Design, analysis and fabrication of robotic arm for sorting of multi-materials

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Abstract

This paper presents about design, analyses development and fabrication of robotic arm for sorting multi-material. The major problem that urges the initiation of the project is the fact that manufacturing industry is growing at relatively faster rate. Most of the company produce high load robotic arm. Less company create light weight, and affordable robotic arm. As the result, light weight and affordable robot is develop to cover this issue. Plastic material was used to construct the body of the robotic arm, and an optical sensor was implemented to provide basic recognition of object to be carried. The robotic arm used five servomotors for overall operation; four for its joints, and one for the gripping mechanism. The gripper was designed and fabricated using Perspex due to the light weight and high strength of the material. The operation of the robotic arm was governed by Basic Stamp programming sequence and the device was expected to differentiate material and other objects based on reflective theory, and perform subsequent operations afterwards. The SolidWorks was used to model the detail design of the robotic arm, and to simulate the motion of the device.

1. Introduction

A robot arm is a device which is to do performs automated task, either according to direct human supervision, pre-defined program, set of general guideline, using (artificial intelligence) techniques. The task is to replace human work, such as construction, carrying heavy thing or hazardous material. The action of taking material or move an arm, is control by computer programming or microcontroller. The robot arm is consist of robot arm, gripper and control program.

A mechanical gripper is a robot component that uses movable, finger like levers to grasp objects. It can be used for various types of industrial and household applications. In this case, the mechanical gripper is utilized for industrial pick-and-place purposes. Some mechanical grippers are controlled by servomechanism while others are driven by some linear actuation mechanisms

The most commonly used type of mechanical gripper is the parallel type. This type of mechanical gripper uses two finger like levers (that move towards each other) to hold objects by applying adequate amount of normal force onto the object. For holding circular objects, a mechanical gripper with three moving levers can be used.

2. Background Study

2.1 Previous Robot Arm

Various types of robot are available and can be search from the internet. For example, there are construction robot, manufacturing robot, aerospace exploration robot ,medical robots ,industrial robots and the others.

Morgan Petterson had created a robot arm named Arm controller For Robot Waiter. The objective of his project is to control or command the robot joint in order to shift the gripper into a certain position. The robot waiter is supposed is to replace real human work which is serve customer seated by a table on command.

The robot waiter consists of the robot arm which is the robot able to control system and visual servoing system. The control system and the visual servoing system was located in different specified places in computer.

A lots of position calculation had to be calculate in order to attain the specific point in space. The joint coordinates of robot arm receive the data from the program. No error should be appear when inserting the command into the program. The objective of the project is to able to pick and place an object. The arm coordinate system must able to guide the robot gripper to the position. When facing moving object, the system need to find way to handle it. Example, a customer decided to move a glass while we are trying to fill the glass. That is a slow and small movement. Summary Communication, control system of the robot arm and technical characteristics is most important and it able to discrepancy a robot arm.

2.2 Force and Torque Calculation

Mechanical of material is a branch of mechanics that studies the relationships between the external loads applied to a deformable body and the intensity of internal force acting within the body. To design any structure of machine, the first thing must to apply is the principles of statics to define the force acting on the both and within its various members.

There are four different types of resultant loading can be defined which is normal force (N), Shear force (V), Torsion moment or torque (T), and Bending moment (M).

If a robot arm is long and slender, as in the case of a rod or beam, the section to be considered is generally taken perpendicular to the longitudinal axis of the arm. This section is referred to as the cross section. In most robotic appliance, the robot is subject to a breed of external force. These force may be due to disturbance, interaction with work piece, impact with the obstacles, etc. The performance of the robot controller of this situation is more critical to the success of the operation.

To make an extendable arm, a linear actuator can be used provide linear motion along vertical and horizontal axes. To produce such driver at an affordable cost, a combination of belt drive and a motor is more preferable. Nevertheless, selecting a suitable motor for the application requires a very detailed calculation to avoid over sizing or under sizing of the motor.

