Restoration of the Baxter Robot for Research and Teaching

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Abstract

This paper covers the restoration of the Baxter Robot project at the University of Plymouth, which ended in 2016. This includes an in-depth look into the Baxter robot and surrounding field, which incorporates topics such as teleoperation, robot-human interaction, robotics arms, industrial robotic and domestic-home robotics. As part of the Baxter robot's restoration a replacement end effector has been designed using Autodesk Fusion 360. The design underwent a series of structural analysis tests in the form of finite element analysis (FEA) simulation software, which concluded that the models designed could endure the stress testing, whilst retaining a factor of safety above five. A simulation in MATLAB is used to show the full range of Baxter's arms in 3D. Additionally, a 2D representation can be seen, mapping all the possible end effector positions of one of Baxter's arms. Additionally, the inverse kinematics are also derived and demonstrated in a simulation in MATLAB. The project also used the Rethink Robotics ROS Baxter robot simulator carry out interactive testing with the Baxter robot using the keyboard. Lastly, an interactive programme in MATLAB was used to carry out semaphore signalling, which was used to spell out Baxter, when the user inputted the characters. The paper then concludes that the Baxter robot retains a lot of value for research and teaching purposes and that the project provides a starting point for future projects to continue from.

Keywords

Baxter, Kinematics, Semaphore signalling, MATLAB, Simulation, Autodesk Fusion 360, Finite Element Analysis (FEA), Human-Robot Interaction, Industrial Robotics

1. Introduction

The overall focus of this project is the restoration of the University of Plymouth's Baxter Robot (Robots IEEE, 2020a), which has been out of use since 2014 and due to researcher's departure and damage sustained. The Baxter robot is designed to for a variety of purposes including object identification, light assembly, material handling. The Baxter robot has two industrial robotic arms with 7 degrees of freedom each, with compliant joints which have force sensing capabilities, a 360°-sonar detection sensor, and 3 cameras (Rethink Robotics, 2012). The University's Baxter robot has a damaged end effector which needs replacing and requires, software to be provided to interact with the robot in order for future research to be carried out. Therefore, the overall goal of this project is to restore the Baxter project to the point where research using the robot can once again take place at the University of Plymouth.

The first objective involves designing a new replacement end effector which can be 3D printed and fitted to Baxter robots' arm. Autodesk Fusion 360 was used to create 3D CAD models of the end effectors grippers, and to carry out structural analysis on the models in the form of finite element analysis (FEA) which provided me a level of confidence with my design when experiencing extreme forces. The second objective involves creating an environment with MATLAB and ROS where a physical and mathematical model of the Baxter Robot is present and ready for testing. Which includes providing instructional documentation for installing Rethink Robotics simulator, which uses legacy software, on the University's system. Additionally, for the MATLAB aspect of this objective, the focus is on providing the kinematics of the Baxter robots arm and the robots parameters. Objective three is focused on using MATLAB and ROS to interact with the Baxter robot. In ROS, the goal is to interact with Baxter's arms in a Gazebo 7 simulation and the MATLAB implementation to focus on demonstrating the kinematics of the Baxter using the MATLAB robotics toolbox and to provide an interactive semaphore signalling simulation. Lastly the fourth objective is to provide additional project ideas and uses for the Baxter robot to be used in future research projects at the University of Plymouth.

The code for both the MATLAB and the ROS simulations that were carried out during the project can be found on the projects GitHub repository: https://github.com/bwickenden/PROJ509_Baxter_Restoration_Project.git along with other documentation and results. The ROS simulations were carried out in a virtual machine boot of Ubuntu 16.04, using ROS Kinetic and the MATLAB simulations were running of MATLAB R2020a.

