Book Shelving Robotic Arm

The Proposal

Submitted By: Yoseph Kebede

Submitted To: Dr. Reza Monfaredi

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Project 02: Proposal

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Introduction

It has been more than a decade since robots have become to be used extensively in our daily lives, besides their use in manufacturing and storages. In the global scope, while sectors ranging from self-driving cars to household items like Roomba are becoming casual ways of managing tasks, there are still places that have not been given enough focus compared to our frequent usage. One of these places are libraries. Although books have become digital now than ever before, people still enjoy going to libraries to either borrow hard copies or sit and read or do their work in the quiet and appealing space. Thus, except for few well-funded huge libraries that are beginning to try out a robotic system for sorting and retrieving books, most local libraries still rely on manpower to retrieve books from shelves, regardless of their height (The University of Chicago Library, n.d). Therefore, the objective of this project is to design a simple robotic arm stationed on one edge of a bookshelf that's able to move to the various rows vertically, extend to the different books in a given row, have a reaching end effector that can extract the book and rotate to change the orientation of the book, and a rotating arm base with a joint and two links so that the robot can accommodate to different types of shelves with varied row dimensions.

Organization

The report is organized as shown in the outline above where the need for the robotic design's application is first highlighted, followed by the description of the robot and various applications. Then, the details of the product design along with assumptions used will be explained. Finally, the specific plans on how to model and test concept will be laid out, with any recommendations into to anyone interested in pursuing this route in the future.

Motivation

Space, as in land that people dwell in, keeps on getting expensive as the years go by. For this reason, one solution has been to vertically tally items up so that one can efficiently provide service, live in, or utilize the part of land he or she owns to their desired needs. This comes with a cost, however, as shelving items higher and higher would mean that people need to device ways to bring those items down for access and return them to their storage location when done. To this end, apart from many sectors and services that usurp various solutions to address the storing and accessing challenge, due to lack of substantial financial resources and the comfort of using one task repeatedly for thousands of years, libraries – for the most part – have been using the basic way of accessing out of reach books, hence ladders. Besides the obvious safety risks and the number of books one can bring down at any given moment, the current ways of extracting books from tall shelves have been treated as an annoyance only librarians have to struggle with. It is important to note, however, just in 2017 alone, it's been recorded that public libraries have been visited about 1.32 billion times, which comes out to have each American visiting a public library more than 4 times (Institute of Museum and Library Services, 2020).

Therefore, since, as engineers, solving the problems, removing the annoyances of the society and providing better solutions to help societies conduct their daily task is the professional obligation we abide by, providing an time saving, and cost effective solution would indeed simplify the lives of librarians serving the vast number of customers, as well as help bring back shelved books to access with more ease (National Society of Professional Engineers, n.d).

What's the Book Shelving Robotic Arm?

To help address the challenge described in the previous section, the book shelving robotic arm (BSRAm) is proposed in this paper. As the naming suggests, apart from other areas where an assisting tool to help people access besides books is needed, for ease of implementation, and exigence in terms of current potential use as explained before, shelving robotic solution as been termed as such; hence, success in proper application can help spawn design to other needs as preferred. Nonetheless, as shown in Figure 1 below, the BSRAm is a robotic arm that has a prismatic and revolute base attached to a vertical bar, which itself is fixed at one edge of a bookshelf. Furthermore, its remaining links and joints are designed to reach to any row and column within that bookshelf, while also being able to access three rows within one fixture, which allows it to be freely placed in any rectangular bookshelf no matter the height of the rows. More importantly, Figure 1 only shows the core mechanical system performing the extraction, even though the design of the whole system includes a graphical interface for users to input the book row and column number (author last name and indexed column respective to the specific library implementing the device) which translates into cartesian coordinates that the BSRAm calculates in real time to provide actuation commands to its joints. Additionally, BSRAm would also consist of a revolute joint holding a plate, placed underneath joint 6 in Figure 1, that can temporarily hold the books retrieved by the robot as extracting orders from the customer. However, this paper covers on the actual task of extracting books, as designing end user interactions are trivial in comparison.