According to the Panasonic Motor Selection Guide (2007), the procedure of the motor selection must follow the sequence that includes a) Determination of driving mechanism, b) Calculation of the motor speed and the load, c) Checking requirement of specifications, d) Selection of motor model, e) Temporary selection of motor, f) Final determination of the motor and gear head. Load torque, moment of inertia and speed which are converted to those at the motor output shaft have to be calculated. Positioning accuracy, holding of position, speed range and the other environmental resistance need to be checked afterward.[8]

As for the belt-driven vertical axis lifting component, the mechanism resembles conveyor belt carrying loads. Selection of suitable motor must be based on this sort of driven method. According to the literature titled "Motor Torque Calculation" published by Leadshine Technology Co.,Ltd.(2010), load inertia of the system can be calculated using a series of equations that give the separate load inertia of each component. Load inertia exerted by the applied load, the pulleys and the belt can be calculated one at a time. To calculated the load inertia of the applied mass (J_L), equation below should be used. D symbolizes pulley diameter while m_L denotes mass of applied load. All units should be expressed as SI units.[9]

$$J_L = \frac{1}{4} m_L D^2$$

Leadshine Technology Co. Ltd stated that pulleys' inertia moment (J_P) should be calculated using the following equation. Note that m_P denotes mass of one pulley. If two identical pulleys are used, the calculated value should be multiplied by two.[9]

$$J_P = \frac{1}{8} m_P D^2$$

Belt's load inertia cannot be neglected as belts are mostly reinforced by stronger material such as Kevlar or steel cord. To calculated belt's load inertia (J_B), Leadshine Technology Co. Ltd. suggested the equation stated as follows to relate with mass of belt (m_B).[9]

$$J_B = \frac{1}{4} m_B D^2$$

The total load inertia of the system should be summed and yield the reflected load to the output shaft of selected motor. Thus, the total load inertia of the system (J_T) is expressed as the following equation based on Leadshine Technology Co. Ltd.'s literature.[9]

$$J_T = J_L + J_P + J_B + J_M$$

Next, acceleration torque (T_a) required to be provided by the motor should be calculated using the value of total load inertia of the system and the desired angular acceleration (a) by utilizing the following equations stated in the literature named "Motor Torque Calculation" published by Leadshine Technology Co. Ltd. ω_0 and ω_1 denote initial and final angular velocity respectively while t is a symbol for time for velocity change.[9]

$$T_a = J_T a$$

$$T_a = J_T \frac{\omega_1 - \omega_0}{t}$$

As for load torque (T_L), there are two different ways to express the relationship between the applied mass and the load torque required to carry the mass. Leadshine Technology Co. Ltd. stated that load torque calculation must consider the inclined angle of the axis of movement of applied mass, as well as the efficiency of the motor. The efficiencies of motors usually vary between 85% and 95%. Equation 2.7 shows the expression of the relationship. In this case, g, α, and η symbolize gravitational acceleration, angle of inclination of moving plane, and motor efficiency respectively. μ denotes the coefficient of friction of sliding surfaces.[9]

$$T_L = \frac{m_L g D(\sin\alpha + \mu\cos\alpha)}{2\eta}$$

Nevertheless, Panasonic Motor Selection Guide (2007) expressed the relationship differently. The literature did not consider the efficiency of the motor that drives the pulleys. Also, it expressed the gravitational effects in terms of external forces acting on the applied mass.[8] The equation is given as follows and F denotes the external force acting on the system.

$$T_L = \frac{D(F + \mu m_L g)}{2}$$

Total calculated torque (T_T) can be obtained by summing up the value of load torque and acceleration torque, according to Leadshine Technology Co. Ltd.[9] Mathematically, the relationship between these parameters is expression in the following equation:

$$T_T = T_L + T_a$$

Also, Leadshine Technology Co. Ltd. suggested the usage of safety factor when selecting suitable motor for the application. The safety factor (K_S) is merely a constant, user-defined factor to serve as multiple of the total calculated torque.[9] The required motor torque (T_M) is given by the following equation:

$$T_M = K_S T_T$$

2.3 Motor for Automation

Basically, the most comment used for robot arm"s motor are stepper motor and servomotor. These two motor had different usage when operating it. The author of " Robot Building For Dummies " , Mr. Roger Arrick said that a stepper motor"s shaft has permanent magnets attached to it. Around the body of the motor is a series of coils that create a magnetic field that interacts with the permanent magnets. When the coils are moving on and of, then the magnetic field will causes the motor to move.

