4400 dimensions and load diagram

The team consulted the sales contact from ABB about the price of the IRB 4400 model along with IRB 4600 and 460. Surprisingly, it cost the most among the three models. Even though its maintenance cost is expected to be lower than the other two since its reliability, the team still thinks it’s not as suitable as IRB 4600 or 460 for the project.

Unlike IRB 460 or 4600, its protection level is only IP 54. According to the definition by the International Electronic Committee, it has protection against normal dust and splashing of water. The safety mechanisms come along with the robot are double circuits with supervision, emergency stop and safety functions and three-position enable device. Because its more rigorous requirement for the environment and its price, it is treated as the less desired one among the three candidates from ABB, by the team.

2.3.5 End Arm Tooling Options

Robot end arm tooling has never been more important; with increasingly complex operations and high costs users demand a high grade of versatility in their robots. Manufacturers want to deliver flexible intelligent end of arm tooling that adds value to the overall system this is the only way for companies to stay ahead in these competitive times. Because of this companies are opting to manufacture hybrid end or arm tools featuring several kinds of gripping/holding methods in one single machine.

Some of the most common end of arm tools used for industrial purposes include:

- Servo-electric Fork Gripper: One of the most common material handling end arm tool, using electric motors to move two “fork” like jaws that close on the payload creating a basket like enclosure, they are highly versatile for different size payloads with newer models adjusting automatically for payloads within a size range. Since it is electric it requires less maintenance and cleaning that other oil/air base pneumatic systems.
- Servo-electric Friction Gripper: Similar to the fork this kind of gripper uses electric motors to hold payloads by friction applying force horizontally on the sides of the payload. Most new models adjust automatically to size and weight ranges.
- Vacuum Cup Systems: Several suction cups are put in contact with the surface and use vacuum to lift the payload, there has to be complete contact with the surface for the suction to be effective, smooth surface required.
- Magnetic Systems: for some applications when moving ferromagnetic metals some arms may be equipped with magnets with variable strength to move the objects, in industry this

kind is usually associated with recycling applications but newer systems use switchable permanent magnets to create shallow magnetic fields for de-stacking metal sheets.

- Granular Jammer Suction Systems: this technology is quite interesting as it uses carefully engineered foam under vacuum suction to create suction in every pore of the foam, this makes the foam adjust to the surface and achieve suction in every bit of the surface making it significantly more versatile than any other suction method as it can lift most uneven surfaces.

The FlexGripper clamp and claw from ABB are very likely end of arm tooling options we are considering. The FlexGripper is very easy to install and program. The HMI and FlexPendant on the robots are already pre-configured with input/output signals of the FlexGripper. This feature can dramatically reduce the programming and setting up time for the user. Moreover, the graphical interface can simplify the routine testing, setting up, tuning and monitoring of the palletizing. For example, the pick-and-place test can be performed with just one click. (ABB Group, 2011c)

Hook units are used on the end of arm tooling to make sure the stability and secure handling of the cases or objects during high speed movements and palletizing. The FlexGripper has sensors installed on it to detect the presence/ absence of the cases or blocks. The strokes are wide enough to make sure the gripper can pick up cases with different sizes. It comes with all the air hoses and connection cables it requires and is ready to plug-and-play on ABB IRB 460 or IRB 660. (Liu, 2011)

2.4 Automatic Identification Technology

In recent years, China's output of aluminum cans has increased year by year; the current annual consumption of Chinese aluminum cans is from sixty to seventy billion cans. The National Bureau of Statistics, in 2002, ranked China's beer output first in the world with 23,868,300 tons. The use of produced cans is mainly for beer and carbonated soft drink industries. Aluminum cans occupy a large proportion of the beverage packaging companies' products as well. Can manufacturing companies' integration of metallurgical, chemical, machinery, electronics, food and many other advanced technology industries, has become a microcosm of the deep processing of aluminum. With the growing competition in the beverage packaging market, how to minimize the thickness of the sheet metal cans production, reduce the quality of a single tank, improve material utilization, and reduce production costs are their main goals.

The manufacturing process of aluminum cans is a very long, age-old production line. The process steps are as follows: Volume conveying → roll lubrication → blanking, drawing body shaping → trimming → washing / drying → stacking/unloading → drying →background color → priming → drying→waiting for the inner coating to dry→necking →lubricated rotary compressing in the neck. In the process, the blanking, stretching, body shaping, trimming, necking, and flanging process require more molding. Blanking, mold stretching, and body shaping, the more critical steps, directly affect the quality and production cost of the cans, thus requiring a precise, technological level of expertise in mold design and manufacturing.

In actual production, there will inevitably be a lot of waste. Recycling waste has become a major source of corporate profits. The use of image capture and automatic identification technology, at the time of metal scrap processing, synced with an industrial robotic arm able to clear this waste, has not yet appeared in the can manufacturing market. This idea, while new, is a very promising long-term prospect for the future, holding many benefits.

In order to make this a reality, we must simulate the situation using computer software called OpenCV. By programming OpenCV correctly, we will be able to distinguish unpainted and painted blocks via color extraction. This will be linked to a camera that will work simultaneously with OpenCV to take the photo image, distinguish the type of block, and finally send a signal to the robotic arm. This signal with give the robotic arm knowledge of how to handle the type of block it is looking at. In Figure 2.4.A you can see the process of how the camera works to send a signal to the robotic arm. It starts in the camera and takes an image, which than is analyzed by OpenCV. OpenCV determines the type of block and sends a signal of 0 for unpainted or 1 for painted block to the robotic arms controlling software. This allows the robotic arm to manipulate the block accordingly.

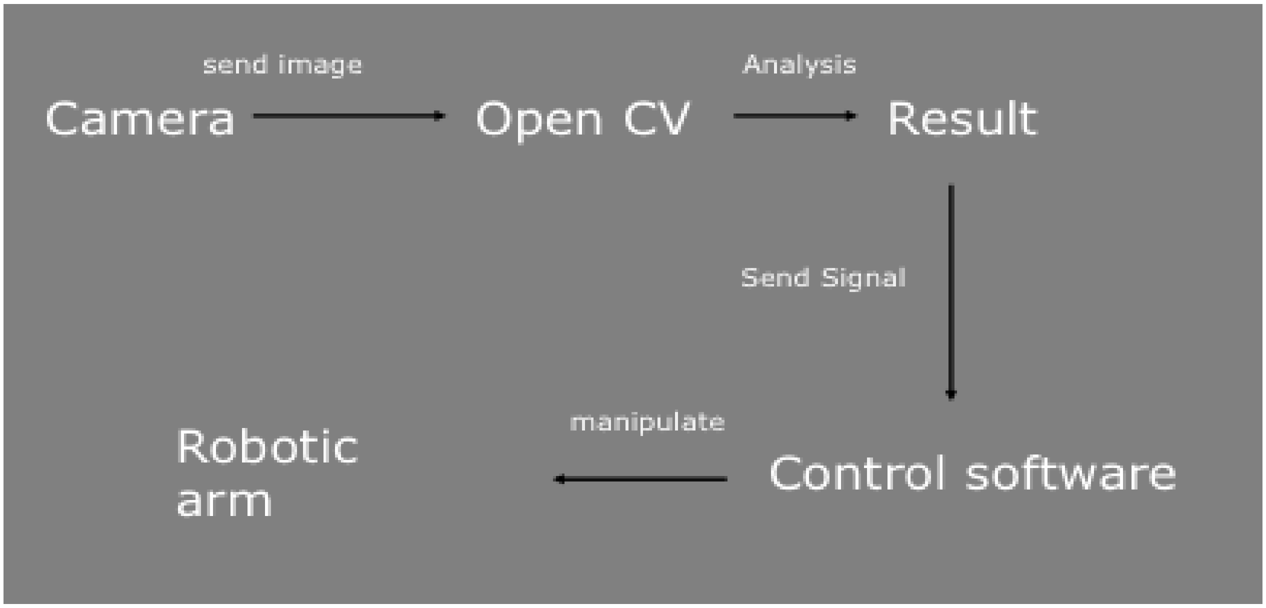


Figure 2.4.A Schematic Map of OpenCV Software

Leaving out most programming and coding aspects of OpenCV, we will explain briefly how the software works to distinguish and extract color.

2.4.1 Image Feature Extraction

2.4.1.1 Image Characteristics: Common Scan

Features Introduction

Feature extraction is a concept of computer vision and image processing. It refers to the extracted information in an image. The use of a computer is necessary to determine whether each point of the image features characteristics of an image. The purpose of feature extraction is for points on the image to be divided into different subsets. These subsets are often for isolated points to be categorized as a continuous curve or a continuous area.

The situation or the type of application often determines the precise definition of the characteristics. A digital image of an "interesting" part of the image, or a part with the most activity, is the starting point for many computer image analysis algorithms. Therefore, the success of an algorithm is often used and defined by its characteristic decision. The most important characteristic feature extraction is "reproducibility"; different images of the same scene of the extracted feature should be the same.

Feature extraction is one of the primary image processing operations, it is also the first operation of image processing that is carried out. It checks for each pixel to determine whether the pixel represents a feature. If it is a bigger part of the algorithm, then the algorithm generally only checks feature areas of the image. As a precondition for feature extraction operation, the input image by a Gaussian blur kernel is generally smooth in scale. After this process, partial derivatives are used to compute more characteristics of the image.

If the feature extraction requires a lot of computing time, a high-level feature extraction algorithm can be used for control, so that only part of the image is used to find features.

Many computer image feature extraction algorithms are used as primary computing steps. A large number of feature extraction algorithms have been developed for extracting a variety of features; their computational complexity and reproducibility are also very different.

Regional Types of Characteristics

A. Edge

The edge is the boundary between the two image regions composition (or edge) pixels. The general shape of an edge may be arbitrary or it may also include intersections. In practice, the edge is generally defined as a subset of the image and has a large dot gradient composition. Some commonly used algorithms will put high gradient point links together to form a more perfect description of edges. These algorithms also may make some restrictions on the edges.

B. Angle

An angle midpoint in an image is characterized by having a two-dimensional structure locally. The early edge detection algorithm is performed first, and then analyzed to find the edge to edge to turn (angle). Later, algorithm development no longer needs this step in edge detection, but can look directly at the height of the curvature of the image gradient.

C. Area

The difference in angles is a description of the image regions of a regional structure. The region may be composed of only one pixel, and therefore many can also be used to discover the area. An area monitor detects an image and an angle monitor detects smooth areas. Area detection can be thought of as a sheet of image reduced to the narrow angle images.

D. Ridge

Elongated objects are called ridges. In practice, the ridge can be seen as a representative of the symmetrical axis of a one-dimensional graph. In addition, there is a local ridge width for the ridges of each pixel. They tend to use ridge gradient detection in aerial photography to distinguish the roads and heights.

Features Extraction

Features are detected and can be extracted from the image. This process can take a lot of computer image processing. The result is called the feature description or feature vectors. Common image features include: color features, texture features, shape features, and spatial relation characteristics.

2.4.1.2 Image Retrieval Based on Color Recognition

Color Features

A. Characteristics

Color features are a global feature. They describe the surface properties of an image or image area corresponding to the scene. General color features are based on pixel features, and then all the pixels belonging to the image or image area have their own contribution. The colors of the image or image area are not sensitive in direction or size so the color characteristics of local features are not well captured in the image of the object. In addition, when using only the color characteristics of the query, if the database is large, often a lot of unwanted color imaging would also be retrieved. Color histograms are the most common method of expressing color feature. This is advantageous because it is not affected by changes in image rotation and translation, to further help it can be a normalized image scale from the impact of changes. Disadvantages include not being able to express spatial distribution of color information.

Commonly Used Feature Extraction and Matching Methods

A. Color Histogram

The advantages: it can simply describe the global distribution of colors in an image. It puts in proportion the distribution of different colors in the entire image, especially for hard to describe images. The disadvantage is that it cannot describe the local distribution of colors in the image and the space in which there is position in each color. It is impossible to describe the image of a particular object or objects.

Color histogram is a color feature in many image retrieval systems that are widely used. Particularly it is suitable for images that are difficult to describe with automatic segmentation.

Match histograms only consider the probability distribution of pixel values, without considering the positional information, the only benefit is small and easy normalized computation.

The most common color spaces: RGB color space, HSV color space.

B. Color Set

Color histogram method is a global color feature extraction and matching methods cannot distinguish between local color information. Color set is the color histogram of an approximate first image from the RGB color space and will be converted into a balanced visual color space (such as HSV space). Next, automatic color image segmentation is divided into several zones, each with a quantized color space linked to a color component of the index, which will be expressed as a binary image color index set. In the image matching, spatial distance and color region will be compared to create relationships.

C. Color Moments

A color moment can be described as a mathematical basis of the method comprising; an image of any color composition can be described by a moment. In addition, because the color distribution information is mainly in low-end torque, the use of only three-color moments [first moment (mean), the second moment (variance) and third moments (Skewness)] is enough to express the color distribution of the image.

D. Color Coherence Vector

The core idea of coherence vectors is to parse every pixel to the histogram in two different categories, polymerization and non-polymerization pixels. If the area is contiguous of some pixels within the shank occupied by more than a given threshold, the pixel region is of polymerization pixels. As a non-polymeric pixel, the opposite is true.

From the introduction of color features, the color histogram is most suitable for aluminum cut image recognition features. Color aluminum cuts in its original color distribution are random, and we do not care about the color of its location, we are only concerned whether the picture is colored aluminum chop, or white. The color is what concerns us and for identifying the location of the white color and colored aluminum.

2.4.2 Algorithm

After the picture's color features are extracted with the color histogram color, the next step is to color histograms. OpenCv contrast histogram provides five ways to distinguish color: CORREL (relevant), CHISQR (chi-square), INTERSECT (intersection), BHATTACHARYYA, and EMD (minimum working distance). CHISQR is the fastest, and EMD is the slowest, there are many restrictions. However, EMD works the best. EMD's approach requires starting with a histogram conversion matrix. It is worth noting that a different approach to compare the results results very differently.

BHATTACHARYYA Pap distance: In statistics, Bhattacharyya distance (hereinafter referred to as Pap distance) measures the similarity of two discrete or continuous probability distributions. The Bhattacharyya coefficient is calculated and a very close relationship. Both calculations are named with A. Bhattacharyya; Bhattacharyya is a statistician at the Indian Statistical Institute 30's work. The Pap coefficient is used to find the relevance of the two samples that are measured. This method is often used to make classification algorithm. Bhattacharyya coefficient (Bhattacharyya Coefficient, Pap coefficient) is an approximate calculation of the two statistical sample of the amount of overlap between the images. As a result, this formula will result in a block with two members have a common sample that becomes larger. Block number depends on the number of members selected in the sample; if the block is too small due to overestimation of the overlap region then it will lose accuracy.

If the two samples do not overlap entirely, pasteurized factor will be equal to zero, because each block will multiply by zero. This means that the complete separation of the sample cannot be measured separately.

In the case of fast but not very accurate matching, the effect intersection method is good, and in the case of a slow but more accurate, the chi-square or pasteurized method is better.

For related and intersecting contrast histograms, the greater the resulting value (ie, higher brightness) where the higher the degree of matching. For chi-square histogram, Bhattacharyya, EMD contrast, the smaller the resulting value (that is, the dark) places, the higher the degree of matching. But we know that in this practice, in order to work with OpenCV, used in the comparison is pasteurized distance indicators (1-Bhattacharyya). Figure 6 shows the equation used to complete the tasks.

Correlation (method = CV_COMP_CORREL)

$$d_{\text{correl}}(H_1,\ H_2)=\frac{\sum_i H_1'(i)\cdot H_2'(i)}{\sqrt{\sum_i H_1'^2(i)\cdot H_2'^2(i)}}$$

Chi-square (method = CV_COMP_CHISQR)

$$d_{\text{chi-square}}(H_1,\ H_2)=\sum_i \frac{(H_1(i)-H_2(i))^2}{H_1(i)+H_2(i)}$$

Intersection (method = CV_COMP_INTERSECT)

$$d_{\text{intersection}}(H_1,\ H_2)=\sum_i \min(H_1(i),\ H_2(i))$$

Bhattacharyya distance (method = CV_COMP_BHATTACHARYYA)

$$d_{\text{Bhattacharyya}}(H_1,\ H_2)=\sqrt{1-\sum_i \frac{\sqrt{H_1(i)\cdot H_2(i)}}{\sqrt{\sum_i H_1(i)\cdot \sum_i H_2(i)}}}$$

Figure 2.4.2.A Equation used for OpenCV

2.5 Computer Aided Design for 3D Modeling

In order to properly assess the possibility of implementing the robotic arm in the work area it is essential to have accurate models of how the robot fits and moved in the area. Computer Aided Design (CAD) software can offer tools to recreate any scenarios and components of the work area as well as model any motions that will occur. The main two pieces of software that are being considered for this project are SolidWorks, which is developed by Dassault Systèmes SolidWorks Corp. and Creo, which is developed by PTC (Parametric Technology Corp.). Both alternatives offer modeling tools that can complete the modeling objectives successfully (PTC, 2015).

CAD software works by utilizing parameters (constraints), which determine the geometry and size of the models/assemblies. These parameters are either numeric, such as distances, angles, diameters etc. or they can be geometric, with relationships such as concentric, horizontal, parallel etc. The author's uses these relationships to create his design intent, which is the way that he wants the part to respond to changes. In order to create the parts the author must use features, which are the shapes and operations used to constructs the part, these are the building blocks of the part and are usually created with 2D or 3D sketches using bosses, slots, holes, etc. these shapes are then extruded or cut to add or remove material. With the right training an author can create complicated parts that can be used for virtual demonstrations or posterior printing/machining. A sample part can be observed in the Figure 2.5.A. The view clearly shows the different parameters of the part, these distances and constraints illustrate the design intent of the author, and should allow for further modification of the part given changes in certain key feautres of the part (Dassault Systems, 2015).

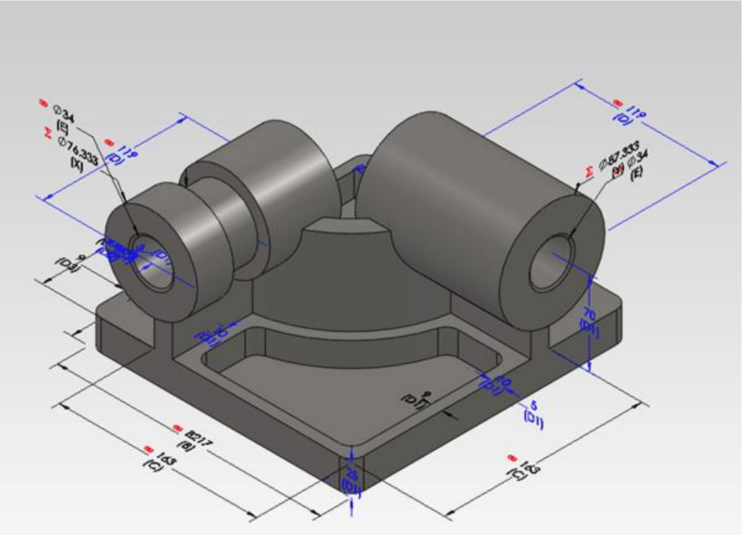


Figure 2.5.A Sample Part of CAD Software

Combining several parts into a single assembly file allows the author to add motion constraints and other relationships to simulate an assembly’s motion and functionality. These assemblies can be used to create a visual demonstration of how a part will work without having to print or machine it.

Both PTC Creo and SolidWorks are excellent tools for CAD, they are the two leading software in this particular area, they both have very compelling and useful features ideal for use in this project, which of the two options will be used shall depend on the features that are most important for the project. Features to be considered in the decisions are: Parametric Feature Solid Modeling, 3D Direct Modeling, 2D Orthographic Views, Finite Element Analysis and Simulation, Schematic Design, Technical Illustrations, and Viewing Visualization.

3. Methodology

The team will follow the DMAIC methodology of solving and implementing a solution for Pacific Can per visit. The DMAIC process is used in Six Sigma applications as it exposes the five phases of implementing a solution. It stands for: Define, Measure, Analyze, Improve, and Control. The DMAIC process helps to elaborate the framework of approaching and implementing a solution. It will help us to redefine the purposes of our project each visit based on feedback and suggestions we receive from Pacific Can engineers. Additionally, each visit will contain the progress of each subgroup of the project (mechanical, detection, and alarm).

Our timeline for the project is as follows in Figure 3.A Prior to completing our PQP paper in our preparation to leave, we created a timeline to provide ourselves with reachable goals throughout the trip. The timeline follows a week by week focus, with a main landmark goal for each week.