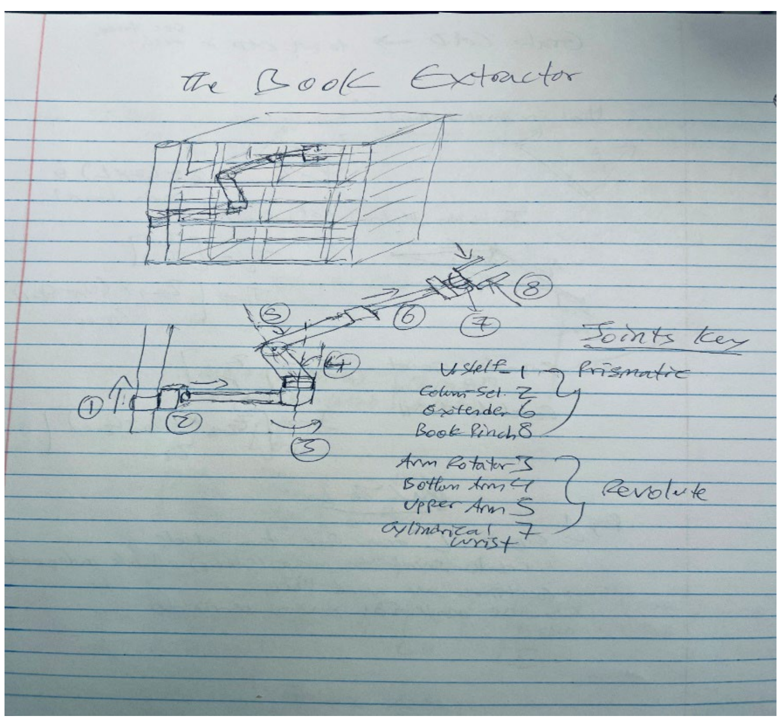

Figure 1. The BSRAm Rough Sketch

Here is a summary of the BASm's sensors, joints, motors, and material.

Parts responsible for movement in 8 DOF system, with (X) as labeled in sketch:

- Vertical Bar (1, Prismatic joint attached) (1)– robot arm base uses to travel vertically
- Robot arm base (1, Prismatic joint attached) (2)– Extends from Bar to book column
- Link base (1, Revolute joint attached) (3) – rotates arm into or out of book shelf when presenting books to user at the end
- Robot bottom link (1, Revolute joint attached) (4)– Rotates bottom link to provide horizontal reach to the BASm
- Robot upper link (1, Revolute joint attached) (5)– Rotates from bottom link to reach more shelves both vertically and horizontally
- Book grapple base (1, Prismatic joint attached) (6)– Extends end effecter from upper link to get book gripper next to book.
- Book gripper base (1, Revolute joint attached) (7)– Picks up book and can also rotate along the grapple base axis to place book by the plate attached to bottom link
- Book gripper (1, crankshaft) (8)– Rotates two pinching plates to grapple or release book

Motors:

- Stepper motors, servos

Sensors:

- Cameras (to read bookshelf row and column number, to verify book capture), gyroscope (measure link angle), Lidar (to measure gripper proximity to book)

Materials:

- Aluminum (for the links), Steel (for the vertical bar), Rechargeable batteries for motors and sensors

Design Selection

This design was considered after assessing the present setup of most libraries, i.e. currently looking for ones in the US. As mentioned in the introduction, most designs out there in the market are either humungous systems with tunnels built into buildings like the Joe and Rika Manseuto Library or mobile autonomous robots – like the AuRoSS robot – currently utilized to work independently by reshelving books and other mundane librarian tasks (The University of Chicago Library, 2022)(Phys.org). Thus, current solutions are high cost, implemented offline, and not easily dispensable towards those libraries identified as target audiences. Therefore, in order to target the numerous customers accessing libraries daily, the BSRAm design conveniently allows the setup to be placed essentially on every shelf due to the minimal items needed to obtain and setup. Furthermore, for the task of retrieving books, the BSRAm can access more than one bookshelf row and book from one order. Moreover, it can coexist with traditional ways of extracting books, since it can get stationed on either edge of a shelf when not needed. Therefore, simplicity, efficiency, and cost effectiveness to say the least, make this design well suited for the task.

