FARA: Framing Assembly Robotic Arm System for Construction Sites

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ABSTRACT

The project aims to develop a manipulator type construction robot empowered with necessary sensors and software so that it can be controlled via manual control to survey the environment, conduct assembly work and avoid obstacles in the work site. An adaptation of Lynxmotion's AL5D servo robotic arm is used to 3D-print a scaled model, and the motion of the robot is studied. Assembly of a 3D-printed model representation of a precast frame construction site is also presented. The manual control of the arm is fully achieved using an Xbox controller, coded with inverse kinematics. Further implementation of IR sensors mounted near the tool tip proves successful to detect obstacles. Additionally, a Microsoft Kinect motion sensor is utilized to provide surveying by using its RGB-D camera, and detecting workers on site to increase safety features. The findings indicate the feasibility of a full-scale Framing Assembly Robot Arm (FARA), as it would potentially reduce in-site casualties and lower the cost of labor.

Keywords

Construction Robots, Robotic Framework Construction, Framing Assembly Robotic Arm, FARA.

1. INTRODUCTION

Since the use of machinery in construction, we have been able to build larger structures and longer roads. Safety at the site, however, has been an area that needed more thorough work. Even with rigorous code and safety checks, workers still suffer injuries and even death. In the year 2015 alone over 900 casualties occurred in construction sites all over the US, with the "Fatal Four" being falls, getting struck by objects, electrocution, and getting caught in between [13]. A solution to keep these numbers low is to look for answers in robotics and automation, while also adding the necessary safety precautions.

Currently there are few simple robotic systems being used to aid in construction, such as the cement 3D printer or the pavement laying machine aided by sensors, to name a few [14]. This project aims to prove the feasibility of a 6-DOF robotic arm in the construction of a single story, simply supported structures made of pre-fabricated parts as well as to test collision avoidance. The robot will essentially become a Framing Assembly Robotic Arm (FARA), which is manually controlled and able to sense its environment. To achieve the goal, FARA will have the task of assembling a 3D-printed model of the single story frame consisting of a base representing the foundation, three types of columns and the beams.

For better safety features (and future automation) to be further achieved, IR sensors and RGB-D cameras are also implemented to the prototype and testing. The safety of a full scale model is tested with the IR cameras mounted onto the arm itself, while surveying of the site happens with the use of Microsoft's Kinect [12]. The latter can potentially aid in the future plans for full automation of FARA, via shape recognition and mapping. This paper is only concerned with the manual control tasks, collision avoidance, and testing out of the surveying capabilities of the Kinect's RGB-D cameras.

2. LITERATURE SURVEY

After a review of automation and robotics in construction publications, it was concluded that although prefabricated or precast pieces already exist in the industry, robots and automated systems for assembly in terms of framing structure mounting is lacking [1]. This is the first attempt at using a 6-DOF robot for construction purposes. Further research into other currently available products in the market, such as brick-laying robots or the cement 3D printers, only have 2 to 3 DOF, limiting their versatility [4]. Other limitations affect these products, for example the "concrete printing" process has material properties to take into account, and can only be useful for smaller paths [7]. As far as bricklaying robots, their task specific capabilities are in fact quite remarkable; however, must be assembled to be fed by conveyors [8]. Australian bricklayer SAM is a notable example of robotics in construction [14]. Robots such as SAM and other material printers are currently paving the way for automation in construction.

3. DESIGN GOALS

Proving that the manual control of the FARA prototype has the necessary safety features to work in the real world requires testing for good user interface, obstacle avoidance and surveying. The buttons on the controller should easily control FARA's movements with fluid and accurate displacements and rotations. The incorporation of IR sensors to the robotic arm will work in conjunction with a Microsoft Kinect V2 for surveying the site by detecting personnel, thus increasing the safety of operations. When the IR sensors detect obstacles, the X-box 360 controller will vibrate, to inform the user. The Kinect's detection of personal would inform the user when and where to move FARA, externally from a surveying tower. The estimated a total budget of $250 dollars including all servos, linkage, sensors, controller and additional parts.

4. PARTS

4.1 ALD5 and SCC-32U Servo Controller

The AL5D is commercially available as a 5-DOF robotic arm by Robotshop/Lynxmotion Inc. This robot, operates by means of a servo controller, SSC-32U [3]. The linkage is primarily integrated by laser-cut steel plates/brackets, metal fasteners, ball bearings, plastic pieces, etc. An additional servo motor was added to improve its mobility to 6 DOF. After trial and error, it was noted that keeping the four links between the base and tool tip coplanar while only rotating the base and the tool allowed for better manipulation for assembling the model. The coplanar adjustment also made it easier for calculations and coding using inverse kinematics [9], [10]. The total weight of 9 lbs and maximum reach of 30 in is envisioned for the scaled first prototype.