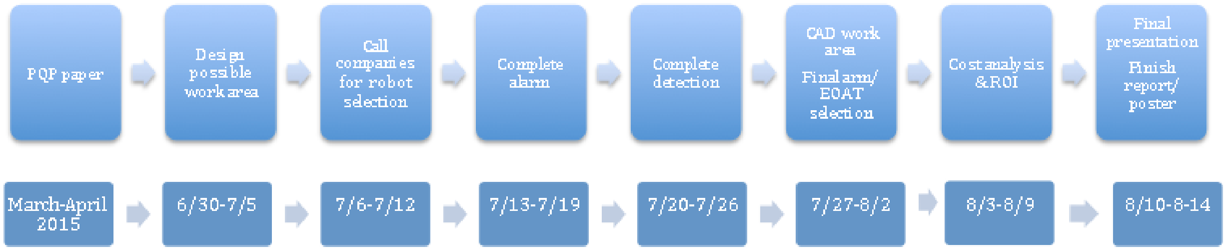


Figure 3.A Timeline of main focus during this project

Our first week, we designed possible work area layouts that would correctly fit with proper measurements. The work areas involved fitting in a conveyor belt, robotic arm, and wooden pallets. Week two we began contacting companies and researching robotic arm companies that had provided robotic arms for situations akin to this. This involved abundant email/phone communication translated into English, as well as providing companies with qualifications we had and information about our situation. Weeks three and four were due dates for completing our detection and alarm simulations for the new process. Finally, our last three weeks were for our final selections of the robotic arm and EOAT, our CAD work area design of the new work area, a cost analysis/ROI for the purchase of the arm, and finalizing the report, presentation, and poster.

Throughout the project we also promised some deliverables that were included in the timeline. These final deliverables also changed overtime, but in a more general sense were as follows:

- Alarm function simulations
- OpenCV block detection success
- Robotic arm example simulation of its function
- New designed work area, proportionally correct, designed in CREO/SolidWorks
- Detailed and in depth selection of a robotic arm and end of arm tool
- Calculations for cost analysis/ROI and why the arm is beneficial

These deliverables helped us complete our timeline and follow a structured idea of where we wanted to take the project throughout the trip. Assigning a main deliverable for each of the seven weeks assured the group to reach a final goal that both the company and the group sought.

First Visit 06/29/2015

During the first week of the project, the group made a first visit to Pacific Can facility. The visit was very important for the group to obtain a closer look to the problem. As the team got the opportunity to see the flow of the metal scrap block for each of the two chutes. In addition, the team recognized the necessity for Pacific Can to change or improve the current process. Also, the team was able to discuss some question with the engineers from Pacific Can in order to define the objectives for completing the task.

3.1.1 Define

Pacific Can Company Limited is one the largest can-making corporations in China. It is a company that focuses on both the production rate and the quality of the products. Thus, the factory in Beijing produces a large amount of metal waste down the assembly line, which mostly includes unqualified cans. These metal scrap cans be recycled and reused if organized properly.

There are two types of unqualified aluminum can scrap. One is for the unpainted can scraps, and the other one is for the painted can scraps. The value of the two types differs economically. Now there are two machines in the company that can compress unqualified cans into rectangular cuboid according to colors, which then creates a cuboid of unpainted metal waste or painted metal. However, the current method of organizing and sorting these cubic metal scrap blocks in the Pacific Can Beijing facility, and other facilities is manpower. The workers are required to do two jobs; one is to sort these blocks into two piles and the other job is to stack these two piles onto separate pallets. The mass of these blocks can count up to 5 tons per day, and this amount of work per day can easily exhaust workers. Thus, the value of money is wasted on the matter of using human resource.

Currently, the facility is considering replacing the two workers who are assigned to complete this task with a robotic mechanical arm. The robot should be able to complete certain tasks such as moving, sorting, and stacking the blocks of aluminum scraps. It should be able to complete the tasks of separating the two types of metal scrap based on their color. Every day, approximately half a ton of aluminum can scrap are produced from the assembly line of the Beijing facility. It requires a large effort from the four workers to do this job alone, they must take many breaks because they are easily exhausted. The facility believes the robot would benefit the process greatly. Pacific Can also strongly believes in contributing to the environment. Therefore, the ability to achieve the conversion of this difficult task that required human labor forces them to complete an automated process that would contribute vastly to development of the aluminum recycling process.

Requirements to Achieve:

There are multiple requirements that the mechanical robotic arm should be able to complete. Some requirements, or tasks, are technical, and other requirements are needs and assignments that the mechanical arm needs to complete. To attain a better understanding of the two types of requirement, they are listed.

Technical Requirements:

- Ability to sort, moves, and stacks the metal scrap.
- Ability to carry blocks weighing between 20 – 28 Kg.
- Ability to carry blocks that have rough surface.
- Ability to carry and stack blocks that have different dimensions.

- Ability to sense the formation of the metal scrap block.
- Ability to identify the two types of scraps.

Non-Technical Requirements:

- Ability to work independently.
- Ability to replace the human labor 100%.
- Ability to work faster than human labor.
- Ability to achieve accurate work.
- Ability to achieve efficiency by introducing the robot.
- Ability for the robot to consume low energy.
- Ability for the robot to operate 24/7.

3.1.2 Measure

Since there are two exit holes where the blocks would come out, it is advised to design a mechanical arm with at least four degrees of freedom, which means the arm has the ability to move up, down, forward, back, left, and right. So the arm can maneuver freely to do whatever is programmed.

The size of the blocks is uncertain according to how much metal waste was inserted into the machine that would compress it, so a visual detection device is also needed to identify the size of blocks and confirm how much force is needed to lift up the block.

Considering the blocks need to be stacked up to a certain height, an arm with actual gripper for its hand is not be recommended because it would cause uncertainty in control and more difficulties in stacking. So the *End of Arm Tooling* (EOAT) has to be chosen carefully. A vacuum gripper is normally advised for mechanical arms for stacking. But since the blocks are made up of compressed cans, the surface is undoubtedly rough and sharp and, therefore, not able to create enough force to lift up the blocks. Other kinds of EOAT include flip type grippers and fork type grippers.

The second task is difficult because the mechanical arm has to be programmed to identify different sizes of the blocks and stack it to form a large square of stacked blocks that will fit on a 45-inch by 55-inch pallet, which makes it easier to move around. These pallets when full will be around 1100kg in weight and contain around 60 blocks. This requires the machine to be able to do some simple calculating about how the blocks should stack and also precise placement. Additionally, the company needs the arm to be able to alarm the workers to move the blocks away, using a forklift on the pallet, when it reached a certain mass, so as to further recycle it. Since the company only plans to provide us with one mechanical arm but there are two exit holes (2 machines) where the blocks would come out. It is also required to set up an alarm system for when the blocks would come out; in order to determine which side it should pick up the block from.

Working along with our partners at BUCT, some information was obtained such as the measurement of the metal scrap designated area, (Figure 3.1.2.A).

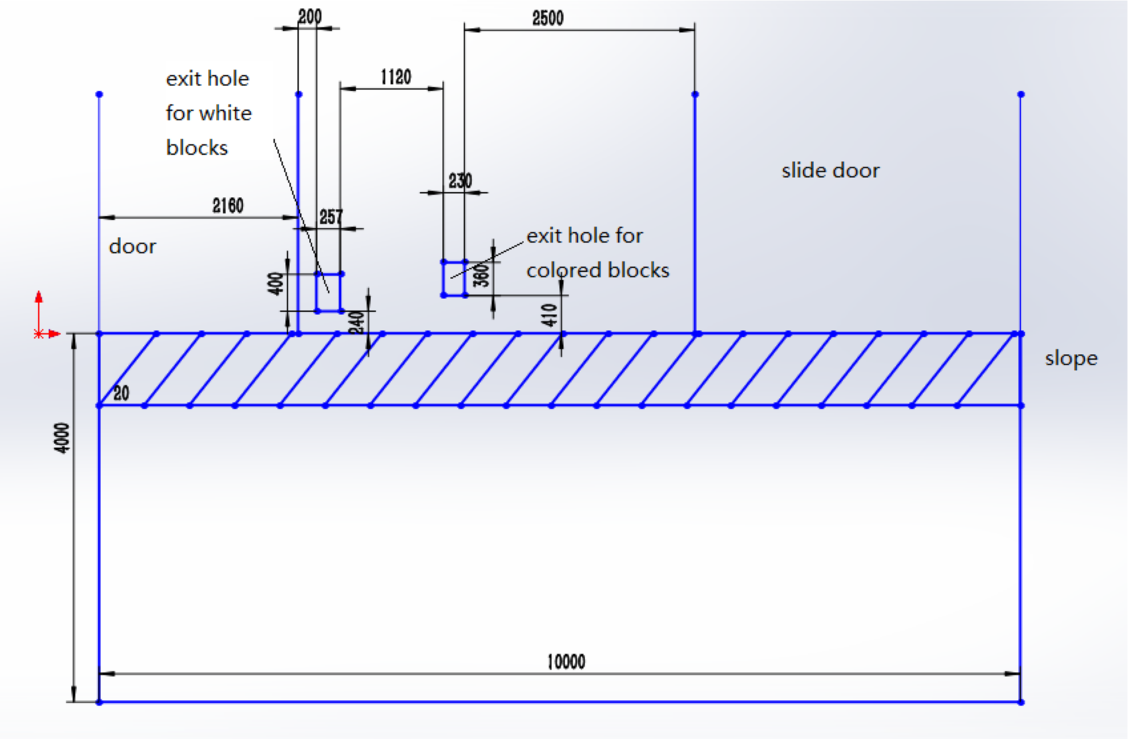


Figure 3.1.2.A Metal Scrap Designated Area

3.1.3 Analyze

After visiting the sight at Pacific Can during the first day of our project we noticed the designated area for the metal scraps was an open, outdoor area. The assigned manager of our project, Mr. Tian, told the team that an enhancement could be made to the open area so that a ceiling or room could be built. The reason for building the ceiling or room would be for the robot to work easily and to avoid environmental damage from wind and rain. As the robotic arm operates on electricity, it would not be useful without a power source as well; thus, it is an efficient to have it work inside.

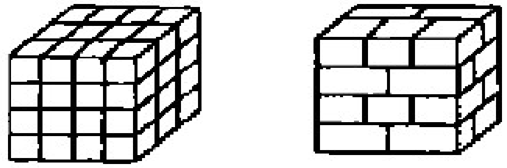
It was also noticed during this visit that the ground after the chutes was on an angle. Pacific can was sure to let us know, if necessary, the ground could be flattened. This outside area is also home to the fire lane of the company building. This means that no immovable objects may be situated in the fire lane. It also required there to be two large evacuation doors. This severely limited our usable space, as the chutes are right between the evacuation doors and further limited on the other side by the fire lane.

Pacific Can hopes to address this issue in a way where the problem can be solved permanently. Nowadays, companies are moving toward an efficient use of upgrading all their processes so that benefits and profits can be gained. Each investment must be considered a positive investment for Pacific Can to oblige. Therefore, seeking a simple and efficient solution is necessary.

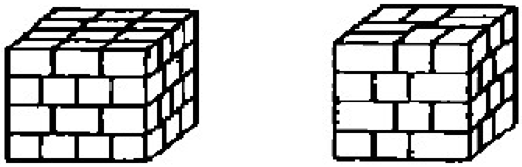
The visit gave the group vast information to help understand the problem more clearly. During the visit, pictures were taken in order to obtain a better idea of how everything functioned.

In Figure 3.1.3.A, you can see a better idea about how the blocks are sorted onto pallets. Also, it is noticeable how dense each of the scrap metal blocks is. During the sorting procedure it is important to identify the differences between blocks, as the proposed robot will be programmed to accomplish the necessary types of sorting depending on the block type. The palletizing robot group at BUCT has proposed three types of sorting method that the robot might follow (See figure 3.1.3.B).

Figure 3.1.3.A Current Stacking Style



（a）重叠式　（b）正反交错式



（c）纵横交错式　（d）旋转交错式

图 1　货物码放样式

Figure 1　Stacking style of goods

Figure 3.1.3.B Types of Stacking Style

Figure 3.1.3.C Current Method of Stacking

Figure 3.1.3.D Current Method used for Stacking the Metal scrap and Sorting them.

Figures 3.1.3.C and 3.1.3.D illustrate the current methods of sorting and stacking the metal scrap blocks.

To further complicate the issue, we noticed that the two chutes do not only produce one type of block. Sometimes a chute is used for unpainted metal scrap blocks, and sometimes it alternates. Additionally, the engineers were sure to inform us that at times one of the chutes can be shut down and all the blocks will be produced from the other chute. This was important information to know. This meant that the group could no longer assume a standardized size or type of block to come out of a certain chute meaning the robotic arm will need a substantial amount of versatility. A hybrid design was thought of to possibility combat this issue. By adding the blocks to a connecting conveyor belt, and putting them all in one space, the robot could focus on one block at a time and be able to adapt to its type and shape.

3.1.4 Improve

An essential idea of designing the room will be by building a hybrid system that consist of the conveyor belt to have the metal scraps come from, and a stand for the robot to function, as well as proper positioning for pallets. The reason for building the conveyor belt is to have the blocks smoothly come to one place after exiting one of the two chutes, thus, giving the robot the chance of distinguishing and sorting them up easily. This is also a necessary surface needed for the robotic arm’s EOAT to be able to interact with the blocks. Conveyor belts with slits or a giving surface make it much easier for the arm to interact with blocks, depending on the type of EOAT. (See Figure 3.1.4.A) The figure, actually a video simulation, shows the robot operating with the final EOAT design. In contrast, a critical concern arose about whether the robotic arm should be built on the floor or possibly a wall or ceiling due to the limited space Pacific Can has for the robot to be built.

Figure 3.1.4.A Conveyor belt, and the robot.

3.1.5 Control

A main concern the team has is the feasibility of the whole project. During the next week, a visit will be made to Pacific Can factory in order to collect more data such as the measurement of the entire work area in order to further plan the actual possibility of the project. There will be a presentation given by our partner students at BUCT in order for the management of Pacific Can to comment and provide their concerns. The layout of the design plan is not finalized yet; however, after the meeting with Pacific Can management; especially, Mr. Tian, the technical engineer, their comments would be considered in order for the group to meet the requirement of the company. The company's main goal is to obtain a proposal that will convince the management department that the plan is worthwhile for the company to pursue. The company wants to achieve an effective and efficient operation, while also being more cost effective than their current method.

3.1.6 Team Progress

Prior to the first visit, the group still managed to progress considerably. We were able to met with our Chinese counterparts and understand their projects. Once we were able to learn their project goals and deliverables we had better knowledge of the whole situation. After discovering Pacific Can’s desires as well, we merged our four teams into one that would attempt to complete the project to Pacific Can’s satisfaction. The subgroup descriptions this week involve what the BUCT students were working on when our groups merged.

3.1.6.1 Mechanical

The mechanical team focused on a technology called Servo, which is a programming software used to communicate with a robotic arm. With it they were able to create an algorithm command for how the robotic arm would operate to move to and from different blocks based on which type of block it detected. Figure 3.1.6.1.A shows the command in Servo and Figure 3.1.6.1.B demonstrates how the command functions. The yellow line is the command and the purple line represents the robotic arm’s ability to follow the command. In this case, it is functioning quite well.

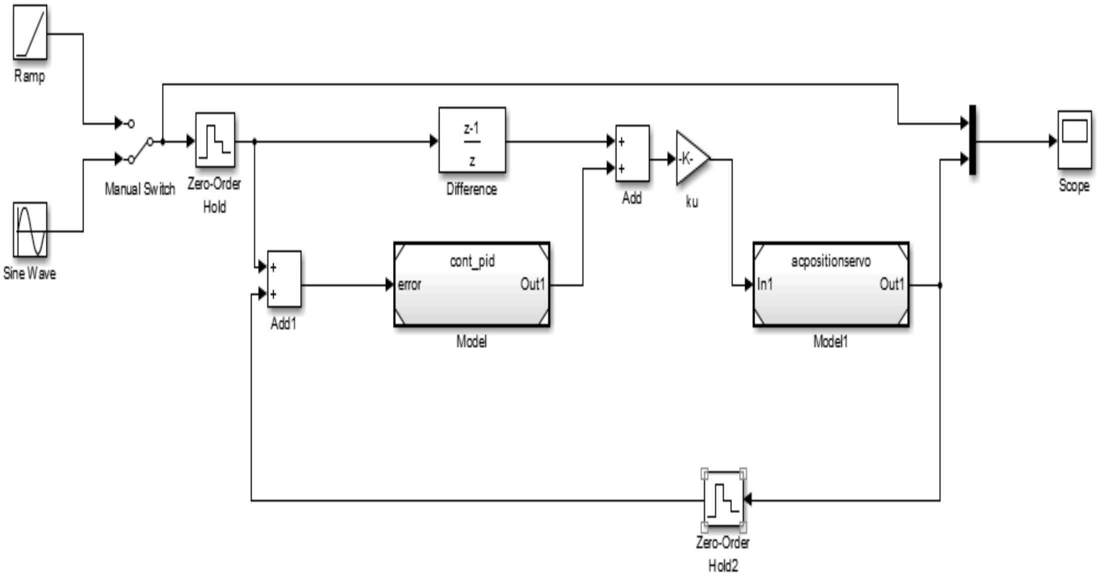


Figure 3.1.6.1.A command in Servo

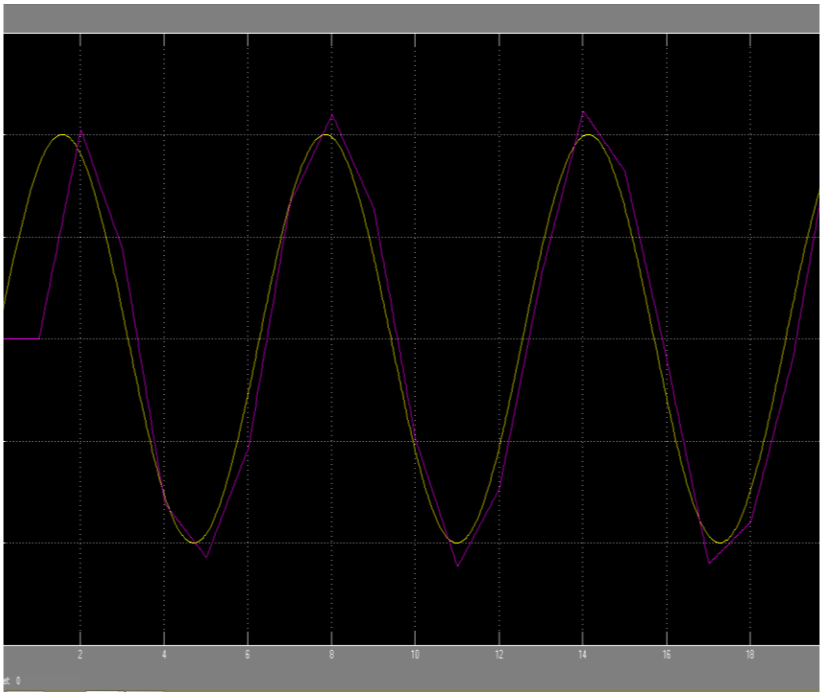


Figure 3.1.6.1.B Servo command function

3.1.6.2 Detection

The detection subgroup, explained to us OpenCV and how it functions. The recognition runs on OpenCV software, which can be run on a PC. It can use multiple pre-defined functions and algorithms that will be matched directly to recognition. Also, it has the ability to differentiate the blocks by color. Besides that, it is synced to a camera in order to complete the detection task by signaling the robot. In the diagram below, it shows a schematic map for the detection software. The camera first takes a picture, which is then sent to the OpenCV software. The OpenCV make the analysis of the picture in order to determine the colors of the metal scrap blocks. Then, the results are sent in a signal to the control software which analyzes the results, after, the robot would sort the block accordingly, depending on its type (See Figure 3.1.6.2).