Scope

The Book Shelving Robotic Arm project includes, by the very least, these areas of study. To name a few: user interface for obtaining instructions from potential librarian or visitor, program for recording user entry and translating destination commands and actuation controls for the actuated joints, sensing and control feedback during motion, kinematics and dynamics involved in moving book gripper to desired destination as well as extracting book, verifying design via CAD and Gazebo plus RVIZ simulation, refining accuracy plus efficiency per book order, and finally maximizing scalability and mass production using lean six sigma and other mechanisms.

In this project, the focus will be on the CAD modeling and Gazebo plus RVIZ simulation area when moving the robotic gripper from its home state to the desired state; that is, the rotational and translational movements involved in every link and joint will be accounted for, materials selected, and finally the synergy of entire setup will be checked whether design hypothesis holds true as end effector is actuated in gazebo's physics engine.

As working towards accomplishing this project, the basic goal aimed to achieve is to have user manually interact with the simulation via RVIZ, so that he/she can move the end effector to an arbitrarily chosen point in the simulation space, thereby proving the robot model in its entirety is a cohesive system able to achieve the task it's intended to. If this goal is met in a timely manner, the project's ambitious goal is to design a simple user interaction terminal whereby utilizing ROS's Gazebo, one can enter a bookshelf row and column entry (both valid and invalid) which the program can take, process and simulate on the environment, which will have the additional book shelf CAD spawned and fixed in the gazebo world, so that the full implementation of the design from input to processing to output can be visualized. If, this can not be achieved in time, while the basic requirement is met, the ambitious goal will get predicated to either manually experiment with the BSRAm on a modeled bookshelf, or simply simulate the BSRAm alone in an empty world environment.

Model Assumptions

Below are listed the assumptions considered in designing and testing the Book Shelving Robotic Arm.

- The BSRAm is a stationary robot with links that protrude and rotate to accomplish task.
- The BSRAm is designed to be used on Earth, ie for Earth's gravitational field
- The design assumes to have prismatic and revolute joints to be well lubricated, such that friction on joints is negligible.
- The BSRAm cannot retrieve more than 5 books at once, or until total mass of books on plate is 15lbs, whichever is satisfied first.
- If the bookshelf's width extends 2.5meters, the BSRAm will need to have it's prismatic Robotic arm base (2) connected with the rows on the bookshelf with a rail so that the link does not bend, break or shorten its life span.

- The actuators and sensors on the BSRAm are battery powered, to avoid entanglement with power cables.
- Homebase station will charge all motors and sensors, thus the BSRAm will assume efficient packing configuration to enable recharge of essential components
- The gripper, link holding plate and gripper base, cannot exceed turning out of the shelf by 90 degs
- The project assumes there are no human, or objects standing within 2.5ft proximity of bookshelf during operation
- The actuators, sensors, and joints can be purchased off the shelf. Links can also be bought as general rectangular or cylindrical bars with minimum machining to fit and assemble with joints. Thus, no new manufacturing needed for prototyping
- The project assumes all books have barcodes generated used in recognizing ordered books. Future iterations of project will have visual inspections on the gripper to detect more information besides barcode.
- ROS Melodic will be used to test gazebo simulation on Ubuntu 18.04 LTS OS.
- Python 2.7 will be used to perform automated simulation using ROS.
- Visual Studio Code interpreter will be used to work with ROS package, URDF files and meshes.

