

Design and Feasibility Study of Cost Efficient Robotic Arm for Object Pick-and-Place Application

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ABSTRACT

In this study, our aim is to mimic object picking application with robotic arm from shelves in a warehouse environment, and our goal is to develop a robust, low-cost, and practical robotic arm system for that purpose. The designed robotic arm correctly picks the desired items from shelf locations and place them into desired bins. Fully autonomous robotic arm operation is accomplished using developed algorithms and Arduino microcontroller. The developed system is tested and evaluated in terms of (i) number of items picked-and-placed correctly, and (ii) increase in the number of objects picked-placed under a certain desired time. For performance evaluations, object weight/size capability results, results of maximum load, and required force results are presented.

Keywords

Mechanism Design, Automation, Robotic Arm, Kinematics.

1. INTRODUCTION

In today's world, the robotic systems are becoming a part of our daily life with a new application field every day. They are used in the wide range of application areas including healthcare, manufacturing, agriculture, and education. One of the most popular areas of robotic system use is warehouse automation for pick and place application.

There are several attempts presented in the literature with bio-mimicking their natural counterparts in the nature, such as octopus arm [1]-[4], fish [5], and elephant trunk [6]-[7]. There are also several examples in the literature for pick-place application using robotic arm [8]-[10]. Although all these studies are presented in the literature, very little attention is given the cost effectiveness of the aforementioned platforms.

In the framework of Enterprise - Engineering Design class in Mechanical Engineering Department at University of West Florida, our primary goal is to develop full autonomous robotic arm for pick-and-place applications. To accomplish this goal, we create smaller tasks as following:

- A comprehensive feasibility study analyzing budget and technology constraints and provides justification for the selected components.
 - Defined electronic components and capabilities.
 - Defined Bill of Materials for all parts.

- A completely designed model for the entire workstation, with robust static, dynamic, and kinematic analysis for the robotic arm assembly based on requirements defined in the feasibility study.
 - Performance per feasibility study for desired position, velocity, acceleration, and force input-output.
 - Completed design for entire workstation including shelves, retrieval bin, and robotic arm assembly.
- A complete hardware build under the project budget of \$500.
 - A fully operational hardware build.
 - Workstation to fit inside 60cm long x 90cm wide x 90cm high workspace.
 - Assembled workstation including shelves, retrieval bin, and robotic arm assembly.
- Complete software development and integration to facilitate arm operation and fulfill system performance requirements.
 - Phase 1: Autonomous motion to predefined locations using algorithms for motion control and inverse kinematics for position control.
 - Phase 2: Detection and recognition of items using object detection algorithms.
 - Phase 3: Accurate location detection of and motion toward items.
 - Phase 4: Accurately identify items and place them in bin.
 - Phase 5: Calibration of speed and accuracy of motion and visual detection systems - min. 4 items to bin in 5 minutes.

The remainder of the paper is organized in the following sections. Section 2 presents Hardware Description. Feasibility analysis is explained in Section 3. Software Description and Experiments are given in Sections 4. The conclusion is presented in Section 5.

2. HARDWARE DESCRIPTION

The hardware designed and developed in this study includes the robotic arm and the workstation which has equally-sized shelf locations arranged vertically on one end, the retrieval bin on the other end, and the arm assembly in the center. The shelf unit has nine locations in a 3 x 3 grid pattern at one end of the workstation. We select the lengths of the arms, considering extreme positions and using graphical method, as follows. Arm 1 is 25 cm, Arm 2 28 cm, and Arm 3 is 16 cm (Fig. 1).