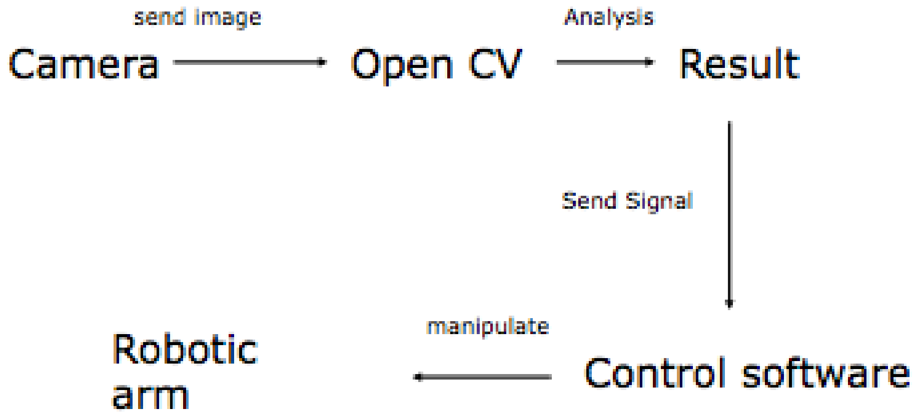


Figure 3.1.6.2.A Schematic map of OpenCV software

3.1.6.3 Alarm

The alarm team worked on their microchip. They used the microchip to simulate the alarm features that a robotic arm would possess. After our first visit, the first thing they simulated was a voltage alarm. The microchip would set off an alarm should the voltage in the chip become too high or too low. A live demonstration of the success was provided. The alarm would be useful in situations where the robotic arm would malfunction and emit a very high voltage. This could happen while performing a task where the robotic arm might try and pick up something too heavy. This will not happen because the robotic arm purchased would sense that voltage peak or valley and immediately shut down the robot's action.

Second Visit 07/07/2015

The team scheduled to have another visit to the facility in which updates can be shared with the technical engineer Mr. Tian. This visit was crucial to the team as more requirements was assigned from Mr. Tian in order for the team to achieve. The team took more measurements for the designated area in which a prober design can be made.

3.2.1 Define

During our second visit to Pacific Can, Mr. Tian informed the four subgroups to work more closely together. Mr. Tian has noticed a gap between the subgroups especially when each of them has worked separately from one another. In order for the problem to be solved and achieved efficiently, each of the subgroups has to manage to perform well at each different basis of this project.

After interviewing Mr. Tian about his main concerns and wants for the project so far we were provided with very helpful guidelines. An important criterion that Pacific Can is seeking is the ability of using the robotic arm for other purposes. It is very essential for the company to be able to satisfy different processes among its factories. Mr. Tian stated important points that the company wishes the robotic arm to satisfy:

- Ability to detect Block *shape* and *size*.
- Ability to stack *uneven* Blocks.
- Ability to alarm for *full pallet*.
- Ability to assure *Human Safety*.
- Ability to detect *over heating* and *fire*.
- All requirements shall be integrated in *one software*.

Mr. Tian informed the group that the working area is used for other matters as it is used for emergency exit. As the area is located at the far end of the factory, it is important to assure the feasibility of the area design. Also, it is critical to identify the general aspects of the robot, such as it height, width, and depth. This is important in order to make sure the space provided is able to house a robot and a conveyor belt.

3.2.2 Measure

During the second visit, the group managed to obtain multiple data and measurements in order to achieve effective planning for placing the robot and the conveyor belt.

- Distance between Chutes:
    - In: 44 Inch.
    - Out: 67 Inch.
- Wall
    - Height: 157 Inch.
    - Width to Gate: 78 Inch.
    - Thickness: 17 Inch.
    - Width: 205 Inch.
- Pallet
    - Height: 45 Inch.
    - Width: 45 Inch.
    - Thickness: 3.5 Inch.
- Distance to fire lane: 155 Inch.
- Left Chute:
    - Height: 16 Inch.
    - Width: 14 Inch.
    - Placed from floor: 9 Inch.
- Right Chute:
    - Height: 14.5 Inch
    - Width: 9 Inch.
    - Placed from floor: 13 Inch.

3.2.3 Analyze

After visiting the sight and receiving the recommendations and suggestions from Mr. Tian, the plan has been changed slightly. Pacific Can management is trying to obtain a deep analytic review in which changes can be made to the process.

After the meeting, the group has stated new goals and made new future plans. The goals are listed below:

- Room and Robotic arm positioning blueprint.
- Alarm simulation. (Done by the Alarm detection subgroup)
- Detection simulation.
- Robotic arm, and Room total *solidworks* demo.
- Robotic arm evaluation, recommendation, and full long-term cost analysis with ROI (Return of Investment)

The room size that the group working on is 20.5 m^2; the dimensions are 5.2 m and 3.9 m. The wall that has the two exit chutes can be destroyed if needed.

The stacking metal scrap dimensions are 4 x 5 x 3 block stacked on 45 in x 55 in pallet. Therefore, the pallet can take only 60 blocks; and it weighs 1158 kg.

The metal scrap is inconsistent; therefore, it is important for the robot to identify the shape of the scrap in which it can be sorted neatly.

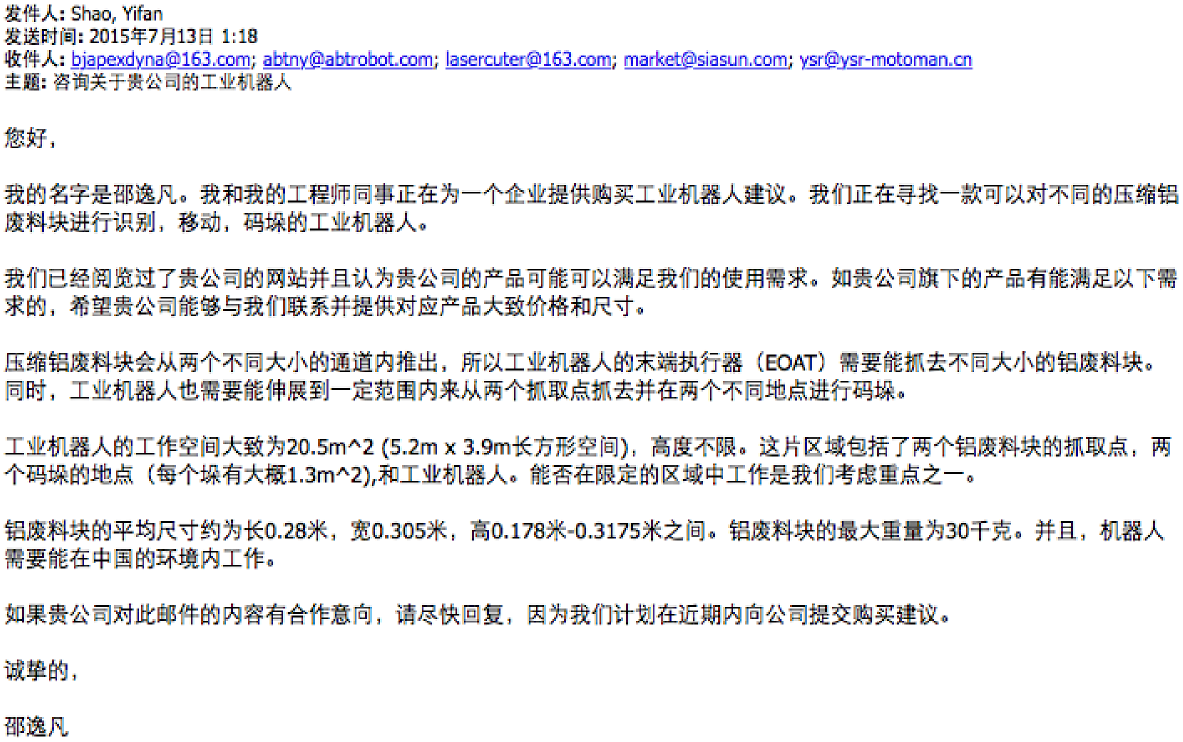
3.2.4 Improve

The team has started contacting several robotic companies in order to obtain multiple robot options. The choosing criteria will be based on the needs of the company as it is defined in *Define* part. The team provided companies with the information about the problem statement as well as measurements of the blocks and work area. Additionally, we stated to companies what functions the robot would need to perform such as moving and stacking with a specific payload as well as being able to have the ability to distinguish blocks.

The companies that the team started contacting during this week are:

- Universal Robots
- Yasakawa Shougang Robot Co.
- Yasakawa
- KUKA
- Denso
- Apex Dynamics Beijing, Ltd.
- Cubebot Technology Ltd.
- Shenyang Siasun Robot & Automation Co., Ltd.
- Hefei Obote Automation Equipment Co., Ltd.
- ABB

In the below figure is a screenshot of the base email we sent to multiple companies, concerning the constraints and needs. As the companies are Chinese companies; the contacting happened in Chinese language (See Figure 3.2.4.A).



发件人: Shao, Yifan
发送时间: 2015年7月13日 1:18
收件人: bjapexdyna@163.com; abtny@abtrobot.com; lasercuter@163.com; market@siasun.com; ysr@ysr-motoman.cn
主题: 咨询关于贵公司的工业机器人

您好，

我的名字是邵逸凡。我和我的工程师同事正在为一个企业提供购买工业机器人建议。我们正在寻找一款可以对不同的压缩铝废料块进行识别，移动，码垛的工业机器人。

我们已经阅览过了贵公司的网站并且认为贵公司的产品可能可以满足我们的使用需求。如贵公司旗下的产品有能满足以下需求的，希望贵公司能够与我们联系并提供对应产品大致价格和尺寸。

压缩铝废料块会从两个不同大小的通道内推出，所以工业机器人的末端执行器（EOAT）需要能抓去不同大小的铝废料块。同时，工业机器人也需要能伸展到一定范围内来从两个抓取点抓去并在两个不同地点进行码垛。

工业机器人的工作空间大致为20.5m^2 (5.2m x 3.9m长方形空间)，高度不限。这片区域包括了两个铝废料块的抓取点，两个码垛的地点（每个垛有大概1.3m^2),和工业机器人。能否在限定的区域中工作是我们考虑重点之一。

铝废料块的平均尺寸约为长0.28米，宽0.305米，高0.178米-0.3175米之间。铝废料块的最大重量为30千克。并且，机器人需要能在中国的环境内工作。

如果贵公司对此邮件的内容有合作意向，请尽快回复，因为我们计划在近期内向公司提交购买建议。

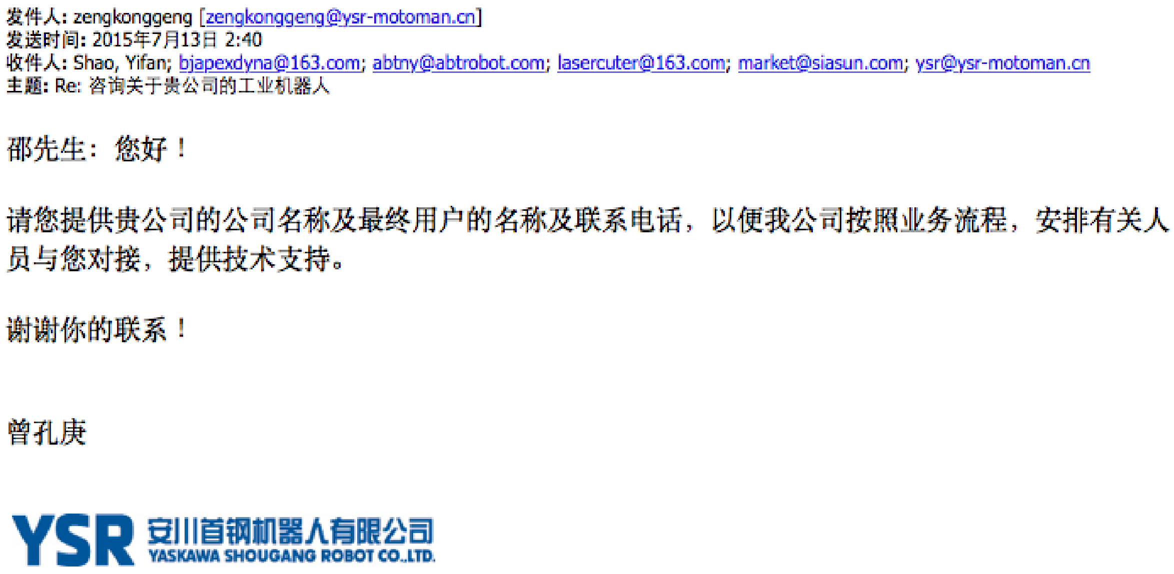
诚挚的，

邵逸凡

Figure 3.2.4.A Communication Email with the Robotic Companies

Universal Robots responded to our email. However, as the company is specialized in small-scale robots; they expressed that they cannot fit our requirements of lifting a metal scrap. Their max payload of lifting robots is 10 KG.

Yawakawa Shougang Robot Co. also responded to our offer. The company gave the confirmation of the ability in making or assembling a robot that will fit Pacific Can requirements. Farther discussion will be made in the following days. In the figure below is YSR answering our email offer (See Figure 3.2.4.B).



发件人: zengkonggeng [zengkonggeng@ysr-motoman.cn]
发送时间: 2015年7月13日 2:40
收件人: Shao, Yifan; bjapexdyna@163.com; abtny@abtrobot.com; lasercuter@163.com; market@siasun.com; ysr@ysr-motoman.cn
主题: Re: 咨询关于贵公司的工业机器人

邵先生：您好！

请您提供贵公司的公司名称及最终用户的名称及联系电话，以便我公司按照业务流程，安排有关人员与您对接，提供技术支持。

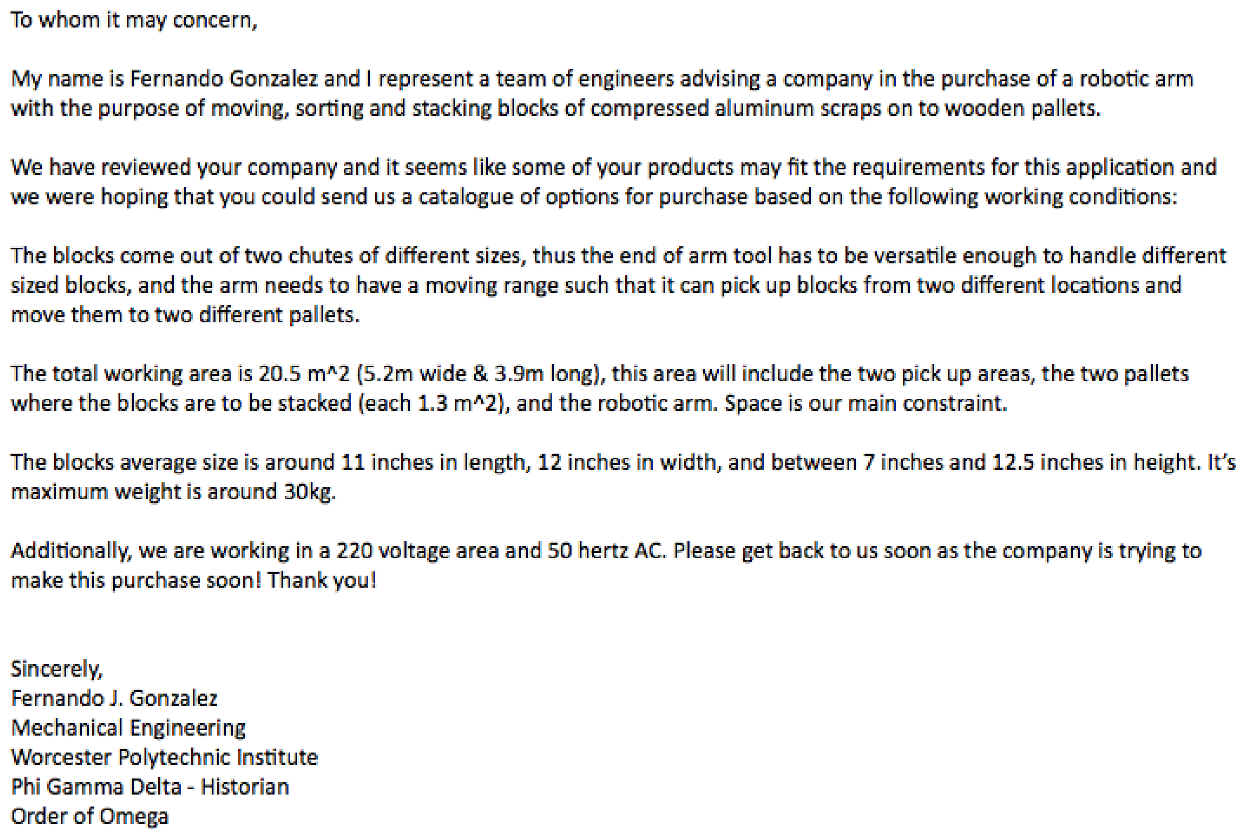
谢谢你的联系！

曾孔庚

YSR 安川首钢机器人有限公司
YASKAWA SHOUGANG ROBOT CO.,LTD.

Figure 3.2.4.B Replay Email from Yaskawa Shougang Robot Co. LTD.

The third company is contacted is KUKA Industrial Robots. In the figure below it shows our team member Fernando Gonzales making official contact with the company (See Figure 3.2.4.C). This email represents the requirements and constraints we provided to many companies so they could fully understand the situation from our eyes. We also provided them with pictures of the work area and spacing.



To whom it may concern,

My name is Fernando Gonzalez and I represent a team of engineers advising a company in the purchase of a robotic arm with the purpose of moving, sorting and stacking blocks of compressed aluminum scraps on to wooden pallets.

We have reviewed your company and it seems like some of your products may fit the requirements for this application and we were hoping that you could send us a catalogue of options for purchase based on the following working conditions:

The blocks come out of two chutes of different sizes, thus the end of arm tool has to be versatile enough to handle different sized blocks, and the arm needs to have a moving range such that it can pick up blocks from two different locations and move them to two different pallets.

The total working area is 20.5 m^2 (5.2m wide & 3.9m long), this area will include the two pick up areas, the two pallets where the blocks are to be stacked (each 1.3 m^2), and the robotic arm. Space is our main constraint.

The blocks average size is around 11 inches in length, 12 inches in width, and between 7 inches and 12.5 inches in height. It's maximum weight is around 30kg.

Additionally, we are working in a 220 voltage area and 50 hertz AC. Please get back to us soon as the company is trying to make this purchase soon! Thank you!

Sincerely,
Fernando J. Gonzalez
Mechanical Engineering
Worcester Polytechnic Institute
Phi Gamma Delta - Historian
Order of Omega

Figure 3.2.4.C Communication Email with KUKA company

KUKA's contact information:

info@kuka-robotics.cn

Denso Sales Phone number:

+86-21-2350-0108 or +86-21-2350-0179

The team approached these ten robotics company during the second and third week, however, none of the companies responded or replied with satisfying answers. In the next stage, the team had to try a different way of approaching to the companies. Using different way of approaching, the team got in contact with the sales contacts from KUKA and ABB.

3.2.5 Control

The team will be obtaining some results for the asked requirements in the future. Also, updates for the alarm system and for the detection system are coming soon.

The next step to control and achieve an effective solution for the problem statement will be presenting the updates to the company’s management. During next week there will be another visit to the facility. For this visit, the team members will be able to meet the CEO of Pacific Can China Limited, Mr. Glenn Yee.

3.2.6 Team Progress

By this point in the project the team had a much better understanding of our goals and requirements as well as that of our BUCT partners. After our second visit to Pacific Can we were able to make significant improvement on the alarm and detection systems. Additionally, we were able to make solid contact with companies including KUKA who gave us their first robotic arm recommendations.

3.2.6.1 Mechanical

After the team met in order to discuss the best option for the robots to be purchased along with whether or not it would fit Pacific Can criteria. KUKA's robots provided proved to be very possible to fit our problem statement.

KUKA has three types of robots that can be installed in our working area where it will accomplish the full requirements the company is seeking. The three types of robot are:

KR 40 PA → is a palletizing stacking robots (See Figure 3.2.6.1.A).

The team believes this type will fit our requirement the most, as it is made for the stacking boxes and any of the kind shape. In the below figure it shows the robot design.

Figure 3.2.6.1.A KA 40 PA Robot

KR 30-3 → is a moving robot with great versatility. In the below figure it shows the robot's design (See Figure 3.2.6.1.B).

Figure 3.2.6.1.B KA 30-3 Robot

KR 30-3 CR → is a flexible robot that combines some of the first two robots features.

KR 30-3 CR also can fit the requirements that Pacific Can seeks. In the figure below it shows the design of the robot (See Figure 3.2.6.1.C).

Figure 3.2.6.1.C KR 30-3 CR Robot

3.2.6.2 Detection

After educating ourselves on how OpenCV functions and is operated, we began to experiment. The first step was to explore OpenCV's different color extracting and contouring possibilities. We originally used other photos to explore this relationship.

In Figure 3.2.6.2.A you can see how the green or base color of the photo is blacked out and OpenCV has only extracted colors that are not green which is how the block distinguishing will be done in a similar fashion.