Methodology

Project will start with designing (obtaining components using grabcad) and then completing the assembly using Solidworks. Then, proper material, linkage and joint assignments will be made after which the assembly's URDF and meshes will be exported as a package to a unix environment. Then, the respective controllers, transmissions, parent - child urdf linkages, and ROS launch files (publisher/subscriber nodes if time permits) will be generated. Finally, the BSRAm will be launched onto both Gazebo and RVIZ, where the 8 DOF system will be tested in RVIZ by manually changing the dialer for every joint to verify correct design execution; Gazebo will be used once the RVIZ check passes successfully. Finally, the automation and similarity to the realistic environment as mentioned above in the motivation will be worked on one at a time, starting with inserting the bookshelf as a base link connected to the BSRAm's vertical bar along with tests for interference and verification of requirements met, followed by attempts to simulate one book extraction order.

To perform the above outlined tasks (both baseline and ambitious goal), this project aims at using Solidworks 2022-2023 for designing model for the components as well as creating the assembly for the entire BSRAm platform including the bookshelf (if time permits) either by creating models from scratch or obtaining already finished designs from grabcad (The GrabCAD Community Library, n.d.). Furthermore, joints, coordinate systems, link associations between parent and children links, and exporting to URDF will be conducting in this software. The exported URDF package will be updated in Linux environment with ROS melodic and VSC interpreter to make necessary updates when simulating the designed model in RVIZ and Gazebo.

Milestones with timeline

Based on current standing, the below timeline has been generated to track progress on project. (* and ** are must complete objectives)

1. Pre-proposal: due October 20, 2022 – completed
2. Proposal: due November 06, 2022 – completed

Currently here: work on CAD prototype << **November 11, 2022 – a month away**

*Begin integration with ROS

*Begin testing on RVIZ << first milestone achieved – **November 25, 2022**

*Begin working on Presentation for minimum goal - **November 25, 2022**

*Continue to next steps if testing is successful - **November 25, 2022**

Begin adding bookshelf and constraints

Begin testing BSRAm with bookshelf << ambitious part 1

Begin coding to accept user input to control joints

Continue coding to control all joints

Finish programming and test full standalone simulation << ambitious goal

Finish and practice presentation, whichever goal gets completed – **December 4, 2022

3. Final Report: due **December 05, 2022 – December 11, 2022**

4. Final Presentation (simulation): due **December 05, 2022 – December 11, 2022**

5. Final Presentation submission: due **December 05, 2022 – December 11, 2022**

Validation Plan (Testing)

To test the design, there will be a table of test cases that verify the proper functioning of all of the links constructed and spawned into simulation. Hence, by proving the proper functioning of each joint and with the end effector attaining the expected point in the simulated space, one can prove the hypothesis has correctly implemented the kinematics and dynamical laws for the robotic model thereby proving, although from a virtual ideation standpoint, the possibility of introducing solution to market. Table 1 is listed below as an example to show how the 8 DOF will be tested. Note (X) correspond to the joints as depicted in Figure 1.

Point	**(1) +z**	**(2) +x**	**(3) α**	**(4)φ**	**(5)ψ**	**(6) +y**	**(7) ϕ**	**(8) rot**
A	5m	2m	45^0	20^0	5^0	2m	0^0	3 turn
B	0m	1.5m	0^0	15^0	15^0	1m	30^0	0 turn

Table 1. Testing table for attaining arbitrary points in space using BSRAm

Once the baseline goal is met, following successful testing, similar method is used to test for the next step of adding the bookshelf to simulation in which case only bounds to rotation of joint (3) will be added. Finally, if this portion is also completed in time, then the last testing method will be to verify the automation where user input in terminal window, gets translated by ROS publisher program to achieve precise movements of the 8 joints to achieve purpose. This part, however, is heavily user interface integration, thus ambitious to test in current scope.

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