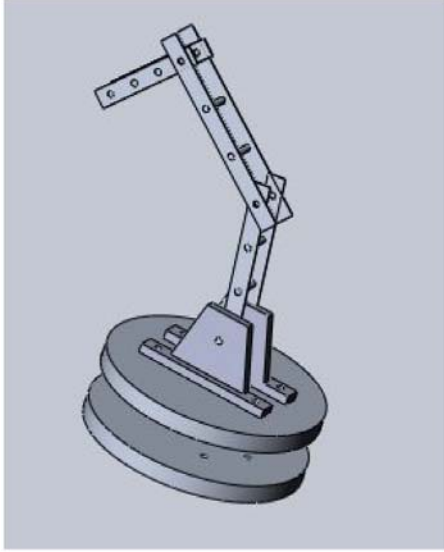


Figure 1. 3-Link Robotic Arm

Since each arm length are different from each other, we decide to keep a simple model of an arm using Aluminum 6061 Alloy with supports in the middle to give the arm more torsional stiffness. The arm width is specified considering an available width that a standard servo could be mounted into. We do not select other materials such as PVC, wood, or abs plastic considering the effects of workability, weight, or even the elasticity of the material. Using this alloy is the best option as it is much more durable and gives it a robust appearance.

The grabber method at the end of robotic arm is selected as a vacuum system. We use a small, aluminum tube with a soft suction device to easily mount object to tip of the arm. We utilize the Sparkfun Vacuum Pump that works with a pressure range of 70-kPa to 220-kPa with the power potential at 12V. In our preliminary trials, we realize that sucking power is not quite satisfactory, thus we utilized a vacuum chamber to draw out a stronger vacuum for effective use on initial contact. We build a 790-cm³ vacuum chamber to draw out a larger suction by building up the vacuum pressure of the chamber. The corresponding volume calculations are given below.

$$\begin{aligned}
 V_{Tank} &= V_{Pipe} + 2V_{Cap} \\
 V_{Pipe} &= \pi R^2 h = \pi(3.85cm^2)(14.0cm) = 652cm^3 \\
 V_{Cap} &= \frac{1}{6}\pi h(3a^2 + h^2) = \frac{1}{6}\pi(2.0cm)[(3(4.5)^2 + 2^2)] \\
 &= 67.8cm^3 \\
 V_{Tank} &= V_{Pipe} + 2V_{Cap} = 652cm^3 + 2 \cdot 67.8cm^3 \\
 &\approx 790cm^3
 \end{aligned} \quad (1)$$

The different weights of the arm at the joints are a decision factor in the selection of our servos. Due to the weight of the arm at the first joint, we select a stronger servo (SunFounder Metal Gear Digital RC Servo Motor High Torque) to give a sufficient amount of torque. This servo has a stall torque of 15 kg/cm at 6V of power. The other two servos for the next joints are both the same which can handle up to a stall torque of 2.3 kg/cm which is

sufficient enough for carrying the user defined items. The Pixy 2 Camera is selected for the object detection and position detection applications. We utilize an Arduino microprocessor that allows us to control the robot arm autonomously.

3. FEASIBILITY ANALYSIS

3.1 Statics

We use Solidworks statics analysis to give us an estimate to see where the most stress is occurred in the main components of the arm. The heaviest object used in the system weighs 80-gram with a force of .7989 N at the end. The downward force at the angles of each arm does not affect the structure of the arm as the weight does not exert a force great enough for any plastic deformation (Fig. 2). The stress at the joints are not significant enough for it to reach failure given that we are using Aluminum 6061 Alloy. The weight of the arm and the servos all contributed with the load at each joint, respectively. The greatest stress is depicted at the point of contact for each connecting joint.