In this robot arm project, servo motor play a very important roles. In the market now a days, there are many companies are making servo motor such as Hitec, Tower Hobbies, Cytron, Airtronics, RC and the others. In this project, one types of servo motor been used such as Tower Hobbies SG5010. The different of precision, speed, strength and torque will affect the price of servomotor. Servo motor are DC motor coming along with a servo mechanism function for precise control of angular position. Servo is refers to an error sensing feedback control which is used to correct the performance of a system. Servo motor are divided into two types which is rotate from 0 ° to 180 ° and 0 ° to 360 °. Servo motor usually does not rotate continually. Servo motor "s rotation is restricted in between the fixed angles and it is used for precision position. Normally, the servo motor are used in robot arm based and elbow , RC toys likes RC helicopter or car and the others.

The 2.1 figure is the servomotor spine and the servo horn. Splines are ridges or teeth on a drive shaft that mesh with grooves in a mating piece and transfer torque to it, maintaining the angular correspondence between them. However, servo horn is a small nylon or plastic or wheel that attaches to the output of shaft of a servo. The purpose of the servo horn is to connect the servo to control linkage if necessary. Normally there are holes at different point on a servo arm to facilitate adjustment in control surface deflection and leverage.

The output of shaft and the arm is to splined in order to transfer torque from one to each other. The arm just able to fix to a number of preset positions. Normally different servo horn have its own purpose. Chose a suitable servo horn is very important to a servo motor.

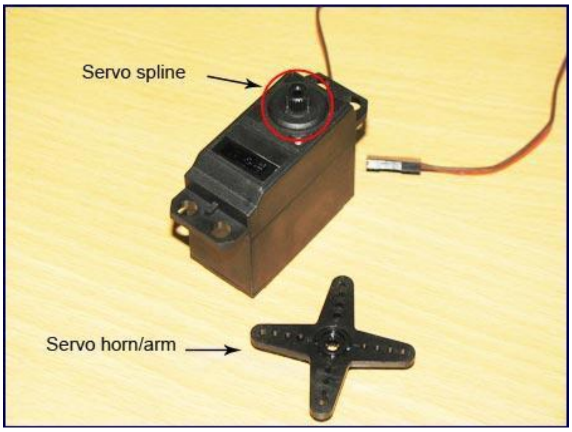

Figure 2.1 : Servo Motor

There are three connector(wire) which is ground, positive supply to the servo motor and control signal wire. There wires of a servo motor are coded different colour. The red wire is the DC supply lead and must be connected to a DC voltage supply in the range of 4.8 V to 6V. The brown wire is ground. However, the third wire (yellow) is to provide control signal for different manufacturers.

Pulse of variable width was send by servo which is to control it. The pulse was send by using wire. There are a few parameters for the pulse which is minimum pulse, a maximum pulse and a repetition rate. Given the rotation Constraints of the servo, neutral is defined to be the position where the servo has exactly the same amount of potential rotation in the clockwise direction as it does in the counter clockwise direction. The different of servo motor will have different constraint on their rotation but they all have a neutral position, and the position is always around 1.5 milliseconds.