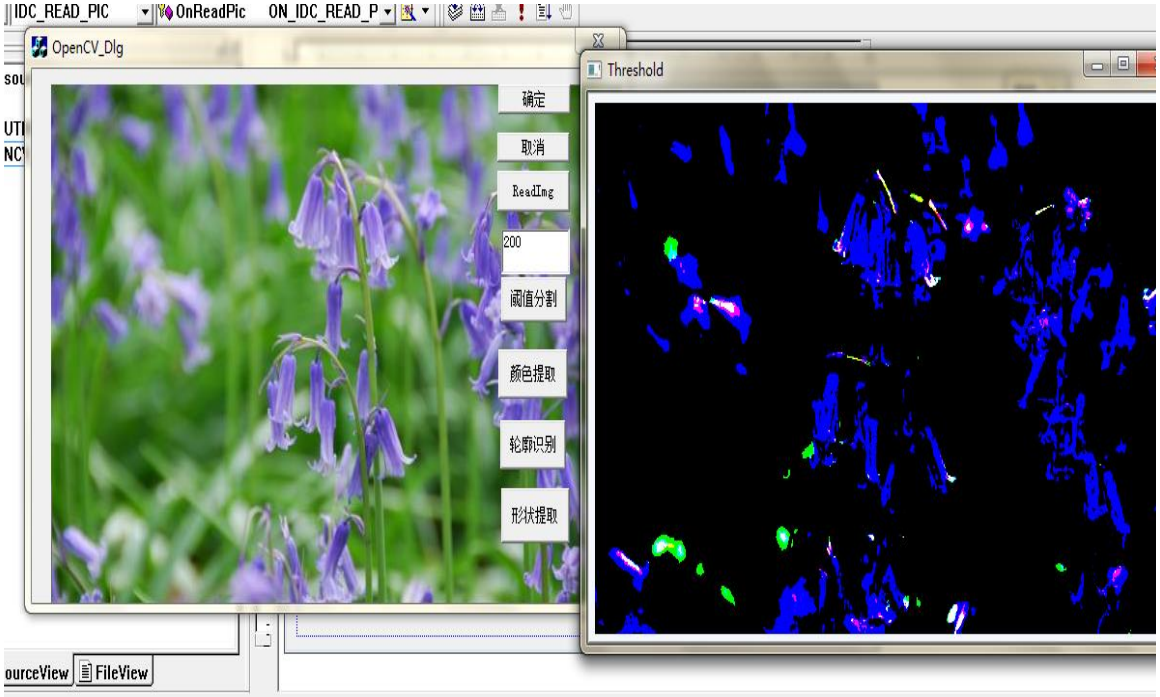


Figure 3.2.6.2.A OpenCV color detection analysis

Additionally, in Figure 3.2.6.2.B a different but also extremely useful technique is shown. The graph represents the color in the photo at different points. So the spikes in the graph represent high color in certain areas of the photo based on the color constraints given to OpenCV to look for.

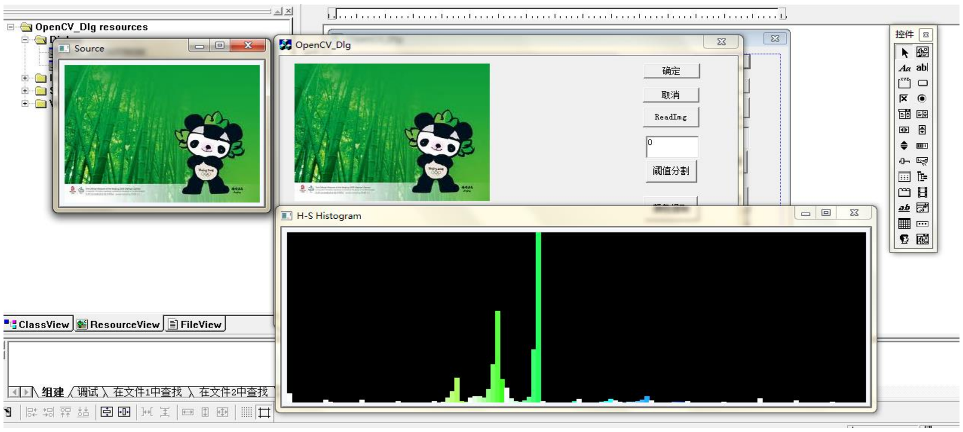


Figure 3.2.6.2.B OpenCV detection graph

3.2.6.3 Alarm

After this visit, the alarm subgroup focused on simulating an overheating alarm. This involved using a microchip to detect heat. When too much heat was detected the alarm would go off. This was simulated live by using a handheld lighter to burn underneath the chip. The chip would then immediately begin sounding the alarm. In a real situation with a robotic arm, the robotic arm would once again, shut itself down.

Third Visit 07/21/2015

During the forth week of the project, the group made a third visit to the faculty. In this visit, the group had the chance to meet Mr. Yee, the founder of Pacific Can, and shared the updates with him. This visit was beneficial for the team as Mr. Yee gave precious advice for the group. After this week, the team was able to process to the last steps of this project.

3.3.1 Define

During this week, the team visited the Pacific Can facility for the third time. During this visit we presented our work to the CEO of the company, Mr. Glenn Yee, and his other assistance.

Before we gave our presentation; some of the team members asked him questions about the company's goal for the success of this project. Mr. Yee gave a very detailed answer for his goals for the company in the future and proceedings about China:

- Most of the factory's equipment is old; therefore, enhancement and changes are required to be made.

- Pacific Can wants to transfer into a fully automated facility for most or even all processes.
- The success of this robot will allow it to be implemented to the other facilities as well.
- Achieving higher learning curve for the Pacific Can in order to move into different facilities.
- Can production facilities are considered one of the longest factory processes; thus, it is very hard to change or improve as it is all in one continuous batch process.
- Can making is very long process, from the coil part until the finishing cans. All the processes are related. Achieving precise work is critical. Combining those processes is very hard; thus, learning them is very essential to understanding them as a whole.
- One mistake in any process will result in losing many cans.
- The students can bring new ideas with creative thoughts.
- Students can learn from manufacturing business.
- The can making factories have intensity, noise, and smell. Also, it is has fast speed, precise results, and long process.
- Everything is integrated in the facility, from the start until the process finishes.
- The facility only stops for 8 hours a month!
- The need to have minimal people involved in the process at the facility is important.
- Simplicity, steadiness, and consistency are important factors to obtain.
- Chain’s labor wages are increasing sharply. Thus, moving to automation is essential.
- China is no longer a place with endless labor.
- Being innovative and a first mover will give you a chance to get ahead of other competitors.

Mr. Yee liked what updates the team has approached. Besides that, Mr. Yee was considering obtaining a patent if possible to preserve the right of such a development.

Mr. Yee also informed the group that the most important thing for them to achieve is getting the experience in such mingling with the factory. Moreover, communicating with the management and seeing what they require from the project is essential. In addition, giving a deep, precise, analytical review is considered a necessity for the management where updates can be made or not.

Important deliverables the team has to give are:

- A sketch of the working area
- Robotic Arm positioning blueprint.
- Physical prototype simulation combining detection and alarm system.
- CAD 3D modeling of arm functioning and stacking process including EAOT
- Robotic Arm evaluation and recommendation
- Long-Term cost analysis and Return of Investment (ROI)

The mechanical aspects need to be focused on are:

- Stacking Strategy
- Arm Selection and EOAT
- Work area design and Blueprint.

The detection teams need to be focused on are:

- Methodology of detection.

The alarm team needs to be focused on:

- Fault Alarm
- Overheat Alarm
- Safety Alarm
- Full Pallet Alarm

3.3.2 Measure

During the presentation, one of the managers noticed an error in our measurements. The error was on the *Length Range* of the painted and unpainted blocks. It was mistakenly written down on; therefore, the team went again to have more measures but this time 10 of each of the metal scrap blocks were measure. The measures are in the the below:

Painted: **Unpainted:**

Block #	Length in cm	Width in cm	Height in cm		Block #	Length in cm	Width in cm	Height in cm
1	44.5	31	21.5		1	31	31	30
2	49	32	19		2	30	31	30
3	46	32	19		3	31	31	30
4	46	31.5	19		4	31	30	33

5	47	31.5	18		5	31	31	31
6	40.5	31.5	19.5		6	31	32	31
7	51	31	19		7	30	31	31
8	51.5	31	19.5		8	31.5	31	31
9	41	31	19		9	31.5	31	29
10	32.5	31.5	18.5		10	30	31	32

Figure 3.3.2.A Painted and Unpainted measurements table

From the measurements taken; it can be seen that the unpainted metal scrap blocks have more consistence measurements whereas the painted ones have more variations (See Figure 3.3.2.A). The painted blocks usually come out of the right chute and are of a more rectangular shape, whereas the unpainted blocks usually come from the left chute and are a more cube-like shape.

3.3.3 Analyze

Along with the selection of a robotic arm, it was necessary to develop blueprints for the work area the robotic arm would operate in. The area where the sorting and moving process takes place at Pacific Can is located in an outside courtyard space. Additionally, it is also located next to a fire lane and therefore has evacuation and fire regulations that must be followed. The area requires to large evacuation doors for the factory on either side of the area we are working with and is further defined by the 13.5-foot wide fire lane at the bottom. This provides us with a 17-foot long and 13-foot wide area of usable space to create the arms work area. In Figure 3.3.3.A, we have provided a SolidWorks replication of the work area.

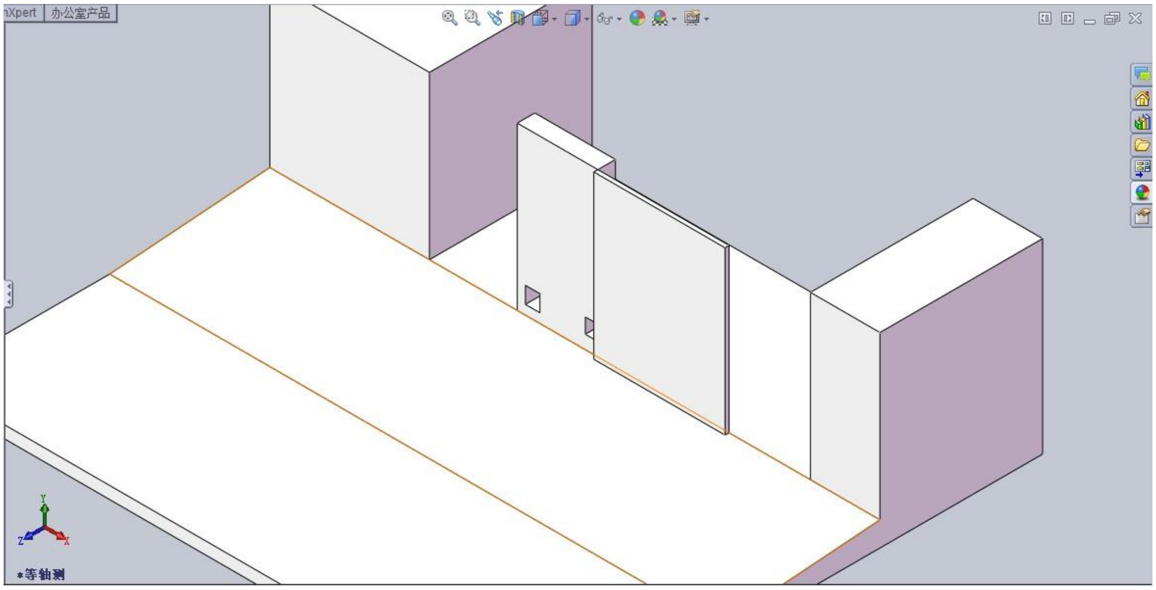


Figure 3.3.3.A Work area design

When considering the work area, we had to consider that the arm must be able to reach blocks from both chutes as well as place them on two different pallets respectively. All the robotic arms we have considered have an arm length of 6.5-feet or longer so this was considered in our decision-making. Also included was being able to create enough space for the base of the robotic arm. The largest base size we came across for robotic arms considered was 3.5 feet by 2.5 feet.

To make the situation easier for the robotic arm to move and stack blocks we decided it would need a conveyor belt extended from the various chutes in order to create a more stable environment to pick up the blocks. The blocks would come out of the chute, onto the conveyor belt and be brought to a flat pick-up area where the robotic arm would process and identify the block as painted or unpainted. Once processed, the robotic arm would sort it accordingly. The conveyor belt also provides the necessary surface for the end of arm tooling of the robot to be able to pick up the blocks. Whether that is a flat surface with a little bit of give or a surface with slits to allow a claw like EOAT to create a basket for the block. Our first design, showed in Figure 3.3.3.B incorporated the conveyor belts.

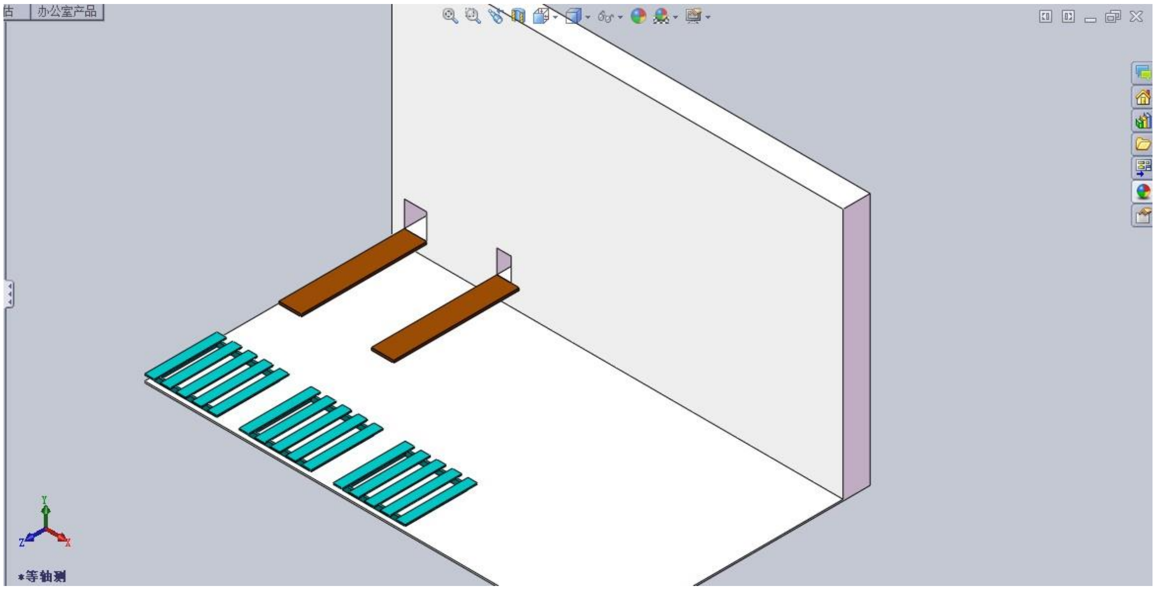


Figure 3.3.3.B first design for possible work area with conveyor belts

This idea, however, needed to be expanded upon. The robotic arm would not be able to fit in between the conveyor belts due to lack of space. If the robotic arm was placed on the other side of the right conveyor belt, it was then out of range of the space needed. In Figure 3.3.3.C we managed to provided a space, between the conveyor belts, of about 4-feet by 4-feet for the base of the robotic arm. We did this by bending the right conveyor belt outward. The space for the robotic arm would be sufficient, however, cramped.

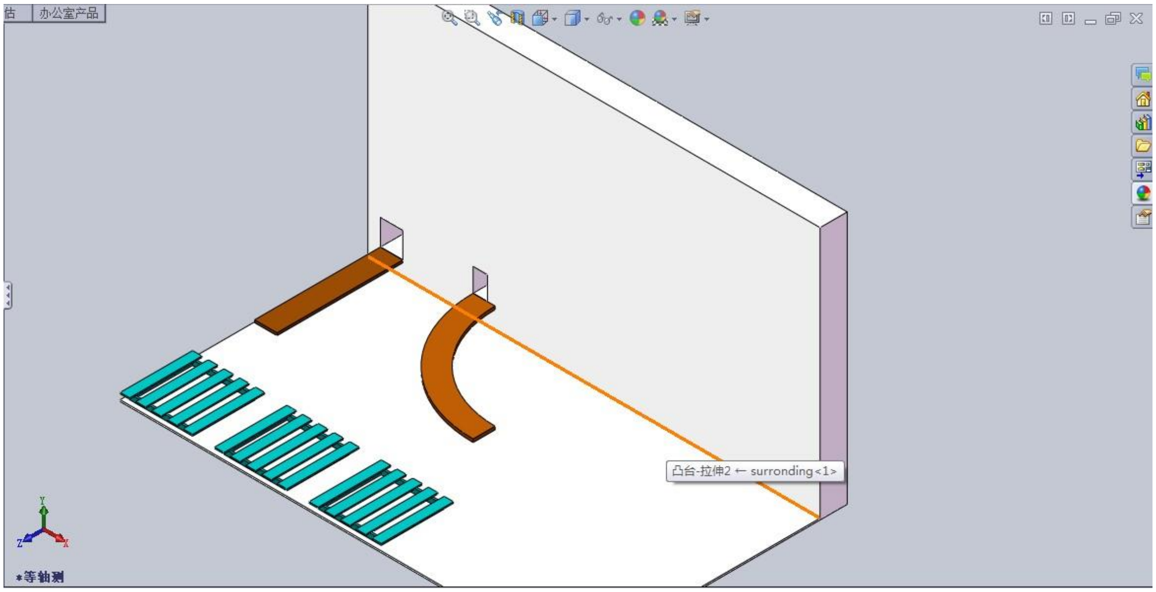


Figure 3.3.3.C Second design for possible work area with conveyor belt

After further thought, efficiency of the robotic arm also had to be considered. The speed of the robotic arm's capabilities as well as its general convenience would be considerably lessened should the robotic arm have to decided and watch two different conveyor belts. This brought us to our final design of the robotic arm and conveyor belt placement. We decided to curve the right conveyor belt into the left conveyor belt at the beginning. This provided more space for the robotic arm as well as a more efficient use of the robotic arms capabilities by allowing all blocks to flow on one conveyor belt. This way the robotic arm only needs to distinguish and watch one conveyor belt. Additionally, it would require less programming and fewer functions for the robotic arm to complete.

This work area is displayed in Figure 3.3.3.D. The robotic arm would be placed just below the turn in the right conveyor belt. The space provided is 5.5-feet wide and infinitely long, providing a much less cramped space as well as a range very reachable within 6.5-feet. In our calculations, we also assumed a conveyor belt size generously larger than the chute. So in reality, there is probably more space than we have assumed, which is a very positive thing.

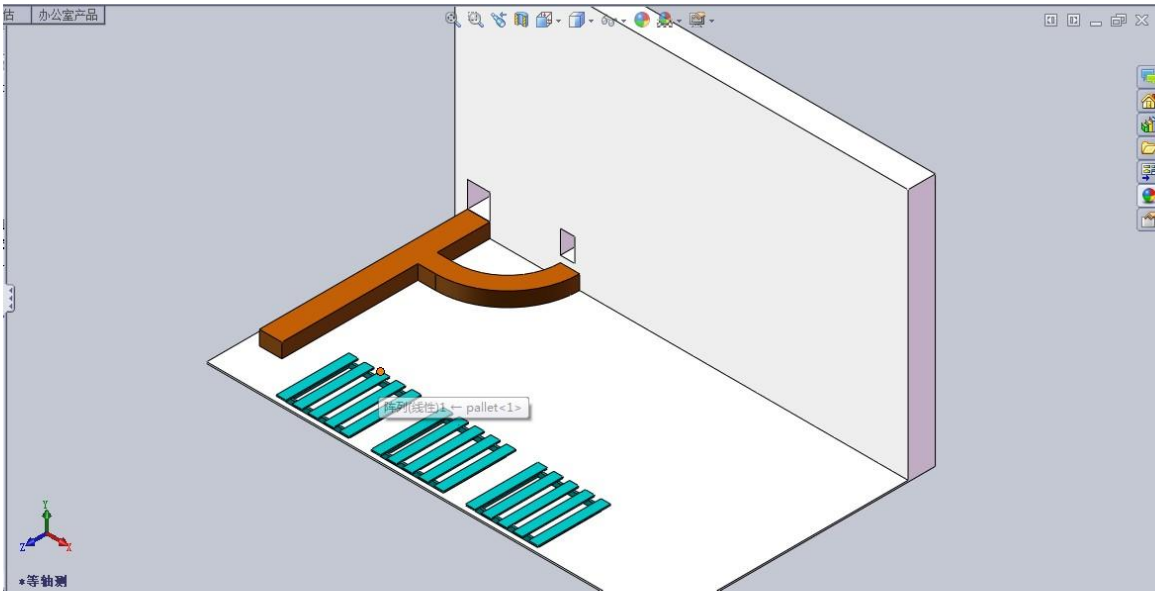


Figure 3.3.3.D third design for possible work area with conveyor belt

The work area inside would now be complete. However, it will probably be necessary to add walls and a roof to this area so that the robotic arm will not rust or take damage from the environment, rain, snow, heat, and etc.