2. Background Literature

2.1. Industrial Robots

In 2015, Rethink Robotics released the Sawyer robot, which was the successor of Baxter (Robots IEEE, 2020b). The Sawyer robot has a singular industrial robotic arm with seven degrees of freedom and has two integrated cameras, along with built in force sensing capabilities (Rethink Robotics, 2019a). Sawyer is designed to carry out pick and place tasks as well as specific manufacturing task such as CNC machining, injection moulding, circuit board assembly, and packing, along with many other tasks (Rethink Robotics, 2019b). With Sawyer's force sensing capabilities, it allows Sawyer to carry out task carefully, by monitoring both the torque and position of each of its servos individually and simultaneously (Rethink Robotics, 2019c). By doing this it allows the robot to monitor and control the amount of force that it is applying to its target. With this ability, the Sawyer robot is able to carry out tasks within a sensitive environment, where a regular industrial robot arm, without force feedback capabilities would not be able to operate within safely. This is a similar trait that the Sawyer robot shares with its predecessor, the Baxter robot, that also made use of compliant joints with force sensing, to operate within its environment safely (Rethink Robotics, 2012). One difference between Sawyer and Baxter robot is that the Sawyer robot is less bulky and is instead flexible and streamlined to enough to work in environments which may be difficult for its human counterparts to operate within (Rethink Robotics, 2019a). This is achieved with the application of Rethinks Robotics' Inertia Software and advanced embedded vision system, which allows for the Sawyer robot to reorient its position into a dynamic pose to suit the operational environment (Rethink Robotics, 2019b).

2.2. Cooking Robots

In a research study carried out by Zhai, J. et al., (2015) they simulated a dual arm, 6 degree of freedom robot to carry out Chinese cooking methods, with the idea of providing quality dishes autonomously, without the need of a master chef. In the paper, they focus on the action required to flip food within a wok, which is achieved with the use of inverse kinematics and dynamic equations, which are provided by the Lagrangian method, which calculates the Kinect and potential energy of the arms. In a study ran by Petit, A, et al., (2017), they were able to train a robot to make a pizza. This was achieved by using an RGB-D 3D camera to create a point cloud, which enables the robot to track elastic deformable objects that are textured, such as pizza dough. The unique aspect of this research is that unlike other research projects this deals with handling non-rigid objects, whereas most research appears to be in the handling of rigid tools.

2.3. Human-Robot Interaction

In a study carried out by Li, C. et al., (2020) they used force sensing with a KUKA LBR iiwa robotic arm to provide a massage to the user. The idea behind the project was to provide the service without the need of a person being present and to design a system that would allow for the robot to provide the massage dynamically to suit different users. With the robot being able to autonomously complete its tasks without being controlled by another person, it allows for the robot to be applied to a home robotics setting, such as a smart home. Whilst a massage for many is a luxury, for some people it may be required due to healthcare reasons and therefore this provides an important solution to this service.

2.4. Teleoperation

One example of teleoperation is using robots to work from home; this is achieved by a company in Japan called OryLaboratory, which has created a service robot that can be remotely controlled named the OriHime robot (OryLaboratory, 2020). In 2018 OryLaboratory conducted a trial in a café in Tokyo called Dawn Ver Café, where the service was provided by robots controlled by people with disabilities which prevented them working, via teleoperation with the goal of allowing them to remain independent (Steffen, 2020). The robot interface to control the OriHime robots has been designed to be interactable for people who have ALS and are paralyzed, which is achieved by the use of eye control, body language and simple gestures (OryLaboratory, 2020), (DAWN, 2020).

3. Theory

3.1. Kinematics

Both inverse and forwards kinematic were developed for the project. The main difference between inverse and forward kinematics is the control inputs. For inverse kinematics the user would input the target location and the model will produce the values for the joint angles in order for the pose of the robotic arm to position its end effector within the target location. Forward kinematics allow for the user to use the joint angles of the robotic arm as the input controls, where the kinematic model is then used calculate the pose of the robot and the resultant location of the end effector within the environment. In figure 7, I have used MATLAB's robotics toolbox (MathWorks, 2020) to calculate all of the possible positions of the end effector within Baxter's workspace using forwards kinematics as seen in Figure 1.