Figure 2.2 is the duration of pulse with signal. There are two types of pulse which is maximum and minimum. The duration of the pulse width signal is 20ms.[5]

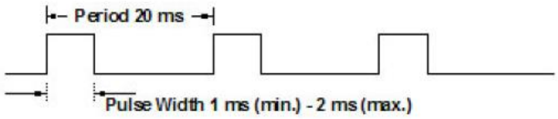

Figure 2.2: Duration of Pulse Width Signal

The speed of servo motor is control by the switches which is open and close in order to make use of the average voltage across the motor. Pulse Width is the duration of a pulse that applies to the control wire. The direction of servo motor is determined by the length of the pulse. For example, a 3.0ms pulse will causes the motor to turn 180 degree clockwise.

The servo motor also able to move and hold a position by giving the command. The maximum amount of force the servo motor can carry out the torque rating of the servo motor. The position of servo motor unable to last long so, the position pulse must rekey in to make the servo motor to stay in position.

Figure 2.3 shown 3 types of pulse which is, minimum pulse = 1 ms, neutral position which is 1.5 ms wide and the maximum pulse = 2 ms wide. When pulse width 1ms is 0 position. Pulse width 1.5ms is 90 position and finally 2.0 ms is 180 position. The three position is the servo motor turn rate.[7]

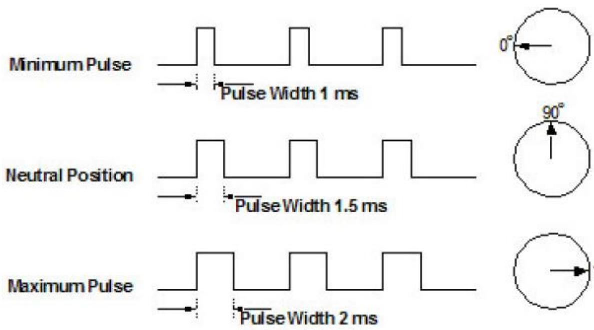

Figure 2.3: Servo Turn Rate

2.4 Mechanical Gripper

The mechanisms of robot arm gripper can be classified into some ways. The style of finger movement is the first ways. The closing and opening gripper can be actuated by either pivoting, or linear or translational movement.

The purpose of mechanical gripper of robot arm is for grasping an object with its mechanically operated finger. It is used as end effectors in a robot arm. Normally in industries, two fingers for a gripper are already enough to hold a material. But, more than two fingers are also can be use based on the different application and purpose. Most of the gripper now a days are replaceable type because it can easily change for other intention.

Drive system is needed to establish the input power of hydraulic, pneumatic and electric robot arm. The output(power) is sent to the gripper to make the finger to move. Beside that, it also can make the finger to hold an object by open and close. The main point is , an enough force must be provide to hold an object.

There are two different way to hold an object by a mechanical gripper such as :

- By applying more gentle and soft material finger pads(cushion)
- By applying the finger pads similar with the shape of the work part

For the first method , the finger must be able to provide enough force to grip or hold the object. To prevent scratches on the object, a gentle and soft pads are need when fabricating the fingers. Then, the coefficient friction and the surface of finger will increase and become more better. This method is more low cost and easy to make it. Slipping can be prevent by designing the gripper using the force exerted.[5]

$$(\mu)(n)(F) = w$$

μ = coefficient of friction between the object with the fingers

n = number of fingers contacting

F = force of the gripper

w = weight of the object

The (1) equation must be replace to (2) equation if the weight of the object is more than the force (because cause slippage). During fast griping work, the weight of the object will increase into double.

$$(\mu)(n)(F) = wg$$

g = g factor

3. Research Methodology

Normally, the design projects abide by following the workflow of product development process used by EMS companies and other product development departments.

The systematic design process is beginning from gathering design input, then follow by design and development. Next is design output are generate then finally is design review will be conduct. If the design is successfully passed the review, approve document will be issue if it is required by certain corporations. The design will then b realize by making of prototype. Any design should be tested for verification and if there is no changes is required, then the design validation (e,g. field trial of medical/healthcare product) will be conducted. The design transfer will be done if the design process passes the trial period.