3.3.4 Improve

The team contacted more companies during this week in order to obtain more information. Besides Yaskawa, and KUKA; the other companies contacted are ABB, Denso, Apex, Cubebot, ShenyangSiasun, Hefei, and UniveralRobots. The main requirement was to attain from the connections each of the robot's specifications, purpose, and constraints. The specifications and constraints were things such as price, arm length, size, outdoor assembled, base size, maintenance, user interface, detection ability, payload, and safety ability. Also, what other possibilities the robot had for the end of arm tool.

The next step for the detection team is to increase the accuracy of the analysis. The main goal is to achieve an 80% accuracy or higher. Also, the type of the camera would play a big role in increasing the efficiency. However, the coding part is what the team trying to attain to improve the accuracy.

The alarm subgroup has made improvement to their work. As Mr. Tian informed the team before that some requirements need to be attained. Therefore, the alarm subgroup made some enhancements and changes in order to complete task required for them. The completed tasks are, the overheating of the robot, and the fault malfunctioning of the robot. The other tasks need to be completed are the maximum block weight, full pallet detection, and human protection alarm.

There are three main functions of the alarm. Firstly, if there is a problem or an error with the robotic arm, the buzzed sound will be activated to alarm the workers for an issue. Secondly, if there is another type of problem occurred, the LCD screen on the alarm device would show the type of occurred problem in order for the workers to notice it; beside it will be beeping in order to notifying the workers. Thirdly, if there is a critical problem with the robotic arm, the PLC (Program Logic Controller) would stop the robotic arm from its work; beside it will be beeping for the workers to come in order to find out what the issue it.

3.3.5 Control

The next step for the team is to obtain more information for the robots offers. Currently, the team is in the process of receiving responses from the contacted companies. Once the team obtains options for the robot; further studies will be made such as making a decision model analysis, and a Return of Investment study.

Other requirements that need to be achieved by next week are obtaining a higher accuracy results for the detection task. The subgroup assigned for this job informed the team that the work would be finished and concluded by next week.

Meanwhile, the alarm subgroup needs to make further improvement to their work especially on detecting the human movement around the robot. This is the main requirement for the subgroup to be achieved. The alarm subgroup believes that they will be finished working on the alarm system by the upcoming two weeks.

3.3.6 Team Progress

In these closing weeks, we were able to finalize our selections on the mechanical aspects of the project including the robotic arm as well as end of arm tooling. In addition, the alarm and detection subgroups were also able to finish their final simulations.

3.3.6.1 Mechanical

Aside from finalizing the work area set up, the mechanical team worked on finalizing end of arm tooling from companies. ABB was very helpful in the selection. They narrowed it down to two end of arm tools capable of fitting our needs. Here are their specifications:

Figure 3.3.6.1 FlexGripper Claw

FlexGripper Claw Maximum weight per lift: **50 KG**

Claw Weight: **60 KG**

Figure 3.3.6.2 FlexGripper Clamp

FlexGripper Clamp

Maximum weight per lift: **40 KG**

Clamp Weight: 45 KG

3.3.6.2 Detection

After taking multiple photos of the work area and the different types of blocks, painted and unpainted, (represented in Figures 3.3.6.2.A and 3.3.6.2.B.) we began using the OpenCV on the blocks with the camera we had synce to OpenCV in order to test it more accurately.

白色

Figure 3.3.6.2.A Unpainted Metal Block

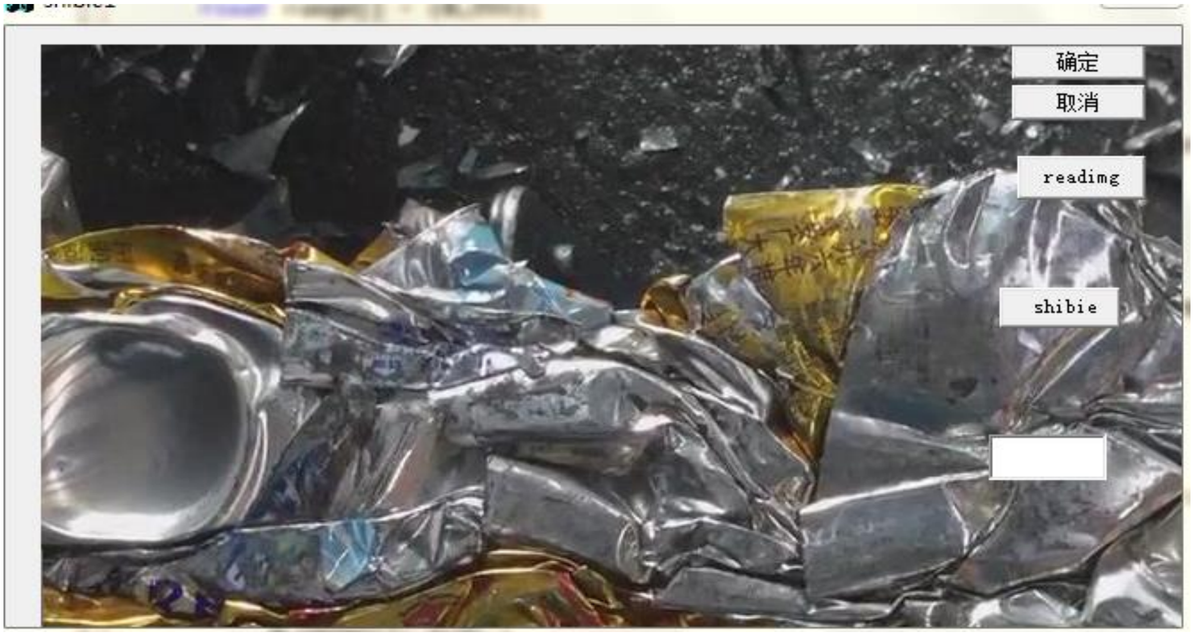


Figure 3.3.6.2.B Painted Metal Block

By making using the similar photo contouring methods we were able to succesfully distinguish good colors from the photos. Setting the whitish gray color as a base color to ignore and any other color as a striation we were able to achieve great success as shown in the graph of Figure 3.3.6.2.C and 3.3.6.2.D. The graph shows many color spikes in the painted block allowing it to create a signal of 1 to send to the controlling software. For a case involving an unpainted block the graph would show no large striations in the graph, sending a signal of 0.

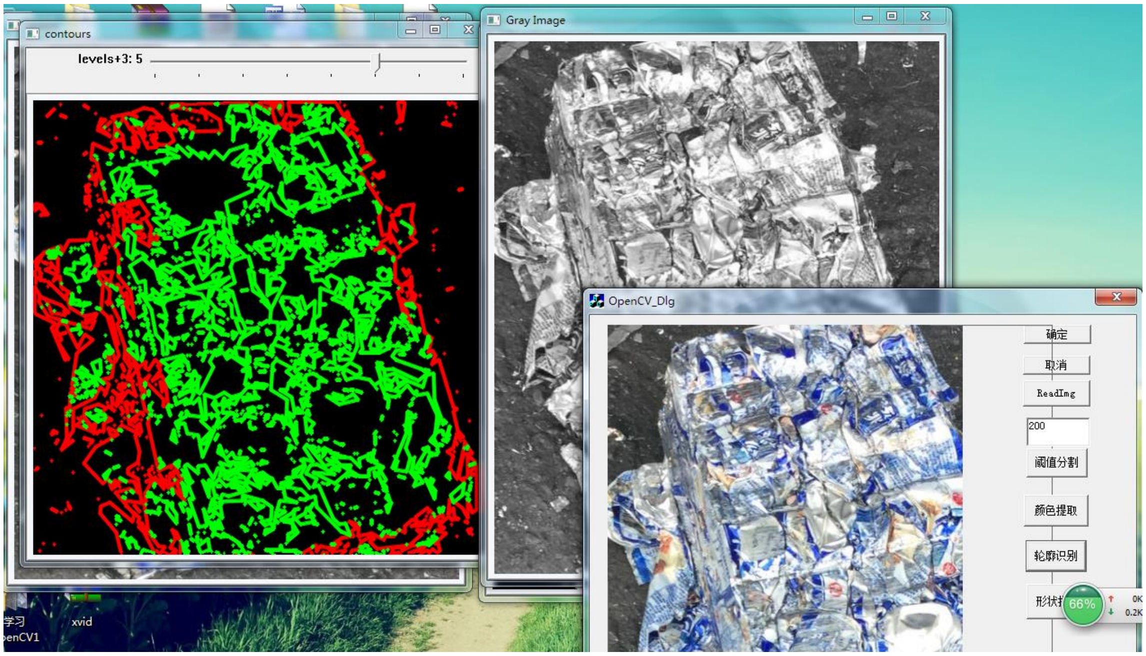


Figure 3.3.6.2.C Unpainted Block Photo Synchronizing

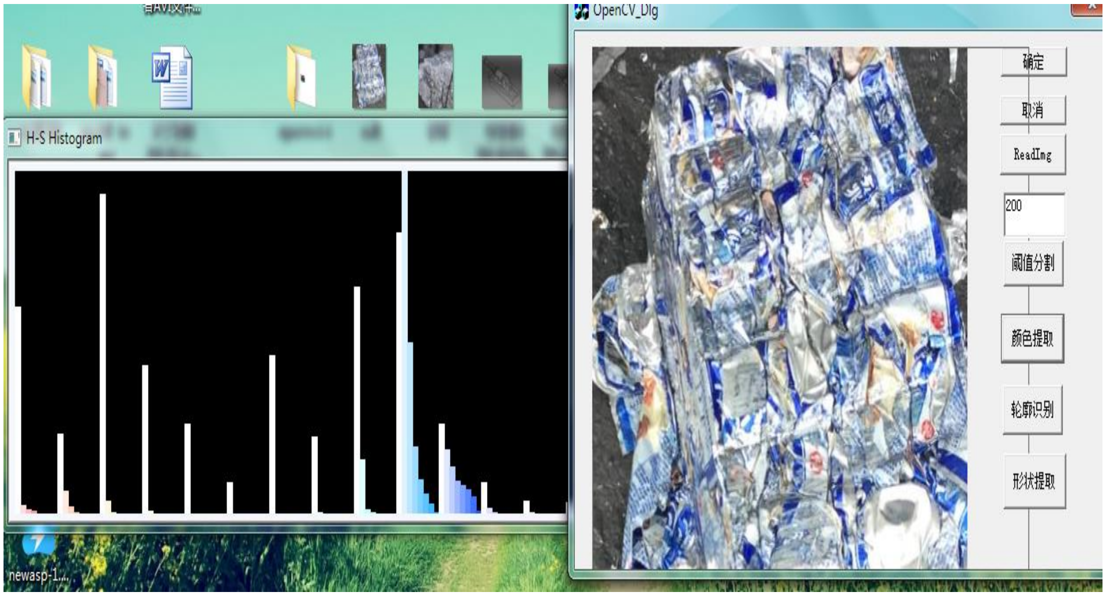


Figure 3.3.6.2.D Painted Block Photo Synchronizing

After achieving a distinguishing success of 80% on most blocks we decided the data was sufficient for the simulation to work. In our recommendations, we plan to list companies we have contacted with that provide professional recognition software for robotic arms and their pricing.

3.3.6.3 Alarm

Since one of the company’s requirements is to achieve high safety requirements, the alarm team has spent time working on an infrared sensor that will detect people. The infrared sensor will detect human presence and then set off an alarm and shut down the robotic arm. An infrared sensor is very cheap, has simple installation, and is an energy saver. In order to achieve a higher efficiency rate; multiple infrared sensors can be installed with different angles and direction for detecting people more precisely. Figure 3.3.6.3.A shows the infrared sensor microchip we are currently using for testing. A live demonstration was provided of the success.

Figure 3.3.6.3.A Infrared Sensor

4. Results

In this chapter, we will outline the steps and procedures we completed in order to bring us our final deliverables. We will show the final progress of all the subgroups as well as our final deliverables.

4.1 Detection

As seen in the summary of the end of the third visit to Pacific Can, the detection team was able to reach an 80% success by using OpenCV on pictures of the aluminum can scrap blocks. This was sufficient to send a signal to Servo, the robotic controlling software, in order to simulate the robotic arm taking the signal. Thus, the detection team completed its requirements and was a successful deliverable for simulating how a professional integration company might use visual detection software.

4.2 Alarm

Also seen in the earlier summary of the third visit, the alarm team was able to complete the three most necessary fault alarms for the robotic arm. The alarm team used three different microchips to simulate all three alarms. The voltage alarm, overheating alarm, and the infrared sensor were all demonstrated live and were a successful simulation for how a robotic arms fault alarm system may function. Thus, the alarm team was also successful in their endeavors.

4.3 Mechanical

The mechanical team was used SMART decision model for evaluating the best option among the six offered ones. They then performed an analysis on the arm as well as its suggested end of arm tooling. Additionally, the mechanical team completed a small simulation of how a miniature IRB 460 (the selected robotic arm) might function after receiving a command from a detection system such as OpenCV. Finally, a cost analysis and ROI were completed for the robotic arm including calculations on the future value of money/labor wages, to propagate a purchase for the company.

4.3.1 SMART Decision Model

The team picked six robots from ABB and KUKA and asked for price quote from the sales contact. After comparing the specifications of the models, the team decided to choose ABB

IRB 460 as recommendation after using the SMART decision model. SMART decision model refers to *Simple Multi Attribute Rating Techniques*. There are various reasons for using SMART as our decision model such as the transparency of this model, and the deliverable of this model is unbiased, which exclude many rising concerns.

SMART consist of seven steps in order to reach the final decision. The first step is identifying the decision maker; in this project, it is Pacific Can management. The second step is identifying the alternative courses of action, which are the different types of robots. The third step is identifying the relevant attributes (See Figure 4.3.1.A). The forth step is determining a weight for each attribute (See Figure 4.3.1.A). The fifth step is measuring the performance of the alternatives on each attribute (See Figure 4.3.1.C). The sixth step is weighting the average of the values (See Figure 4.3.1.D). Finally, the seventh step is making the provisional decision.

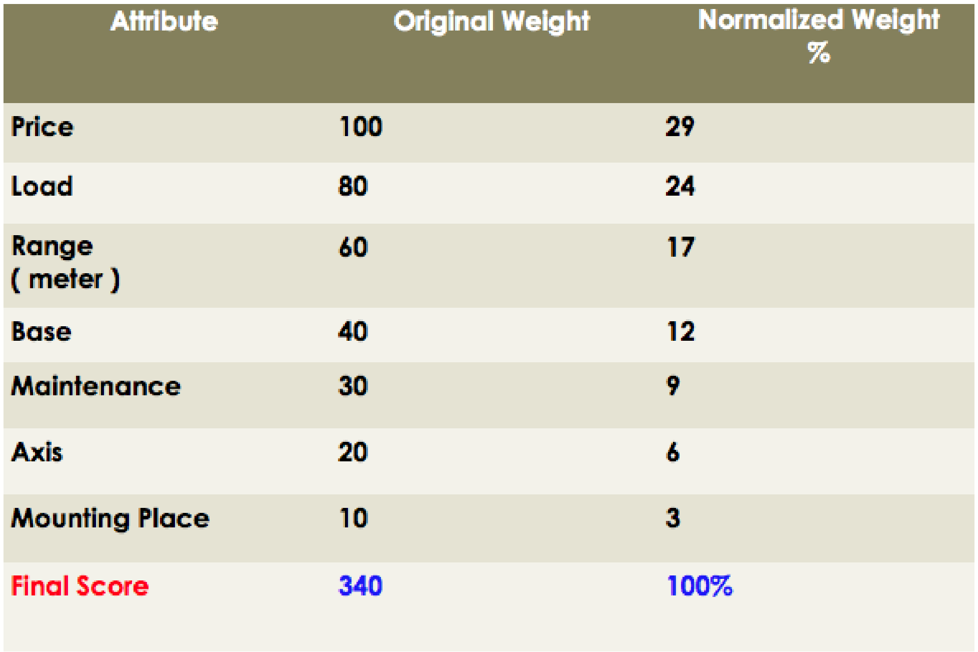
The three types of robotic arms the team quoted from KUKA were the KR 40 PA, KR 30-3 and KR 60-3, based on the basic information reviewed from the data library on KUKA website. The sales contact, Mrs. Chen, responded to the team’s price quote request with the information on the three robotic arm models and maintenance prices. The prices for KR 40 PA, KR 30-3 and KR 60-3 are 250,000 RMB, 300,000 RMB and 320,000 RMB respectively. The price quotes excluded any cost for the end of arm tooling, installation or other external equipment prices. The KUKA sales contact actually only recommended KR 40 PA and KR 60-3 to the team after learning the condition of the work area and parameters of the project. Additionally, the weight of the end of arm tooling was calculated directly toward the payload of the robot, so there is a chance combining the weight of block and end of arm tooling will exceed the maximum payload of KR 30-3, which was 30 kg, thus further disqualifying the KR 30-3.

The other prices included maintenance that would be required for all KUKA robot models every 2 to 3 years. The cost for maintenance can vary from 5,000 to 8,000 RMB. Additionally, visual detection components can be added to the robot, following the user's requirements. The robot can communicate with visual detection modules purchased from companies such as Cognex from United States and Daheng from China. Since KUKA(China) itself was not involved in the robotic arm integration business, the team had to find a third party integration company. The sales contact from KUKA actually recommended a professor from Beijing University of Chemical Technology because they he had done work with multiple corporations in the past. The team did not ask for integration fees of the robotic arm from Professor Zhang because the team chose ABB 460 in the end.

The robotic arm models quoted from ABB by the team were the IRB 460, IRB 4600 and IRB 4400, based on their payload and other specifications available from the online database of ABB. The sales contact from ABB, Mr. Ying, provided the price quotes on the robot. The prices for IRB 460, IRB 4600 and IRB 4400 are 310,000 RMB, 320,000 and 400,000 RMB respectively. The ABB robots do not need any maintenance for up to 5 years in normal working environments. If maintenance were necessary, the price would be 2,000 RMB per day, excluding any hardware replacement fees. Mr. Ying referred the team to an integration company in Beijing for the price quote of integration fees. This introduced the team to Mr. Zhou from Machinery Technology Development Co., Ltd complete sets of technology and equipment division. This is ABB's integration company located in Beijing, Haidian District.

All these robotic arm models were qualified or very close to qualified in payload, range, and size. This made it very difficult to pursue the best option. Therefore, a breakdown of the statistics of the six arms was completed in order to make a proper analysis of which was the best. For a more detailed description of each robotic arm, see the literature, section 2.3.

In Figure 4.3.1.A it shows which attribute were selected; thus, what weight were given to each one of the attributes based on their importance.



Attribute	Original Weight	Normalized Weight %
Price	100	29
Load	80	24
Range (meter)	60	17
Base	40	12
Maintenance	30	9
Axis	20	6
Mounting Place	10	3
Final Score	340	100%

Figure 4.3.1.A SMART model, relevant attributes and weight

In Figure 4.3.1.B, it shows each selection specification to their assigned attributes.

Robot Attribute	IRB 4400	IRB 4600	IRB 460	KR – 40PA	KR-30-3	KR 60-3
Price	300,000 RMB	350,000 RMB	310,000 RMB	250,000 RMB	300,000 RMB	320,000 RMB
Load	Medium	Small/Medium	Large	Small	Smaller	Small/Medium
Range (meter)	1.96	2.05 2.55	2.40	2.09	2.03	2.03 / 2.23
Base	Medium	Small	Medium	Smaller	Smaller	Smaller
Mainte-nance	6k/3day 5 years	6k/3day 5 years	6k/3day 5 years	5-8 K 2-3 years	5-8 K 2-3 years	5-8 K 2-3 years
Axis	6	6	4	4	6	6
Mounting Place	Floor	Floor/Shelf	Floor	Floor	Floor	Floor/Ceiling

Figure 4.3.1.B SMART model, Robot options and specification for each attribute

Figure 4.3.1.C shows how options was measures on each attribute. Note: measurement are focused on IRB 4600, and IRB 460 as they scored the highest on this model.