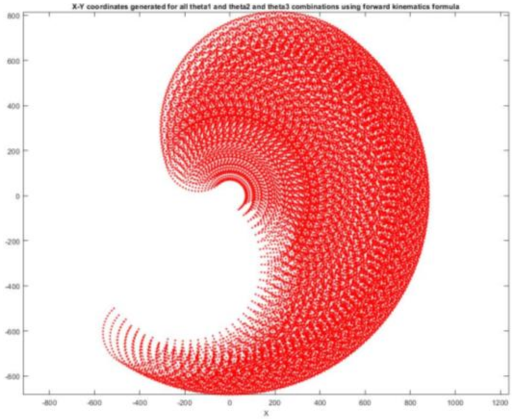

Figure 1: Baxter End effector range 2D

Similar to the forwards kinematics, the inverse kinematics (Equation 1) were also successfully demonstrated using a model of Baxter with MALAB, with the user inputting the target coordinates. Inverse kinematics are useful when integrated with an autonomous system, as they allow for the user to input the target location of the end effector and for the robot to provide a solution for the joint angles. However as discussed, over or undershoot may cause issue when using an open loop system with forwards kinematics, which is why a closed loop feedback system is preferred to maintain accuracy.

$$X = \begin{bmatrix} P_x \\ P_y \\ \varphi \end{bmatrix} = \begin{bmatrix} a_1 c_2 + a_2 c_{12} + a_3 c_{123} \\ a_1 s_1 + a_2 s_{12} + a_3 s_{123} \\ \theta_1 + \theta_2 + \theta_3 \end{bmatrix}$$

Equation 1: Where Px and Py represent the chosen x,y coordinate and a1,a2,a3 are lengths 1,2,3 with s and c representing sin and cos of angles 1,2,3

4. Design

4.1. CAD

The design for the replacement end effector offered different variants for the use of aluminium and ABS/PLA. Both designs are similar; however, the ABS/PLA design has more material added to provide a better distribution of force along the bend. There are two different designs due to the difference in the material properties between ABS and aluminium. ABS has a Youngs modulus of 1.1-2.9GPa when 3D printed (igem, 2015), whereas aluminium's has a Young's Modulus of 69Gpa of (The Engineering ToolBox, 2003). Both designs went through FEA with a force of 35N applied, where the results can be seen in Figure 2. The minimum factory of safety for the ABS/PLA design was 5.501, and the minimum factor of safety for the aluminium design with the same constraints and forces applied was 15, which more than exceeds target factor of safety of 5.

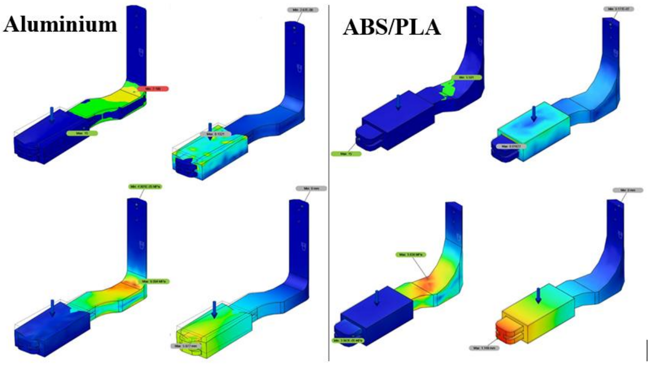

Figure 2: FEA Safety Factor (TL), Strain (TR), Stress (BL), Displacement (BR)

4.2. Semaphore Signalling

Semaphore signalling is a system designed by the Chappe brothers in the 18th century (Centre of Innovation in Mathematics Teaching, 2006) and is a method of using two flags to signal letters by the position of the user's arms when holding the flags. Using the forwards kinematic model in MATLAB, an interactive programme was made, where the user could input the characters to spell Baxter, which results in Baxter producing the semaphore signal using his arms, seen in Figure 3.

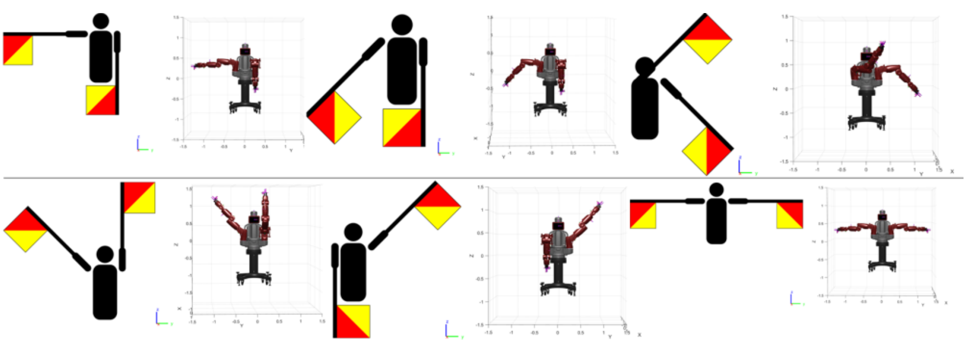

Figure 3: Semaphore signalling, Row 1: B, A, X. Row 2: T, E, R.