At the beginning of the process, information on requirements for the expected product will be collected. For this case, the material to be picked, the required motion, major dimensions, and other related data regarding the robotic arm will be acquired by considering the need and expectation of the users. Design input will be generated, and a series of product design specifications will be proposed to supervisor.

Later on, the design and development stage will be started. Basically, to simplify design process, the expected product will be divided into a few proper modules where concentration and attention of designer will be paid to one module at a time. This is an effective approach to organize design data. By using this method, design data will not be crowded and designer will be able to trace problems easily as they arise. During this stage, researches will be done to gain knowledge or information in order to obtain more understanding on the current design issues. Discussions between designer and advisor will be frequent to avoid misunderstanding and thus misleading to errors and mistakes.

Next, design output will be generated. This is a stage where drawings and 3D models will be produced by designers. All design data must be arranged accordingly and comprehensively to smoothen later processes. Drawings of parts to be custom-made must be provided in order to obtain desired product from vendors/suppliers (if any). All drawings must include comprehensible signs and symbols describing geometric dimensioning and tolerancing (GD&T). This is a way to communicate the desired parts geometry to the fabricator of the parts. Even if the parts are to be fabricated using in-house machining devices, by the designer himself/herself, drawings should be done comprehensively for future development of product (i.e. mass production). Assembly drawings are to be generated for reference of other personnel (if any) involved in the assembly process.

Then, a design review should be conducted thoroughly based on the generated design outputs by independent reviewers. This is to ensure no overlooked factors by the design engineers during the stage of design and development. The reviewer should comment on every doubted area regarding the design and the design engineer is ought to answer to the comments. A meeting should be conducted between the reviewer(s) and the designers to discuss about the issues arose. Reviewer(s) may point out their ideas to improve the design of the product but the designers should always make the final decision by considering all the factors. If there are any changes required, the design process should be brought back to the design and development stage and the consequent stages will be repeated.

If it is required, approve documents should be issued after the stage of reviewing. Documentation and papers describing the design data and their approval information should be kept during this particular stage. This is a record-keeping process and it is done basically by corporate organizations to ensure proficiency of the company and traceability by customers.

Afterwards, the designed product will be fabricated either by in-house facilities or be outsourced. Outsourcing of part fabrication must be done under a condition that the vendor/supplier must be approved or certified for their skills and services. Status and progress of outsourced parts must be known at all time to avoid delay of parts and thus the entire development process. Parts are to be assembled to form a complete product during this stage. Assembly of parts must follow the previous design data (i.e. assembly drawing) produced at the earlier stage.

Design verification or specification tests should be conducted after the construction stage. At this stage, all proposed specification will be tested to see whether the product delivers its function as promised. Results should be recorded comprehensively for future improvements or data interpretation by other teams. If the product is able to perform adequately based on the proposed specification, the design process will move on to the next stage. Otherwise, it will be brought back to the design and development stage where changes will be made and subsequent stages will be undergone again.

The overall operation of the robotic arm is programmed and controlled using BASIC programming language. In computer programming, BASIC (an acronym for Beginner's All-purpose Symbolic Instruction Code) is a family of high-level programming languages. The original BASIC was designed in 1964 by John George Kemeny and Thomas Eugene Kurtz at Dartmouth College in New Hampshire, USA to provide computer access to non-science students. At the time, nearly all use of computers required writing custom software, which was something only scientists and mathematicians tended to do. The language and its variants became widespread on microcomputers in the late 1970s and 1980s. BASIC remains popular to this day in a handful of highly modified dialects and new languages influenced by BASIC such as Microsoft Visual Basic. As of 2006, 59% of developers for the .NET platform used Visual Basic .NET as their only language. The BASIC Stamp is a microcontroller with a small, specialized BASIC interpreter (PBASIC) built into ROM. It is made by Parallax, Inc. and has been popular with electronics hobbyists since the early 1990s due to its low threshold of learning and ease of use (due to its simple BASIC language).