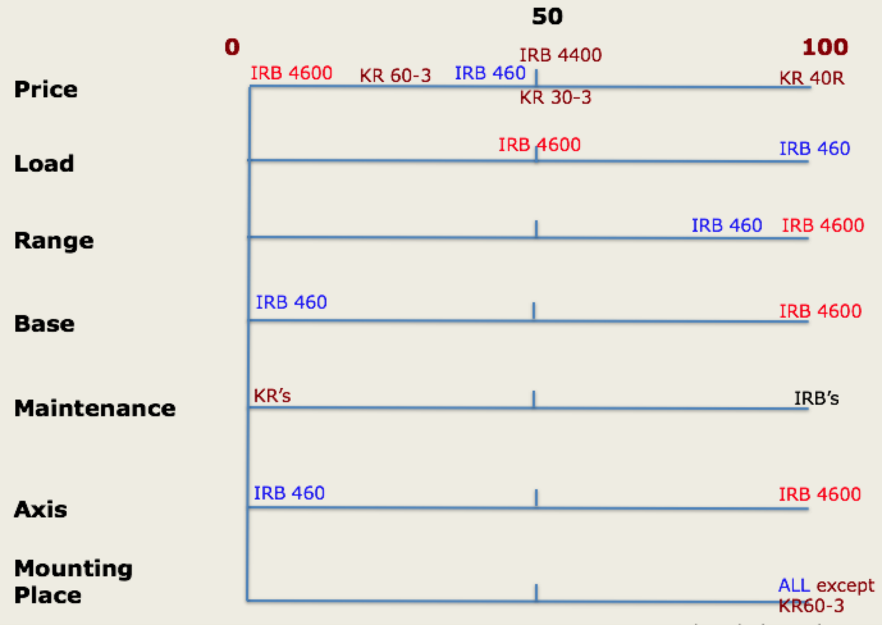
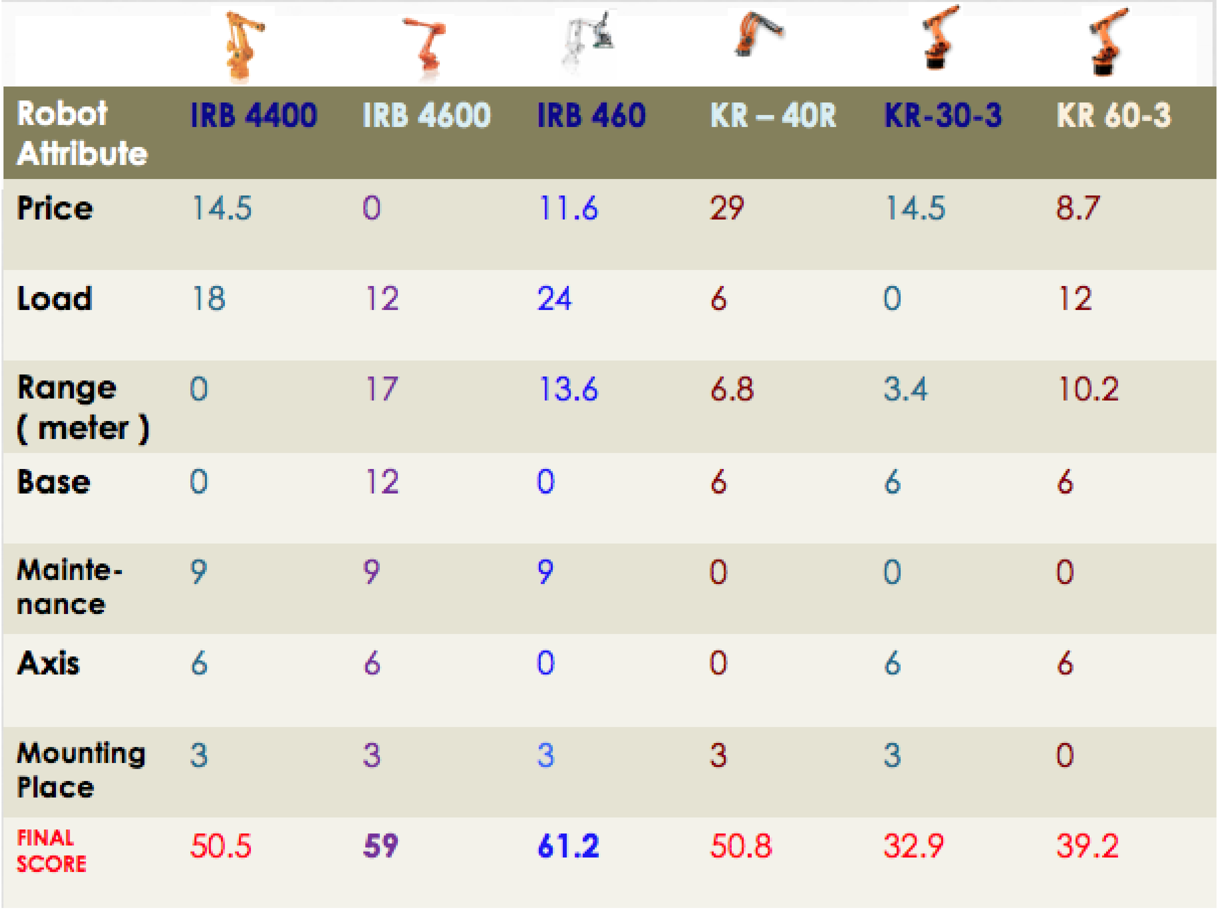


Figure 4.3.1.C SMART mode, measurements of options on each attribute.

Figure 4.3.1.D shows the final evaluation for each of the option. IRB 460 scored 61.2 as it comes on first, while IRB 4600 scored 59 and it comes on second.



Robot Attribute	IRB 4400	IRB 4600	IRB 460	KR – 40R	KR-30-3	KR 60-3
Price	14.5	0	11.6	29	14.5	8.7
Load	18	12	24	6	0	12
Range (meter)	0	17	13.6	6.8	3.4	10.2
Base	0	12	0	6	6	6
Mainte-nance	9	9	9	0	0	0
Axis	6	6	0	0	6	6
Mounting Place	3	3	3	3	3	0
FINAL SCORE	50.5	59	61.2	50.8	32.9	39.2

Figure 4.3.1.D SMART model, final evaluation score

4.3.2 Robotic Arm Selection

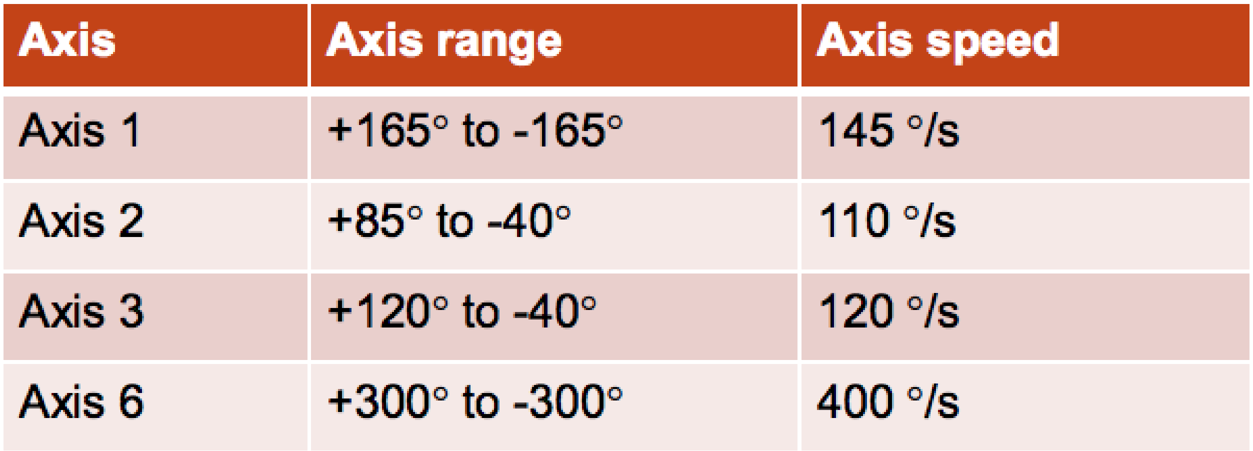
A complete study of multiple different palletizing robots was conducted, after comparing their features, capabilities, facilities requirements, and limitations it was clear ABB's IRB 460 model is the optimal alternative for this application.

IRB 460 Features:

Figure 4.3.2.A IRB 460 robot

- Four different axis of rotation: One at the EOAT to keep the payload parallel to the ground, two at the arm to extend it, and one at the base to rotate it. The axis design contributed to the robot's short cycle time, low weight, low complexity, and ability to hold a higher payload of 110kgs, well above the weight of the scrap blocks.
- Ample operating area: Because of the long reach of the robot, which has a maximum reach of 2400mm from the center of axis 4. This allows the arm the ability to reach all of the objects the robotic arm needs to move, with a very small footprint of 0.73m^2. The robot's size also allows pallets to be places 20% closer to the robot, when compared to other models of similar size. This is crucial since the working area at Pacific Can is quite limited.
- Short cycle time: The IRB 460 is the fastest palletizing robot commercially available, it is carefully engineered compact design allows fast axis rotations which will make the robot

fast enough to clear the blocks at any rate of production. The robot’s speed capabilities are described in Figure 4.3.2.B.



Axis	Axis range	Axis speed
Axis 1	+165° to -165°	145 °/s
Axis 2	+85° to -40°	110 °/s
Axis 3	+120° to -40°	120 °/s
Axis 6	+300° to -300°	400 °/s

Figure 4.3.2.B IRB 460 palletizing capabilities specification

- High precision movement: ABB is a world leader in robotics, one of the main reason people prefer their products is their high precision, their motion control software, QuickMove and TrueMove, and they can guarantee smooth movements with high path accuracy, ensuring the blocks will be handled sensitively without losing any cycle time. Programming the robot to perform any task is also very simple, thanks to ABB’s top of the line software. Since it runs on PC and is user optimized it allows for people with little or no robot programming experience create programs and simulations.
- Reliability: The robot’s design is quite durable; it is a strong structure manufactured to automotive industry standards. On top of that, its servo electric motors allow for minimal required maintenance. ABB is so sure of their reliability that they offer a three-year warranty package ensuring the highest uptime with the lowest maintenance cost, during

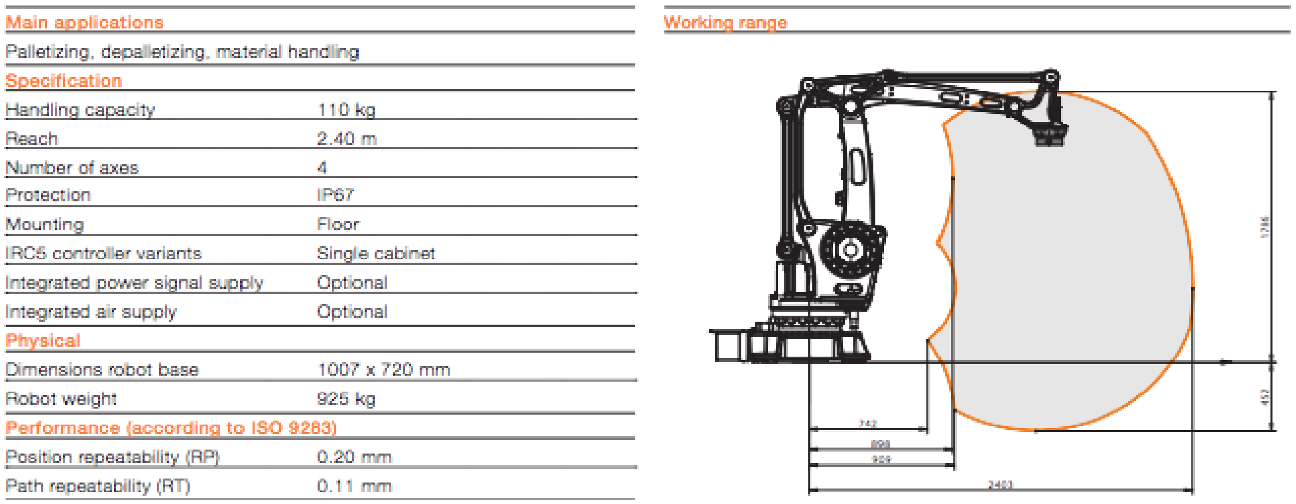
the three-year period ABB will monitor the robot and suggest the optimal maintenance for the robots working conditions.

- Availability of compatible EOATs: ABB produces a variety of EOATs that will work with the robot, with a few designed particularly for our end of line palletizing function.

These features make the IRB 460 the best choice for Pacific Can. The robot is top of the line equipment that will last. It is also compatible with the limitations of the work area provided, a room is built to keep the robot enclosed in a temperature within its working range, and it will be more than capable of managing the current and potentially increased workload of the task.

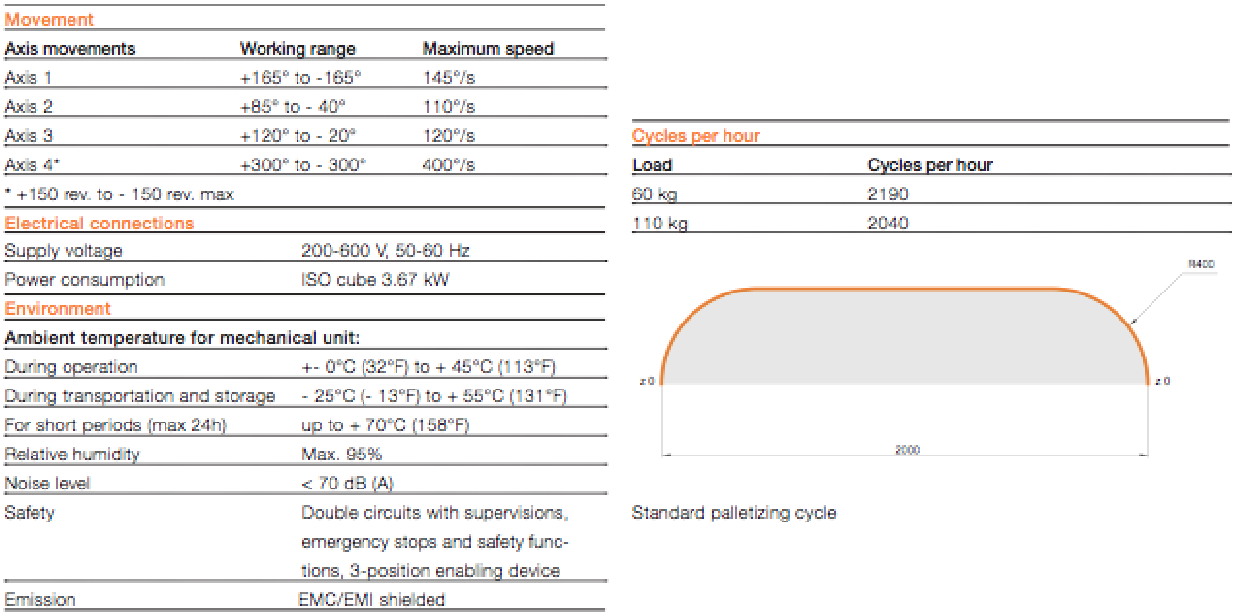
In order to properly install the arm it is important to understand the working conditions and limitations of the robot, while it has the capability of solving the issue at hand improper handling could result in robot malfunction or injury and thus it is important to make sure the following specifications and environmental limitations are met.

Figure 4.3.2.C and 4.3.2.D shows all the specification for ABB IRB 460 robot.



Main applications	
Palletizing, depalletizing, material handling	
Specification	
Handling capacity	110 kg
Reach	2.40 m
Number of axes	4
Protection	IP67
Mounting	Floor
IRC5 controller variants	Single cabinet
Integrated power signal supply	Optional
Integrated air supply	Optional
Physical	
Dimensions robot base	1007 x 720 mm
Robot weight	925 kg
Performance (according to ISO 9283)	
Position repeatability (RP)	0.20 mm
Path repeatability (RT)	0.11 mm

Figure 4.3.2.C ABB IRB 460 Robot Specification



Movement

Axis movements	Working range	Maximum speed
Axis 1	+165° to -165°	145°/s
Axis 2	+85° to - 40°	110°/s
Axis 3	+120° to - 20°	120°/s
Axis 4*	+300° to - 300°	400°/s

* +150 rev. to - 150 rev. max

Electrical connections

Supply voltage	200-600 V, 50-60 Hz
Power consumption	ISO cube 3.67 kW

Environment

Ambient temperature for mechanical unit:	
During operation	+- 0°C (32°F) to + 45°C (113°F)
During transportation and storage	- 25°C (- 13°F) to + 55°C (131°F)
For short periods (max 24h)	up to + 70°C (158°F)
Relative humidity	Max. 95%
Noise level	< 70 dB (A)
Safety	Double circuits with supervisions, emergency stops and safety functions, 3-position enabling device
Emission	EMC/EMI shielded

Cycles per hour

Load	Cycles per hour
60 kg	2190
110 kg	2040

Standard palletizing cycle

Figure 4.3.2.D ABB IRB 460 Robot Specification

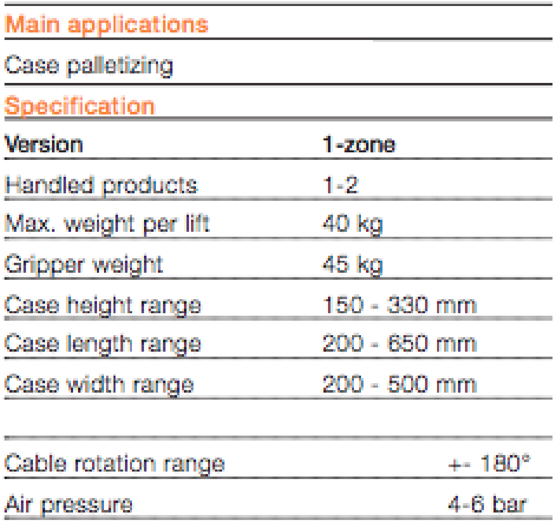
The robotic arm's capabilities include the ability to move and stack blocks that are not a standardized size. This benefits the situation greatly as the aluminum scrap blocks have a difference in size of anywhere between one and five inches. The visual detection software allows the robotic arm to distinguish the type of block it is dealing with (painted or unpainted) as well as the shape and size of the block. Additionally, the robotic arm can complete 2,040 cycles per hour. This means, not including the time taken for the robotic arm to detect blocks, it will move and stack 2,040 blocks in an hour. The robotic arm also comes with a full pallet recognition system so it senses when a full pallet has been stacked and sets off an alarm. Finally, the robotic arm will be moving and stacking blocks well under its 110kg payload. This allows the robotic arm to function 24/7 easily as well as increases its life period due to not having to experience nearly as much strain while working.

4.3.3 End of Arm Tool

After a study of the different types of End of Arm Tooling option available in the market it became clear the options that would successfully complete the task would be either a fork style gripper or a friction gripper. The end of arm tooling is a plug-and-play extension by ABB company to IRB 460 and IRB 660 for high-speed case palletizing applications. There are two versions of clamp FlexGripper available: single zone version and double zone version. The differences between the two versions are the maximum weight per lift and gripper self-weight. In this case, the single zone clamp FlexGripper can lift up to 40 kg of cargo every time while it weighs 45 kg (See Figure 4.3.3.A). Since the maximum payload of IRB 460 at the wrist was 110 kg, single zone clamp can totally satisfy the requirements and needs of the palletizing tasks. Its cable rotational range is positive 180 degrees to negative 180 degrees. It is a pneumatic gripper so it requires 4-6 bar of pressurized air to operate.

Figure 4.3.3.A FlexGripper single zone

ABB provides both of these fantastic options but, because of the end of line palletizing character of this project and the top of the line capabilities of ABB’s friction grippers the team decided ABB’s Flex Gripper Clamp Single Zone Version was the way to go.



Main applications

Case palletizing

Specification

Version	1-zone
Handled products	1-2
Max. weight per lift	40 kg
Gripper weight	45 kg
Case height range	150 - 330 mm
Case length range	200 - 650 mm
Case width range	200 - 500 mm
Cable rotation range	+- 180°
Air pressure	4-6 bar

ABB’s Single Zone Flex Gripper is ideal for end of line palletizing as it can deliver payloads quickly and with great care at maximum precision. It is capable of managing up to 40kg per lift, well over the 20-28kgs weight range of the blocks. With a weight of only 45-kgs, the ABB IRB 460 will be operating well under its weight limits, extending the products working life.

The main advantage of this option over any other EOAT is its precision, since the robot intends to replace a very detailed human labor of stacking irregularly shaped blocks the tools ability to place a block exactly where intended is crucial.

Other favorable features from this EOAT include:

- Hook Unit: ensures clamping of the case to allow for high speed movements.
- Wide Clamp Stroke: allows for different case sizes.
- Mounting plate for IRB 460
- Arrives completely assembled ready to be plugged in and used.
- Includes a Graphical User Interface that allows the user to setup, tune and monitor production.

Figure 4.3.3.B shows the technical specification for FlexGripper EOAT.