Figure 1. Lynxmotion Robotic Arm AL5D (5 DOF) with SSC-32U Servo Controller

4.2 Xbox 360 Controller

For better user interface, a code was implemented to manually control FARA with the controller using inverse kinematics. Figure 1 provides the schematics of the Xbox 360 controller, and Table 1 lists each button's functionality.

Table 1. Button Assignments to Link and Tooltip Movements

Servo No.	Link Description	Button	Movement Description
0	Base Rotation	Left Bumper	Rotates Base CCW
		Right Bumper	Rotates Base CW
1	Link 1	Left Stick	Inverse Kinematics for X & Y axis movement for the position of servo 3
2	Link 2		
3	Link 3	Right Stick	Inverse Kinematics for X & Y axis movement for the position of the gripper
4	Link 4		
5	Wrist	X Button	Rotates Wrist CCW
		Y Button	Rotates Wrist CW
6	Gripper	A Button	Closes Gripper
		B Button	Opens Gripper

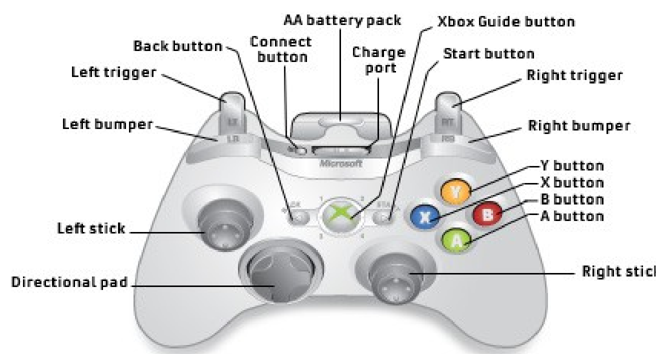

Figure 2. Xbox 360 Controller Map

4.3 Sensors

4.3.1 Sharp GP2Y0A41SK0F IR Sensors

These optical infrared sensors of 4 ~ 30 cm range with analog output are suitable for obstacle avoidance of the FARA, and are attached laterally to the tooltip and at 30 degrees to further increase its sensing field.

The mount was designed and 3D printed for the purpose of incrementing the field of vision of the sensors for better obstacle detection. Figure 3 shows the customized bracket that is commercially available.

Figure 3. Sharp GP2Y0A41SK0F IR Sensors and Mounting Modification

4.3.2 Microsoft Kinect V2

This multifunctional RGB-D camera is used to assist in the mapping of the construction site model, and surveying. Extensive research has proved the effectiveness of RGB-D cameras to not only detect people but also give out information of location in a plane [5].

Future functions to be implemented for full automation of FARA include shape recognition and tracking capabilities [6]. Due to time constraints, testing is only conducted on surveying of the site to detect personnel as FARA is controlled and as it assembles the model.

Figure 4. Microsoft Kinect V2

4.4 Arduino UNO with Shield USB Host

The Arduino Uno will be used to program and control the movement of the robot. A USB host shield will also be stacked onto the Arduino to connect the Xbox controller.

Instead of using the servo controller to control the servos, the Arduino will be used since it provides the means to input the Xbox controller via USB, as well as the IR sensor via analog pins, and output the servos via digital pins within the same board.

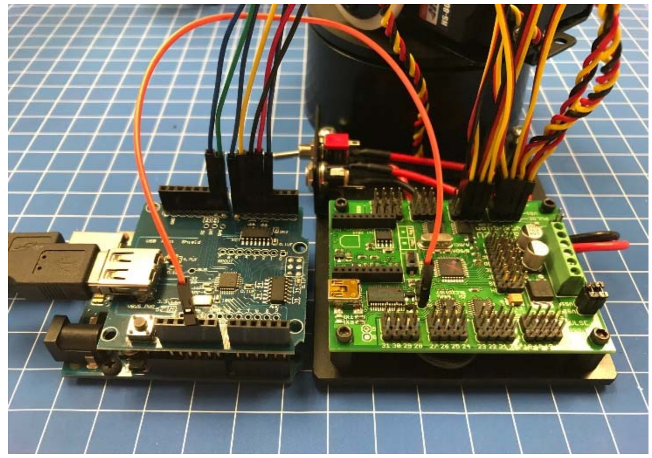

Figure 5. Arduino UNO with USB Host Shield and Servo Controller

4.5 Program and ROS

The Arduino software implements inverse kinematics for the manual control of the arm, basing it on the position of the base. The program also integrates the IR data acquired from the Arduino Board, and the Robot Servo Library for Arduino to control the servos. A Microsoft Kinect interface, i.e. Kinect Studio, integrates recognition of workers on site.