If it involves medical/healthcare products that is potentially harmful to patients or is integrated to patients' physiological system, the product should undergo the design validation stage where field trials come in. Mostly, field trials for medical product will be done for 2 years. If the design of the product is accepted during this stage, then the process will be moved on to the nest stage.

The final stage of the design process is to transfer the design and to deliver outputs. The completed design should be transferred for further development (e.g. process design, tool-making). The designer will then need to communicate the essence of his/her design of product to help in the later development. Transfer of design can also be done on the purpose of delivery to customer as for EMS companies. Such companies sell their design of product as a form of service. Engineers of EMS companies work on a customer's product development project and the customer pays the company in return. The completed design belongs to the customer and they will have the total right of using the design.

This design process is acceptable internationally and a proper design workflow. Product development departments use this workflow as their guideline to products of better quality and simpler record-keeping procedure. By using this guideline for the design project, a better product and a more organized process could be achieved.

The flowchart below shows the overall workflow of the described design process. All looped processes must have the subsequent stage repeated, and no orders of stages should be rearranged.

After have the actual parameter or dimension, drawing process is begin. Solidworks software is chosen to draw all the 3D drawing. Then, assemble all the part which already draw by using solidwords software. After had done all the assemble, convert the assemble file to ansys software file. ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers.

So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment.

ANSYS software with its modular structure as seen in the table below gives an opportunity for taking only needed features. ANSYS can work integrated with other used engineering software on desktop by adding CAD and FEA connection modules.

Ansys software is used for analysing the deformation of the gripper. The force that using for the deformation is 0.029N, 0.028N, 0.027N, 0.026N, 0.025N.

The figure 3.1 below is a analysis about the gripper. The minimum and maximum area is the area which is applying the force. Different force applying in the maximum and minimum area. There is 5 force that apply in the area which is 0.029N, 0.028N, 0.027N, 0.026N, 0.025N . The reason using the 0.029N - 0.025N because want to the motor maximum torque is 0.027N. By increasing and decreasing the 0.001N,we can know the different deformation.

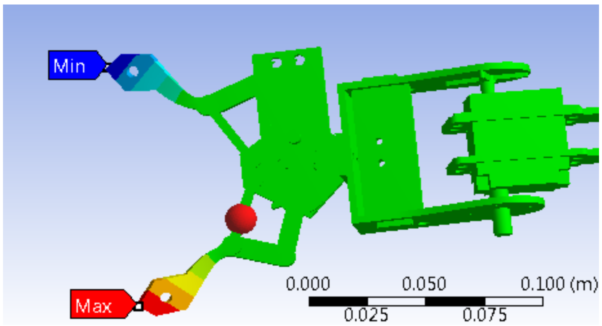

Figure 3.1: Gripper with ansys software

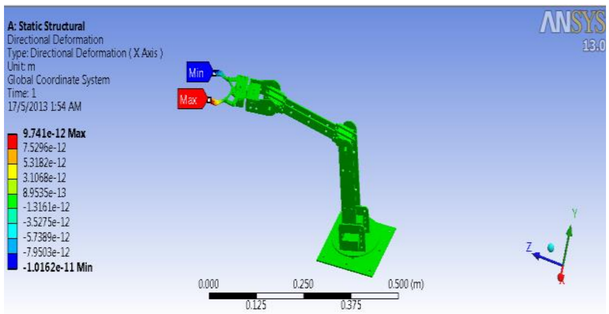

Figure 32: Gripper reaction force when applying different force

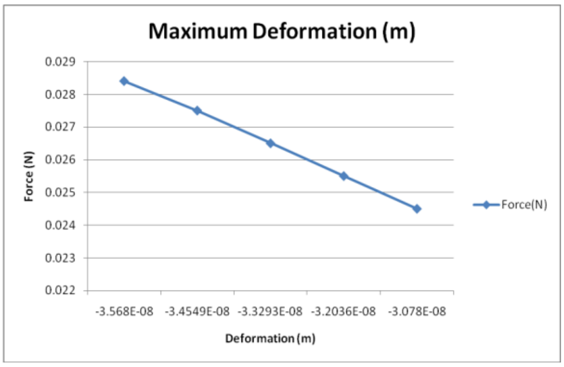

Figure 3.3: Maximum deformation

Maximum Deformation(m)	Force(N)
3.4354E-08	0.0284
3.3266E-08	0.0275
3.205E-08	0.0265
3.0846E-08	0.0255
2.9637E-08	0.0245