Figure 4.3.3.B FlexGripper technical specification

4.3.4 Work Area

Once the robotic arms maximum and minimum reach were taken into consideration, some modifications to the previous work area layout plans became necessary. The main requirement for the conveyer design and robot positioning is the robot's ability to reach everything that it needs to work with: the scrap blocks where the conveyer belt drops them off (the pickup area), the pallet for unpainted blocks, the pallet for painted blocks, and the stack of pallets for replacing fully loaded pallets. Other than that, the robot should be able to push the pallets out of the way once they are fully loaded and place an empty pallet in the pallet loading position. The final proposed position is illustrated in Figure 4.3.4.A.

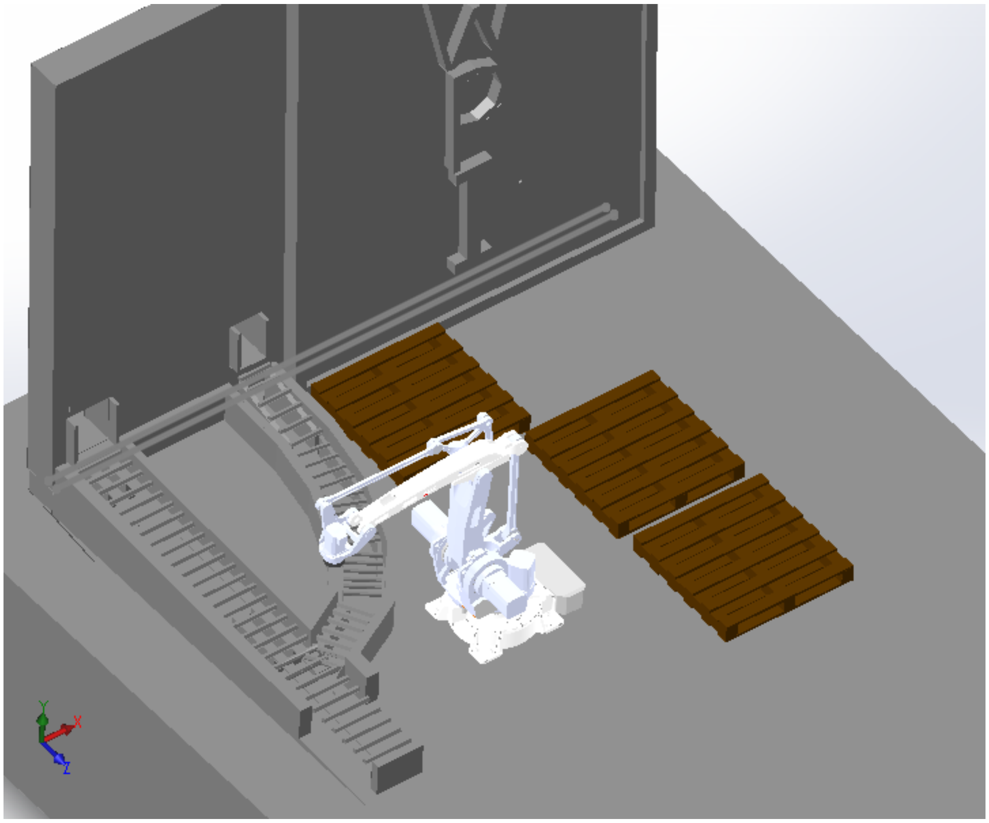


Figure 4.3.4.A Final robot position design

This arrangement is capable of meeting all of the requirements for successful robotic arm operation, and achievement of all of the required functions for full replacement of human labor in this area of the plant.

Figure 4.3.4.B shows how, under this arrangement, the robot is able to fulfill all of the functions required by Pacific Can:

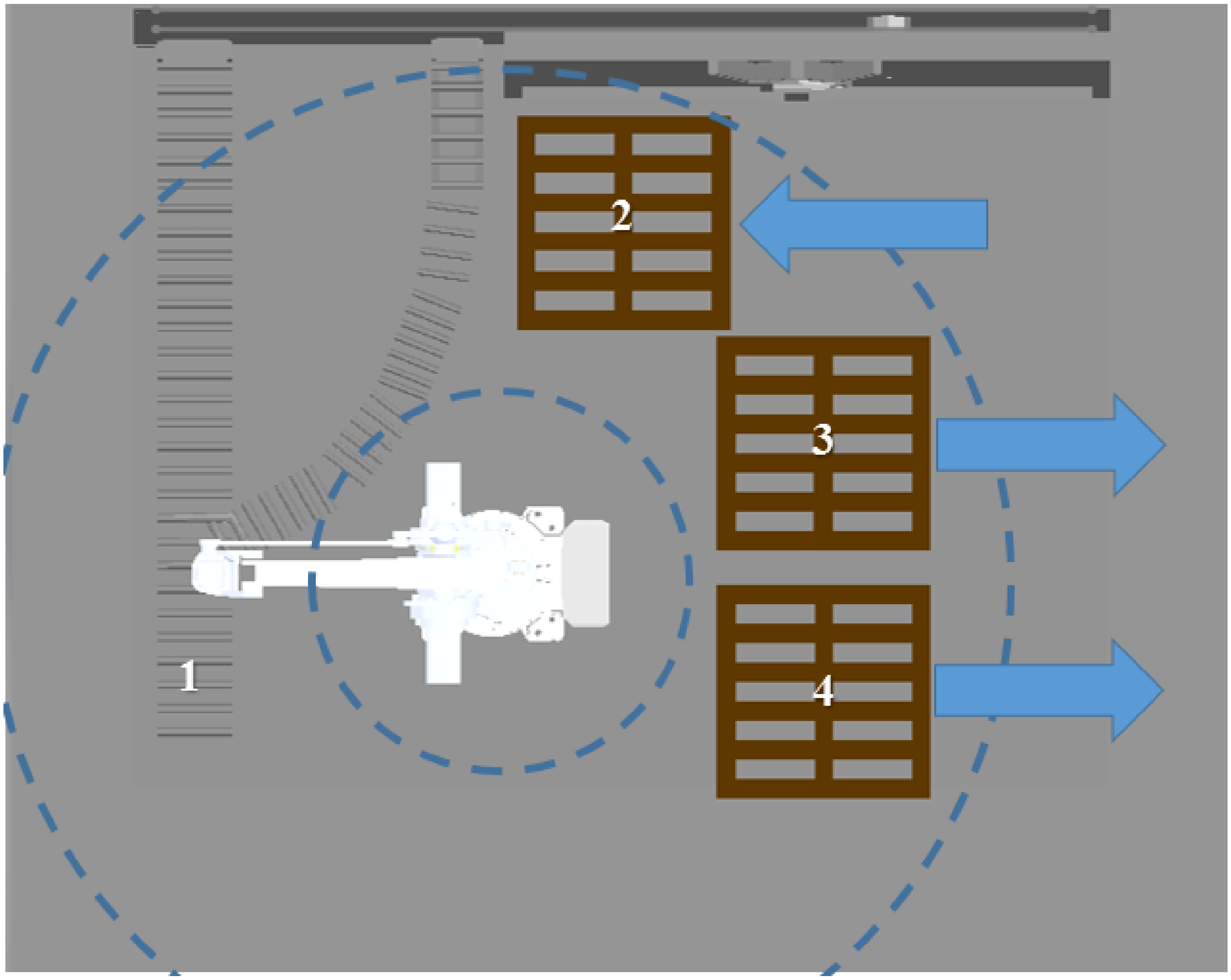


Figure 4.3.4.B Robot working range

The Figure 4.3.4.B illustrates the working range of the robot using two concentric circles that represent the minimum range and maximum range of the robot; the numbers and arrows describe specific task areas:

- #1: This is the pickup area, after sliding from the exit holes in the wall and moving through the slightly angled conveyor rolls the blocks; painted or unpainted, then will stop here to be picked up by the robot. After pick up, the robot will rotate counter clockwise to deposit the block on pallet 3 or 4 depending on the color of the block.

- #2: This is the pallet stack: the forklift team will need to stack pallets here for the robot to replace the pallets in areas 3 & 4 when they are fully loaded with scrap blocks and removed. This increases the amount of time during which the robot can operate independently. The arrow to the right of area #2 shows the clear space the forklift operator will use to deliver empty pallets to the stack.
- #3: This is the blank block pallet; this is where all of the blocks that the software detects as not colored will be deposited.
- #4: This is the colored block pallet; this is where all of the blocks that the software detects as colored will be deposited.

Once pallet #3 or #4 is fully loaded the robot will remove it from the work area by pushing it in the direction of the arrow right next to the area. Afterwards it will pick up an empty pallet from stack #2 and place it in the empty area. The weight of the fully loaded pallet is quite large, well beyond the robotic arms capability. Nevertheless, using rollers to displace the loaded pallets could reduce the force required considerably; enough to make it possible for the arm to push the pallet out of the way. This would ensure that the robot continues operating without having to wait for the pallet to be removed by a worker.

Another useful feature of this arrangement and design is work areas #2, #3, and #4 are easily removable; this will leave a wide-open space for robot to be maintained when necessary.

In addition to the CREO modeling of the workplace done, we also expanded on the original SolidWorks modeling. Figure 4.3.4.C shows a screenshot of the SolidWorks video we created of the IRB 460, with attached FlexGripper clamp tooling, moving and stacking blocks of the sizes we are dealing with. The video is very detailed and effective in simulating exactly how the process would look. This was demonstrated during the final presentation.

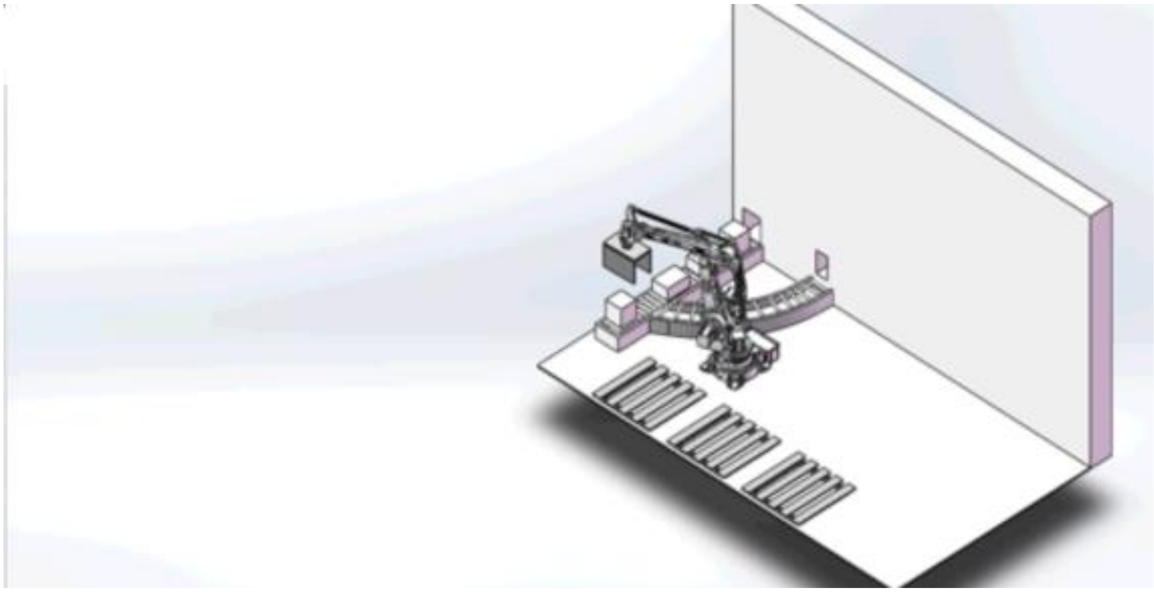


Figure 4.3.4.C SolidWorks robotic arm and end of arm tooling process simulation

4.3.5 Arm Simulation

In the end, the mechanical arm team was able to purchase an IRB 460 miniature. This is a miniature model of the robotic arm selected as the best for its high-speed palletizing purposes. The below Figure 4.3.5.A shows a screenshot of a video simulation of the IRB 460 functioning. In the video, the IRB 460 has been programmed by the team to demonstrate how the arm might before after being given a signal from a visual detection program such as OpenCV. In the video, the IRB 460 moves from where a block might be picked up to a spot where the pallet might be in order to simulate its stacking procedure. It is also simulate to move its end of arm tooling flange such that it might have picked something up and then placed it. For the simulation, however, we do not have an EOAT attached.

It is a necessary simulation for providing Pacific Can with an idea of what the arm is capable of in our hands, let alone in the hands of ABB should they choose to purchase the arm.

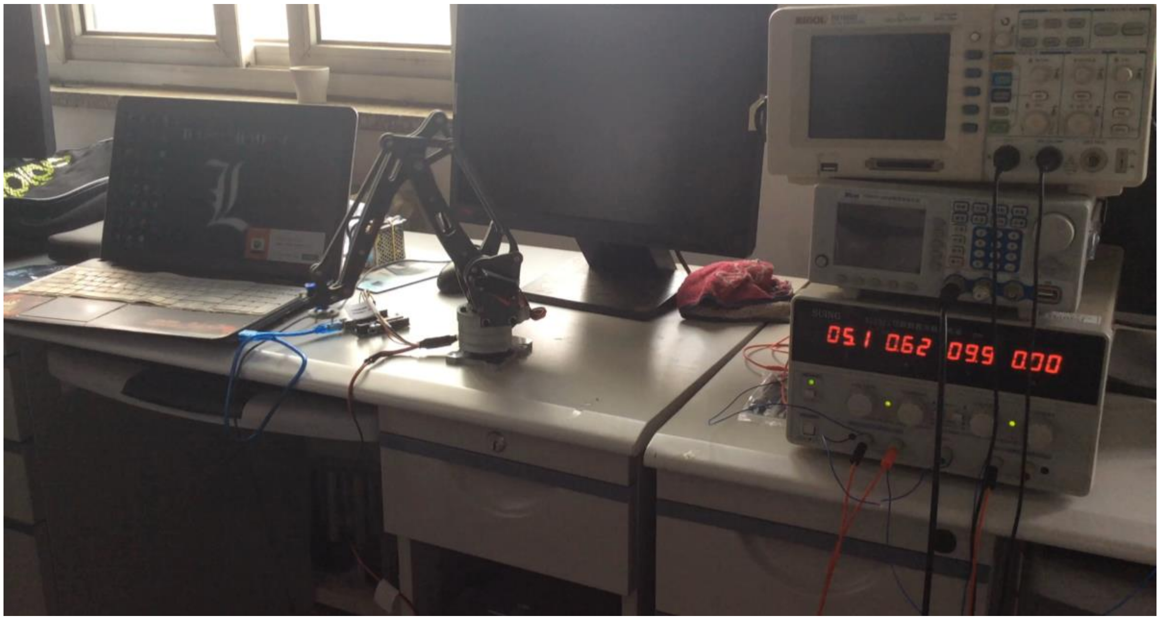


Figure 4.3.5.A IRB 460 functioning simulation

4.3.6 Integration Fee Summary

After receiving necessary pricing values from the sales contact from ABB and the ABB integration company, the team was able to calculate the total initial investment of using IRB 460 to solve the palletizing problem. The total cost can be broken down into two major parts: the fixed costs and variable costs. Below is the price quote the team retrieved from ABB and integration company:

- IRB 460 Robot: 310,000 RMB (including controller, demonstrator and connecting cables)
- Base for the robot: 6,000 RMB
- FlexGripper-Clamp: 50,000 RMB
- Installation Fee: 10,000 RMB

- Calibration Fee: 30,000 RMB – 40,000 RMB
- Visual Detection: 80,000 RMB

Combining the price quotes above, the initial investment required for the robot is roughly 496,000 RMB. The robot is going to be mounted on a base, which is fixed to the floor. FlexGripper Clamp is an end of arm tooling designed by ABB especially for palletizing applications. The installation is a process that in which the technicians will set up the robot, connect it to the controller and power source, attach the end of arm tooling to the robot wrist, connect the end of arm tooling with controller and air hoses, etc. Then the technicians will program and calibrate the robot to do the work it is supposed to do. The visual detection is an external system mounted on the robot to do visual analysis applications. The integration company also offers a rather simple size-detection only system, which costs 25,000 RMB.

4.4 Investment Analysis

The cost effectiveness of the investment is a crucial part of any capital purchase. Using calculations for present value and future value, we will compare the true value of the robot after certain time periods. Important criteria the team has to meet is considering the labor wages of the country, which is China, and currency inflation.

We will repeat these calculations under the current output levels and future assumed output to be obtained from the company’s growth objectives to compare the value of the robots increased output versus the value of hiring extra workers to keep up with production.

4.4.1 Interest Rate

In the last 10 years, the Chinese Yuan has made sharp fluctuation in terms of interest rate. The highest interest rate reached was 10.98% in 1996, while the lowest interest rate reached is during this year 2015 (See Figure 4.4.1.A, tradingeconomics.com, 2015).

Figure 4.4.1 China's interest rate 1996-2015

In addition, in the last 12 months the Chinese Central Bank has lowered the interest rate from 6.0% to 4.85%. The main concern that can be associated with this high fluctuation rate changing is the inflation rate, and the purchasing power of the country. Besides that, the Chinese economy is undergoing fatal crises in its stock market (BBC News, 2015). If the government did not support the market with high funds, the market stability status would have been worse. All these factors play a critical role in determining the interest rate; especially if the Yuan seeks staying in power. An important challenge for the Chinese Yuan is to stay strong against the US dollar. Although in recent years the Chinese Yuan gained some strength against the US dollar, the US dollar is expected to increase against the Chinese Yuan if the Chinese economy keeps bleeding. In figure 4.4.1.B it shows a linear regression model of the Chinese Yuan versus the US dollar.

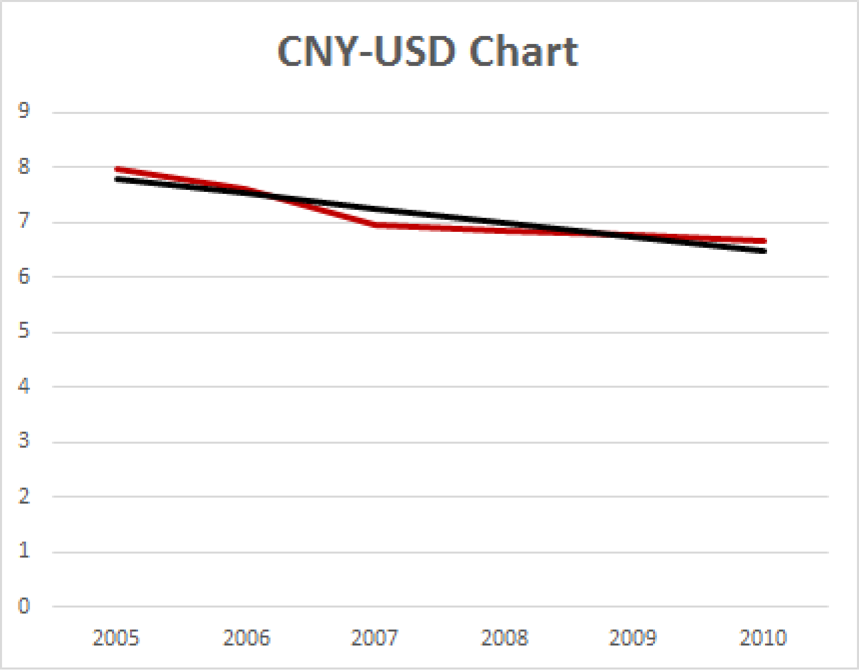


Figure 4.4.1.B Linear regression model for US Dollar vs CN Yuan

The analysis is supported by the linear regression model represents the change over time of the Chinese Yuan is gaining strength (APICS Case Competition, 2015). However, looking at the rate of change from the year 2007, it has been slowed. In addition, in 2010 the rate for each one US dollar was 6.7 Yuan, while today in 2015 the rate for one US dollar is 6.13. This steady slow changing at the currency exchange rate can result in some fear for the Chinese market especially if the Chinese economy faced a bigger economic crisis in the future.

4.4.2 Labor Wages

In the last 10 years, China has become a main location to be selected for companies to offshore its businesses. The high demand to China's human resources availability has been noticed during the last few years. However, as the demand is increasing for the human labor, there have been other effects such as an increase of labor wages, and a decrease on the availability of human resources. Mr. Yee, who is the CEO of Pacific Can, stated the problem of China's labor wages and the decrease on the availability of human labor. Figure 4.4.2.A shows the exponential increase of labor wages in China (Rush, 2011).

Figure 4.4.2.A Annual Average Wages 1996-2010

A main reason now for companies to turn to automation is the ability to stop relying on human resources as their cost have become higher every year. In contrast, the productivity of automation processes compared to the human labor ability to perform certain work type varies sharply. Figure 5.2.B shows a linear regression model of the labor wages in China at the private sector (APICS Case Competition, 2015).