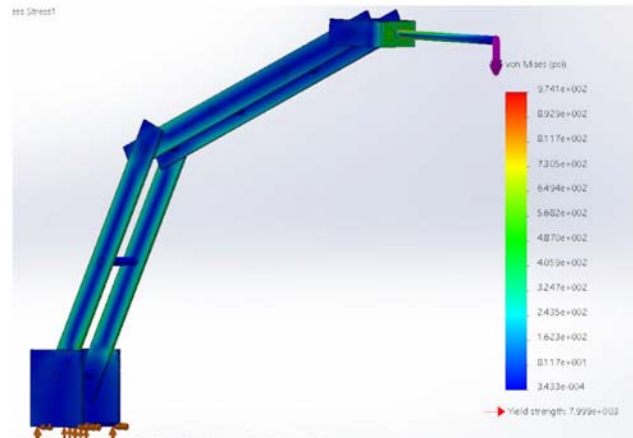


Figure 2. Full Robotic Arm Statics Analysis

3.2 Kinematics and Dynamics

We calculate the maximum angle inputs for the joints considering the extreme end points in the workstation (top-bottom corner shelves). Using forward kinematics and the selected arm lengths, the angles for each joint are confirmed that are in the operation range of servo motors (Fig. 3).

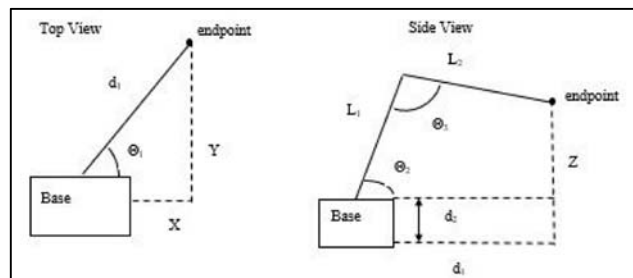


Figure 3. Forward Kinematic Analysis

The dynamic analysis is performed considering a 1-lb force on the arm tip and a rotational force around the base of 120 rpm. Angular and linear displacement, velocity and acceleration are taken for each joint and the end of the arm. All analyses are done using Solidworks Motion Study with an applied motion and applied force. After satisfying all static and dynamic force requirement, we build the robotic arm, as well as the workstation, as depicted in Fig. 4.

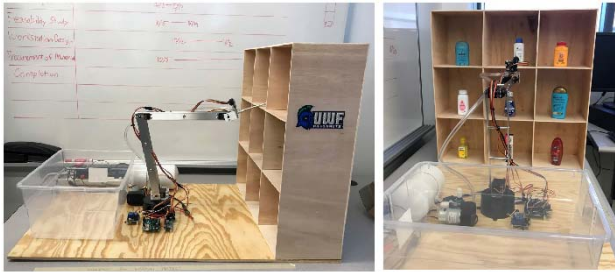


Figure 4. Robotic Arm and Workstation

3.3 Budget

At the beginning of the project, our assigned budget is \$500. One of the most important accomplishments of our study is to design and build the complete system under our assigned budget. The item breakdown is shown in Fig. 5. The main cost of the entire project appears to be the vacuum grabbing system. Upgrades for the vacuum grabber system are totaled almost \$66. These upgrades include a 12V vacuum solenoid, 12V relay, and an industrial suction cup.

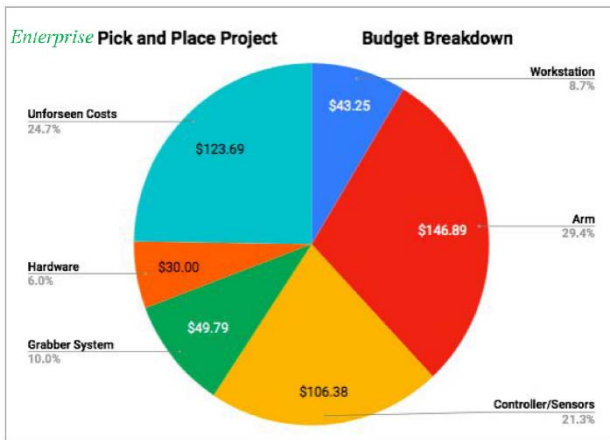


Figure 5. Budget Breakdown

4. SOFTWARE DESCRIPTION AND EXPERIMENTS

In this project, we develop a computer program that includes algorithms for automating the functionality of the robotic arm. The computer program consists of different requirements to meet as follows: automation of arm motion, item detection, item

identification, location accuracy, and successful item placement. We divide the computer program development in different phases. The first phase is to have automation using pre-defined shelf locations using inverse kinematics. The corresponding equations are given below (Fig. 6).