Table 3.1: Maximum deformation data

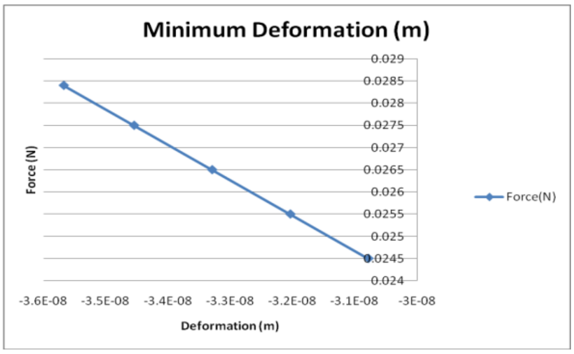

Figure 3.4: Minimum deformation

Minimum Deformation(m)	Force(N)
-3.568E-08	0.0284
-3.4549E-08	0.0275
-3.3293E-08	0.0265
-3.2036E-08	0.0255
-3.078E-08	0.0245

Table 3.2: Minimum deformation data

Result and Discussion

4.1 The Construction of the Robotic Arm

The structure of the robotic arm was built by four assembly part which is base assembly, gripper assembly, arm assembly and finally is elbow assembly. The robotic arm design is very important because it able to easily find replacement robot parts or components during maintenance of the part. Beside that, a good design will helps in providing comprehensible design concept. As the result, machines and devices will more easier to be assembled and managed.

Selecting materials of the component robotic arm is based on the mechanical properties such as hardness, density, strength and the others. Plastic (Acrylic / Perspex) material was chosen to create the structure of the body robotic arm and links because of the low-density feature and affordable cost. Metal(screw) was picked to join all the robot" links due to its high density, easy to find and low cost.

Screws and nuts ranging from size M3 to M4 were used as connections for each part of the assembly. Washers were needed to avoid loosening of screws and nuts due to vibration that occurs during running the robotic arm.

Most of the robotic part is exchangeable and easy to purchase. Example servo motor, and Perspex plate.

4.2 The Main Assembly

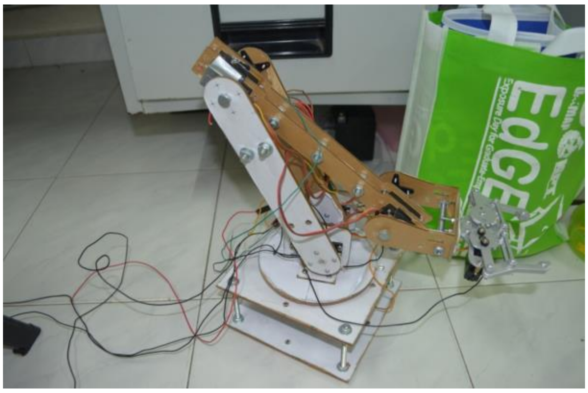

Figure 4.1: The Main Assembly

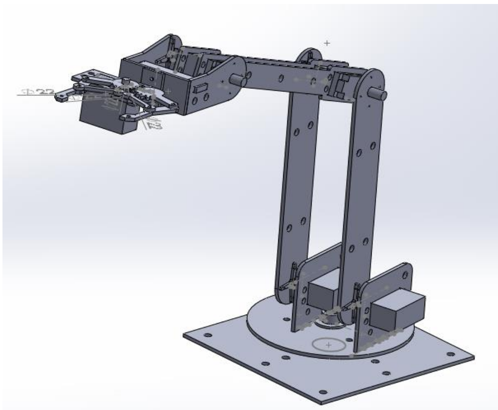

Figure 4.2: The Solid Works model of Main Assembly.