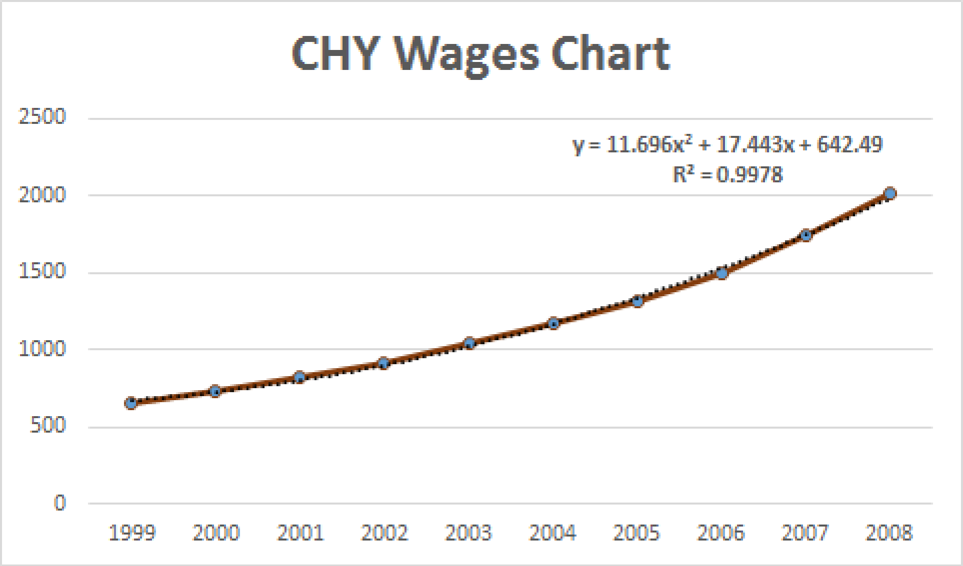


Figure 4.4.2.B regression model for Chinese wages over time 1999-2008

The R^2 in this model is close to 1 thus confirming the result. The model shows that the increase in wages will keep at rising at the same pace. Some researchers claim the labor wages in China increase by a minimum of 13% every year. In 2014, the Chinese government announces new minimum wages across the country. While the minimum wages level in Beijing reached 1720 Yuan per month with an approximate increase of 13%, Guangzhou city had 22% increase at its minimum wages reaching 1895 Yuan per month (China Briefing, 2013).

4.4.3 Return of Investment

In order to assure gaining profits from an investment, a return of investment analysis is a necessary study that has to be made. In the return of investment study, all the financial aspects that surround the project shall be covered; thus, elaborated economically. The study compares all the different options financially. In this project, the ROI will compare the two options that are using the *human labor force* or buying the *IRB 460* robot. A main consideration in this study is assigning the time value of money by using some equation such as the *Future Value of an Annuity,* and the *Present Value*.

Assumption:

- Interest Rate: 4.85%
- Exchange Rate: $1.00 = ¥6.21
- Life Period: 15 years.

Equations:

The *Future Value of an Ordinary Annuity:* $\mathbf{P = PMT\,[((1 + r)^n - 1) / r]}$

P = The future value of an ordinary annuity.

PMT = Annuity payment.

r = Interest rate

n = Number of Period

Human labor force cost:

Yearly cost of (4 Workers):	$20,000	(¥124,200)

After applying future value calculation:

Cost in 15 years:	**$426,730**	**(¥2,650,000)**

IRB 460 Robot:

Robot Price:	$50,000	(¥310,000)
Calibration:	$6,441	(¥40,000)
FlexGripper:	$8,052	(¥50,000)
Robotic Base:	$966	(¥6,000)
Installation:	$1,610	(¥10,000)
Visual Detection Fee:	$12,882	(¥80,000)
Maintenance (Every 5 Year):	$1,049	(¥6,514)
Electricity (Every Year)	$1,000	(¥6,210)

After applying future value calculation:

- **Cost in 15 years:** **$104,679** **(¥649,004)**

Breakeven Point:

- In 4 years' breakeven point will be reached; thus, profit will be gained in the next 10 years.

Profit:

- Profit saved in 15 years equal to **$322,570**; or **¥1,999,936**
- **ROI is 308%**

5. Recommendations

The main objective of the project was selecting the most optimal, efficient fit for a robotic arm that will aid Pacific Can in innovating their process for sorting and stacking compressed can scrap blocks. After our seven-week project, the group had concluded the best recommendation to solve the current process at Pacific Can. The group successfully completed the main goal by developing a metal scrap recognition system using a computer software, developing a safety protection system using infrared sensors, and building a prototype that can simulate the movement of the robotic arm.

Completing this project required giving an innovative solution to the company, which the group well achieved in giving a newly established design workplace for the process. In addition, the group provided an in-depth analysis for the properties and effectiveness of different end of arm tooling that will aid the company in making a successful selection. The analysis includes giving other important details that the company sought such as the ability to use the robotic arm in different processes.

Our short-term recommendations for Pacific Can include purchasing the suggested robotic arm with the researched end of arm tooling and other necessary services given by ABB's integration company. Additionally, we recommend implementing the new work area design and process. This implementation will be a test run at the first facility and the company should measure its success.

The recommended industrial robotic model is the IRB 460 manufactured by ABB. It stood out among the candidates during the selection process as the most cost-effective and efficient model for this project. The sales contact from ABB is Mr. Ying, whose cell phone number is +86 15921971925. We recommend staying in contact with ABB and their integration company because we have informed them of the situation. They have also confirmed through our research that they have the tools necessary to satisfy Pacific Can's requirements.

The team also recommends Machinery Technology Development Co., Ltd as the company to integrate IRB 460 into its working area. This company is one of the appointed integration companies of ABB in Beijing, so the accessories and services provided by the company are reliable and should not have any compatibility problems with ABB robotic arms. This includes the detection system and end of arm tooling (FlexGripper Clamp) that we have researched and Mr. Zhou from the complete sets of technology and equipment division is the contact person the team communicated with; his contact is +86 010-88301416.

Our long-term recommendations include analyzing the results of the first implemented robotic arm and its performance. The company should consider this work area design and robotic arm for the rest of its factories should the test run of the new process prove successful and a worthy investment. The team then recommends that Pacific Can install industrial robotic arms and the new work area design process at all six factories across the mainland since the estimated return of investment is so large. The company will save millions of Chinese Yuan from not paying the workers who are currently doing the job. This is even more effective due to the rising inflation of Yuan as well as the demand for higher labor wages in China. Overall, we hope this process is a strong investment for the company and continues in the future through keeping in connection with the ABB.

6. Reflection on Project (Mohamad Alblaihess)

This section is a reflection of the MQP (Major qualifying project) for the completion of the industrial engineering major. The only member of the project majoring in IE, is Mohamad Alblaihess. This section will briefly discuss the project summary. It will elaborate on the constraints faced during completing this project. In addition, it will share the techniques used from the Industrial Engineering studies and the importance of life-long learning that is obtained during this project.

6.1 Project Summery

During this project, the team's goal was to design a robotic arm that will aid Pacific Can Beijing Facility in order to improve and enhance the aluminum recycling process. The aluminum recycling process consists of two chutes that controls metal scrap blocks that come out of it. It currently consists of a process that is run by human force who lift, sort, and organize those metal scrap blocks into their designated pallets. The issue rises as the current process is performed by human labor in which they are easily exhausted; thus, reaching an inefficiency to fully complete the task.

The WPI team in collaboration with BUCT team worked in correlation to improve the process of sorting and stacking the metal scraps. This was done by helping create/design a designated area and offering the best options in regards to what robot should be purchased. Our main focus of the project was to deliver an in-depth analysis of the mechanical, security, recognition, and financial aspects.

The team was able to design a work area using CREO software, CAD software, and an alarm was created in order to meet the demands from Pacific Can. The CREO software displayed the feasibility of the chosen robot, which is IRB 460. CAD software was used to create simulation that assured the working ability of the robot. The alarm system assured the workability that was asked for human safety. The system consisted of a beeping alarm that would go off when any worker is around the robot, when the robot overheats, when there are fire incidents, and if a malfunction occurs. Nevertheless, the team was able to provide a recognition system that can differentiate the painted and unpainted color blocks using an OpenCV software. The OpenCV software analyzes the pictures taken for each type of the metal blocks; thus, determining its type and sends it to the robot to make the right selection.

6.2 Constraints

Even though the team was able to provide an in-depth study and analysis; the constraints limited the project to reach certain levels. Those constraints are time, financial limitation, language barrier, and group size constraints.

The first constraint was time; the project only ran for 7 weeks. The lack of time prevented the team from further study that was needed in order to meet requirements that Pacific Can wanted. They desired for us to choose a material for designing a room for the designed work area, and choose the type of conveyor belt. The group overcame some of those limitations by giving multiple draft designs for the work area; however, the type of conveyor belt was not submitted.

The second constraint was financial limitation, the financial inability to buy some requirements was crucial. Those requirements consisted of buying the selected robot, visual system, detection system, and the end of arm tooling. In contrast, the group was able to overcome some of those constraints by making simulation for the selected robot.

The third constraint was the language barrier between the members. The project took place in Beijing, China. English is not one the spoken languages in the area. As the team consisted of 6 BUCT Chinese students, 4 among those students were not able to communicate by English language. The language barrier was expected and respected. The group was able to overcome the barrier by the help of our two members from BUCT who spoke modest level of English, and by the WPI team member Yifan Shao who is originally from China. Although the language barrier was noticed, both of the two universities members were able to effectively communicate and overcome the problem. This can be related due to the great environment the group acquired during this project.

The forth constraint was the size of the group. The group consisted of 10 members, 4 members from WPI, and 6 members from BUCT. Making the wheel rotate was a difficult task especially most of the work needed to be finished with correspondence. The group was able to overcome this challenge by dividing the work to each one’s specialty in which the project was completed properly.

6.3 Life-Long Learning

Throughout your life, it is important to comprehend the different dimensions of knowledge whether they were studied, or experienced. Not only this project contributed to me as an industrial engineer; but it is also benefited me as a person to acquire more awareness and matureness. Being able to work with an experienced industrial factory such as Pacific Can aided me to develop as a future worker.

It was essential to complete this project with excellence to use various concepts from the industrial engineering studies. The successful usage of those concepts helped me accomplish the task with ease and feasibility. Not only this, but also it assures the work has gone throughout the correct steps in which an effective solution is reached.

One of the concepts learned during my time at WPI is the importance of leadership experience in projects. Although I was not the main leader to drive the team, my comprehension of the concept helped me contribute to the project with my specialty as an industrial engineer. During leadership practice study, professor French stated the importance of contributing as a leader even though you are not one. Meaning that your contribution should be valuable every time your help is sought. Having a fairly large group of members with different backgrounds required me to clearly identify the differences among each of the members in which fine communication can be reached. Thus, it helped me connect the dots among the group and fill in any missing gap to assure the durability of the work made.

Another important concept learned was the engineering economic study. Completing the investment analysis required solid background in this field. Especially when some calculation involves using the future value of money, or the future value of ordinary annuity. Obtaining clear reliable results to assure the worthiness of the return of investment required a background on the field of engineering economic.

At the last steps of this project, the team obtained some robotic options for Pacific Can to select from. In order to make an unbiased selection; a decision model was formed which is called SMART. The model was learned at the stochastic models class who was taught by professor Konrad. The model helped the team to give the company the right option based on different scaling criteria selected from such price, payload, number of axis, maintenance cost, range and base size. Using the model was essential to show the management of Pacific Can the reasons the selected robot was considered one of the best options for the company to buy.

One of the main concepts followed was using the DMAIC principles. The first time I was exposed to this principle was while I studied the achieving effective operations' class with professor Towner. During that class there was a lab in which the classmates made a process of operating a clock factory. The process helped the students by going in cycles to reach a high level goal. The DMAIC process was used in this project to follow up the different requirements that the company asked for. Besides, it helped identifying the current issues of each phase and how it can be overcome or improved. The DMAIC process is an effective method to use in developing new processes or improving one as it starts from defining the problem and the requirements, then it measured the current status of the issue. After that I analyze the problem in order to move to the next step where you improve it. In the end you reach the control phase where your final work can be given. Thus, the process goes in cycles to assure continuous improving.

Inasmuch as the concepts used in the industrial engineering were important, learning from mingling with the factory, and its management was also significant. The tips given by Mr. Glenn Yee, Pacific Can CEO, during the two meetings were very influential. One of the main advice that Mr. Yee has given to the team during the final meeting was the importance of integrity to succeed. Mr. Yee described integrity as the importance of reaching a goal with the good intention. One example he used was sharing your thoughts and learnings with others; especially during your work, as all parties can benefit and gain more from one another. Giving is the way of gaining as I believe and Mr. Yee reminded us of its importance by drawing it in a different dimension.

6.4 The Importance of Life Long Learning

Consistent learning is a must in life. Each experience is worth swimming. In life we are exposed to diverse cultures, and various types of knowledge. Comprehending them is the toughest part; though, gains are not easy. Completing this project in a new culture was a unique experience as much as living in China. Likewise, the material studied and obtained for this project was valuable too. Grasping the experience along with the material studied is precious. Therefore, learning should be indefinite.

Bibliography

1. ABB Group. (2010). Robotics IRB 4400 Industrial Robot. Retrieved from https://library.e.abb.com/public/0dc8b0df9cc39049c125772e0057e806/IRB%204400%20PR10035EN%20R8.pdf

2. ABB Group. (2011a). Robotics IRB 460 Industrial Robot. Retrieved from https://library.e.abb.com/public/95c9da16ac8a4d92c1257838002bf7ef/ROB0206EN_A_IRB%20460%20data%20sheet.pdf

3. ABB Group. (2011b). Robotics PalletPack 460 Function Package. Retrieved from https://library.e.abb.com/public/7f035104c3b43768c12579370049aadc/ROB0219EN_A_PalletPack460%20data%20sheet.pdf

4. ABB Group. (2011c). Robotics FlexGripper – Clamp Palletizing Gripper. Retrieved from https://library.e.abb.com/public/d7e12bca36dfaa02c1257850005821b5/ROB0208EN_A_FlexGripper%20Clamp%20data%20sheet_final.pdf

5. ABB Group. (2012). Robotics IRB 4600 Industria Robot. Retrieved from https://library.e.abb.com/public/cad39c28b12dab04c1257a85004233d4/ROB0109EN_G_HR.pdf

6. AccountingTools. (n.d.). *What is the formula for the future value of an ordinary annuity?* Retrieved from http://www.accountingtools.com/questions-and-answers/what-is-the-formula-for-the-future-value-of-an-ordinary-annu.html

7. Admin. (2008, Dec. 29). *How Can Recycling Save Energy?* Retrieved from http://www.recyclingawarenessideas.com/2008/12/how-can-recycling-save-energy.html.

8. Alblaihess, M., Karpinski, E., Oliveira, V., & Tang, R. (2015). Polaries Case Study. *APICS Northeast Competition*.

9. Anandan, T. (2014 Aug. 22). *Robotic Assembly: Shrinking Footprint, Expanding Market.* Retrieved from http://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/Robotic-Assembly-Shrinking-Footprint-Expanding-Market/content_id/4981

10. Astrom, F., Harirchi, G., &Landstrom, H., (2012). *Entrepreneurship: Exploring the knowledge base.* Research Policy, 41(7), 1154.

11. BBC News. (2015, May 10.). China cuts interest rates to 5.1% as economy slows. *BBC News*. Retrieved from http://www.bbc.com/news/business-32680744

12. Bengtsson. K. (2011). *IRB 460 The Compact, High Speed Palletizer*. Retrieved from

https://library.e.abb.com/public/1a92f5e79358dcdcc1257863004af353/IRB%20460%20Product%20presentation.pdf

13. Bengtsson, K. (2012). *PalletPack 460 Palletizing Function Package*. Retrieved from https://library.e.abb.com/public/0ea6bc18ebb3ea8ac125799c00488144/PalletPack%20460%20Presentation.pdf

14. Blostein, D. (Producer). (2015, Apr. 23). *Argobot Automates the Work of Berry Harvesting*. Podcast retrieved from http://www.wsj.com/video/agrobot-automates-the-work-of-berry-harvesting/D07A91E8-C453-4652-8ECE-2229FB862F6E.html

15. Brooks, C.(2015, Jan. 5). What is Entrepreneurship? *Business News Daily*. Retrieved from http://www.businessnewsdaily.com/2642-entrepreneurship.html

16. Chen, Y. (2014, Aug. 11). Transformers of Industrial Landscape. *China Daily*. Retrieved from http://www.chinadaily.com.cn/business/2014-08/11/content_18283099.htm

17. China Briefing. (2013, Jan. 28). *A Complete Guide to 2015 Minimum Wage Levels Across China*. Retrieved from http://www.china-briefing.com/news/2013/01/28/a-complete-guide-to-chinas-minimum-wage-levels-by-province-city-and-district.html

18. Craig, J. J. (2004). *Introduction to Robotics: Mechanics and Control*. Upper Saddle River, N.J.: Pearson/ Prentice Hall

19. Curtis, S. (2013, Sep. 13). Samsung to follow Apple with 64-bit smartphones, *The Telegraph*, Retrieved from http://www.telegraph.co.uk/technology/samsung/10307670/Samsung-to-follow-Apple-with-64-bit-smartphones.html

20. Dassault Systems. (2015.). *3D CAD*. Retrieved from http://www.solidworks.com/sw/products/3d-cad/packages.htm

21. Estrin, J. (2008, Oct. 29). Stanford University's Entrepreneurship Corner Entrepreneurial Thought Leader Lecture [Video 2].*Three Types of Innovation.* Podcast retrieved from *http://ecorner.stanford.edu/authorMaterialInfo.html?mid=2087*

22. ISO. (2012, Mar. 1). Robots and Robotic Devices-Vocabulary. Retrieved from http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=25&ics2=040&ics3=30&csnumber=55890.

23. KEEN. (n.d.). Entrepreneurial mindset defined. *KEEN'zine,* 2, 11. Retrieved from http://www.keennetwork.org/KEENzine2/

24. KUKA Roboter GmbH. (2003). *Spez KR 30-3, KR60-3 de/en/fr Retrieved from* http://www.kuka-robotics.com/res/sps/e6c77545-9030-49b1-93f5-4d17c92173aa_Spez_KR_30_60_3_en.pdf

25. KUKA Roboter GmbH. (2005). *Spez KR 40 PA de/en/fr. Retrieved from* http://www.kuka-robotics.com/res/sps/e6c77545-9030-49b1-93f5-4d17c92173aa_Spez_KR_40_PA_en.pdf

26. Liu, D. (2011). FlexGripper – palletizing grippers Clamp, Claw, Vaccum. Retrieved from https://library.e.abb.com/public/ce18bb3ab7eee61cc1257865001d2a84/Palletizing%20Grippers%20Product%20Presentation.pdf

27. Lutz, A. (2014, October 14). Google Express Is Better Than Amazon Prime. Retrieved from http://www.businessinsider.com/google-express-vs-amazon-prime-2014-10

28. Meccano Magazine. (1938, Mar.). *An Automatic Block-Setting Crane*. Retrieved from http://www.mecademic.com/references/MeccanoMagazine1938.pdf

29. Minniti, M. (2007). *Entrepreneurship: the engine of growth*. Westport, Conn: Praeger Publishers

30. Modern Materials Handling Staff. (2015, May 25). *Industrial robotics market to reach $44.48 Billion by 2020.* Retrieved from http://www.mmh.com/article/industrial_robotics_market_to_reach_44.48_billion_by_2020

31. Niku, S. B. (2010). *Introduction to Robotics: Analysis, Control, Applications*. Hoboken, N.J.: Wiley

32. Pacific Can China Holding Limited. (2011). Pacific Can- China's leading 2-piece Aluminum Beverage Can Maker. Retrieved from http://www.pacificcan.com/en/intro.html

33. PTC. (2015.). *PTC Creo*. Retrieved from http://www.ptc.com/product/creo

34. Rush, A. (2011). *China's Labour Market*. Retrieved from http://www.rba.gov.au/

35. Sciavicco, L., & Siciliano, B. (2000). *Modeling and control of robot manipulators*. (2. th ed.). New York; London: Springer.

36. Technavio. (2014, Aug.). Top 21 Companies in the Industrial Robotic Market. Retrieved Goodwin, P., & Wright, G. (2001). *Decision analysis for management judgment* (5 th ed.). Hoboken: John Wiley & Sons, Incorporated.

37. Thomasnet. (n.d.) *Industrial Robotics Principles*, Retrieved from http://www.thomasnet.com/articles/custom-manufacturing-fabricating/automation-electronics

38. Trading Ecnomics. (2015, Jun. 27). *China Interest Rate*. Retrieved from http://www.tradingeconomics.com/china/interest-rate