4.6 Model of Prefabricated Structural Frame

For the purpose of representing FARA's feasibility in the real world, the 3D model was designed to resemble a prefabricated structural single-story framing system. The 3D Printer Selected was a Makerbot 1, and the printing setup was 70% inkfill and 2 shells for Columns and Beams, 15% (to save filament) inkfill and 3 shells for the base. Figure 6 depicts the 3D-printed individual parts of the model to be assembled by the Robotic arm.

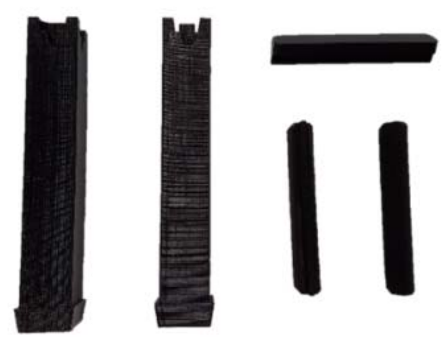

Figure 6. 3D-Printed Columns and Beams

The base that is shown in Figure 7 represents the cleared construction area with the square bores as part of the isolated footings where the columns are to be placed.

The bores have supports as four-sided pyramids truncated at the top part, which are reciprocally the same shape as the column lower columns holes to facilitate the beam-footing coupling. All the girders (beams) are equal prismatic T-shapes, so all the columns have same longitudinal and transverse spacing between each other. The columns are square prisms with respective cut-off orifice at the supports where the girders are placed.

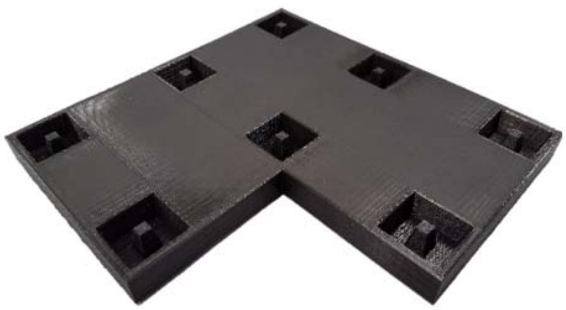

Figure 7. 3D-Printed Base

Furthermore, the columns feature the type and amount of orifices to bear the respective beams according to their location in the framing system; hence, the corner columns have two orifices (for a transverse and a longitudinal girder), the side columns have three orifices (for two longitudinal and one transverse girder), and a center column (two longitudinal girders, and two transverse girders) structural supports are such that the columns are sheathed on the base, and the girders re similarly placed on the column supports.

Although the structural model is statically indeterminate, in the actual construction site the structure is stiffened to any desired rigidity by welding or bolting the supports that are already mounted. This structural system can be described as two mutually double-spanned frames and single spanned frames interconnected perpendicularly by beams as Figure 8 illustrates.

Figure 8. 3D-Printed Structural System

5. FUTURE PLANS

Fully automating FARA to assemble the model is possible by implementing more complex code to the Kinect's RGB-D camera sensory response. Mapping the entire worksite while providing surveying is feasible and not farfetched [2]. Adding the positioning capabilities due to mapping, the Kinect would essentially let FARA know where each hole is located, also where to retrieve each piece. With shape recognition, FARA can also be told to pick up the columns first, then the beams, placing them in the most optimal order and correct orientation; i.e. primary tasks for automated structural framework installation.

6. CONCLUSIONS

The Xbox controller is very sensitive and susceptible to sudden movements when utilizing the joystick, as such, it is not the most desirable controller for a full-scale project. Although it proved useful for the first prototype, a better controller will definitely need to be considered for the actual application. Although the success of manual controls largely depends on the experience and dexterity of the user, the IR sensors proved beneficial in alerting when near an obstacle.

Further design calculations for the full-scale system must also be developed, keeping in mind materials to be handled; however, the basis of surveying using the manual control is shown to be feasible. With the automation part undergoing development, it was concluded that as a full-scale product, FARA has the potential to be cost effective and safe as a long-term investment for construction firms. Ultimately, the model and testing scenario can also serve as a study model for future experiments that would contribute to the field of automation and use of robotics in construction.

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