5. Discussion and Analysis

5.1. CAD

Whilst providing a structurally strong and stable part of a certain quality is important to ensure the grippers of the end effector will not require constant replacement; it is also important to consider the forces that would be applied to the rest of the robot if the end effector experiences a large impact force. With the Baxter robot's servos costing more than a replacement gripper it is perhaps best to design the gripper to break at a predetermined threshold, which would allow for the gripper to be used within normal operation without issue, but would break when experiencing extreme force, in order to protect the servos and their gear boxes. Whilst ABS/PLA are cheaper materials that Aluminium, they are not suited to all scenarios. For example, with the print bed temperature being around 72^0C for PLA (igem, 2015), PLA is not suited for use in hot environments. If the PLA gripper was to be used in a cooking environment, the gripper may experience damage due to heat, whereas the aluminium will be able to sustain more heat and may be better suited.

5.2. Kinematics

The kinematics derived and demonstrated within this project show examples of both forwards and inverse kinematics. For the purposes and scope of the project the kinematics are purely theoretical and demonstrated in a perfect system, and therefore don't fully represent a real system. In a real system, such as using the kinematic model with the physical Baxter robot, the servos would not be perfect and therefore the location of the end effector within a 3D plane may experience some compound drift. Due to experiencing drift the certainty of the end effectors position would decrease, however a solution to this could be solved using a closed loop feedback control system. The implementation of a closed loop feedback control system can be used to increase the accuracy of the end effector by providing feedback data which will allow for adjustments to be made to the joint angles of the servos to reach the required goal. Several methods could be used as a solution this issue including a simple proportional-integral-derivative controller (PID controller) or a Kalman filter.

5.3. Interaction

The current semaphore signalling programme has Baxter produce the signals using his arms alone, without the use of flags. With access to Baxter, further research could be carried out with Baxter interacting with a set of signalling flags, where a project could be centred around using Baxter as a translator from variable or written commands to semaphore signalling. It is also possible that with the use of computer vision that Baxter could be taught to read semaphore signals, to then be used as input commands. In order to do this Baxter would need to make use of RBG-D camera to track the skeletal data of a user which could then be used with a machine learning programme to match the data with predetermined poses (Win, S. et al., 2020).

6. Conclusion and Future Work

In future I would like to carry out a series of tests using the actual Baxter robot to further the semaphore signalling system developed within the project. In a future study I would like to train the Baxter robot to recognise a semaphore signal and to be able to repeat the signal. This would be achieved with the use of a depth camera which could be used to carry out skeletal tracking of a human producing the signals. With the skeletal data recorded, the data could be converted to forwards kinematics for Baxter to replicate to reproduce the same signal. Baxter could also use the values of the joint angles to identify the semaphore signal, and thus translating the signal. A similar experiment was carried out using the pepper robot by Tian, N. et al., (2018), where they used cloud computing to mirror semaphore signals.

Due to Baxter's compliant joints and with the use of torque sensors, which allow him to work safely with humans, Baxter has the possibility carry out cooking related tasks. Using machine learning and neural network applications, Baxter could complete kitchen tasks autonomously. A user can control Baxter via teleoperation to complete cooking tasks. This could be used in combination with a VR headset, allowing the user to see the environment fro m Baxter's perspective (Lipton, J.I. et al., 2018). The user could then input movements using VR controllers in combination with Baxter's torque force sensing to ensure that the appropriate force is being used to complete tasks such as cutting fruit or gripping a saucepan.

Overall, to conclude the project has successfully achieved its goals of restoring the Baxter robot project. Following the literature review of the Baxter robot and surrounding fields, it was concluded that Baxter has a lot of potential to be used for research into areas which involve robots-human interaction. It was also established that due to Baxter's multidisciplinary potential, he also provides a valuable platform to teach students several applications of robotics. Future research into Baxter using semaphore signalling and completing cooking tasks looks promising. With the conclusion of the project, the first steps towards Baxter's restoration have been completed, with a toolbox provided as a footing for future research to be conducted.

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