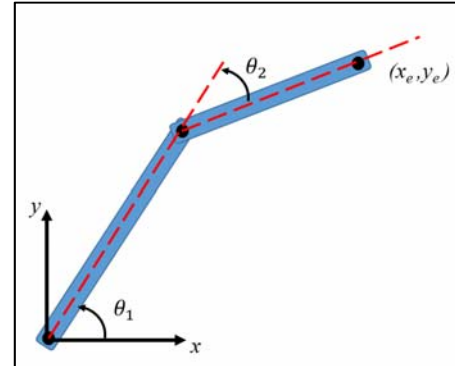


Figure 6. Inverse Kinematics

$$\theta_1 = -\cos^{-1} \frac{x_e^2 + y_e^2 - l_1^2 - l_2^2}{2l_1l_2} \quad (2)$$

$$\theta_2 = \tan^{-1} \frac{y}{x} + \tan^{-1} \frac{l_2 \sin \theta_2}{l_1 + l_2 \cos \theta_2}$$

We develop a state machine in Arduino IDE using inverse-kinematics, and successfully accomplish autonomous object pick-place application. In order demonstrate that, we create an “ARGOzon Menu” for receive user input (Fig. 7). User enters location number of selected item and then arm moves to pre-determined (x,y) coordinates of the corresponding shelf using inverse kinematics. After the arm reached the shelf locations, the suction system turns on, the object is grabbed, and the arm moves to the bin location. In the final step, the arm moves down, approaches to the bottom of the bin, and the suction system turns off for releasing the object (Fig. 8). In phase 2 to phase 5, item detection using the Pixy2 camera is used.

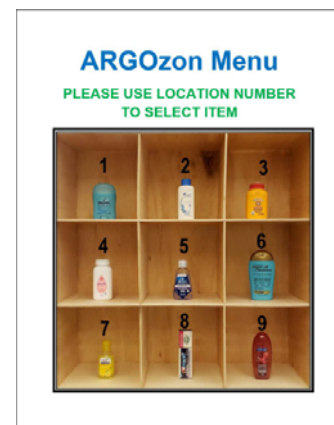


Figure 7. ARGOzon Menu

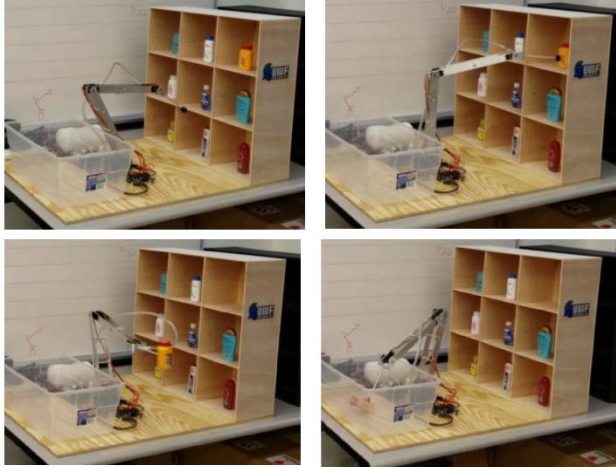


Figure 8. Autonomous Operation of Robotic Arm

5. CONCLUSION

In this study, our goal is to develop a robust and cost effective robotic arm for pick-place applications. We design, develop, and build a 3 link robotic arm and complete workstation with shelf units and object bin. We perform static and dynamic analyses, and we select robotic arm materials, the grabber method as vacuum system, and the servo motors and microprocessor. We complete the entire system under our assigned \$500 budget. Further, we develop computer program that includes algorithms for autonomous operation. Using the ARGOzon menu, user selects desired object and the robotic arm pick the corresponding object from shelf location and place into the bin. The future works, Phase 2 to Phase 5, include object detection and object location detection using the Pixy2 camera.

6. REFERENCES

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