Figure 4.1 shows the main assembly of the robotic arm . The main assembly of the robotic arm was involved two sub-assemblies which is the arm and base assembly. The 3D construction of the robotic arm is by using Solid works.

Figure 4.2 shows the Solid works model of the robot main assembly. The two sub-assemblies were joined by using screw and nut. Suitable washers were used to prevent loosening when operating the robotic arm.

4.3 Robot DOF(Degree of freedom)

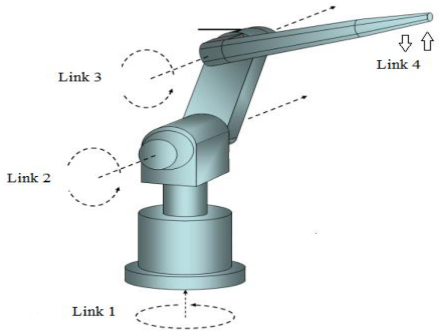

Figure 4.4: Robot DOF (Degree Of Freedom)

In figure 4.4 there are 4 degree of freedom in the robotic arm which is link 1, link 2, link 3 and link 4. 4 link of a robotic arm able to make the movement more flexible. The more location the robot arm able to go if the DOf is more.[6]

4.4 Discussion

Finally working on the assembly had done. The assembly of the robotic arm was successful with the minimal rework needed.

The components used to make the assembly can be easily found and replaced from local hardware store and no exotic manufacturing processes were used to fabricate all the customized parts. This enables convenient replacement of parts and components when the contemporary ones are defected. Furthermore, the design data and output (e.g. part drawings and assembly schematics) allows future improvement by students of the coming batch.

During the process assembly the spinner part with the motor. Problem was founded when assembly the spinner. Screw and nut was loosen when the motor is rotating. As the result by using bicycle tyre rubber to solve the problem.

The moment assembly bracket with the spinner. A problem also occur when the bracket leg fix to spinner hole. The bracket is unstable and unable to stand itself. By using glue to stick the bracket leg area with the surface of spinner is an idea. Unfortunately, in engineering every component or parts which is our design must be flexible and rechargeable.

Beside that, assembling between first elbow and second elbow also occur some problem. The second elbow is shaking because of the servo motor. To overcome the problem, a spring was added to avoid and reduce the shaking problem.

5. Conclusion

The first objective of the project was to design a working robotics arm with ability to perform sense-pick-and-place function. To design a working robotic arm with ability to perform sense-pick-and-place function. The design of the robotic are was stared from the prototyping stage. Drawings and assembly schematics were generated as design data to be kept for future reference if improvements were to be done to enhance the developed device in any possible way. Therefore, the first and third objectives were achieved. The prototype of the robotic arm was successfully developed and it was able to sense-pick-and-place function. It was tested to give a clearer image on its overall reliability. The overall successful rate of the robotic arm to perform its tasks correctly was 90%.

The second objective of the project is to do analysis of mechanical properties of the design of the robotic arm. Calculations were done for the required shear stress on the finger gripper connection hole. This procedure was important to know about shear stress for the gripper. The second objective of the project was therefore achieved..

Acknowledgement

First and foremost, I would like to use this statement to express how honored I am to be able to work with Dr. Zol Bahri Razali for this final year project organized by Universiti Malaysia Perlis. If there is only one comment to make, I will have to say that this final year project has undoubtedly given me a chance to pursue and explore all the things I wanted to achieve ever since I started my engineering study. I wouldn't say that I have achieved greatness, but at least I am off a great start.

Certainly, I have to express my gratitude towards a few persons and organizations. The person I would like to thank firstly should be my supervisor, Dr. Zol Bahri Razali, who was also my reliable tutor. He was the one who granted me the opportunity to work on the project and thus open up all the other possibilities.

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