University of Engineering & Technology Lahore, Faisalabad Campus

Robotics CEP

Analysis of Lay clay and Brick Laying Robot (SAM100)

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Table of Contents

Table of Figures

Robotics CEP

Problem Statement

Propose a serial kinematic chain robotic manipulator to solve construction robot to lay clay bricks while constructing a wall. The robot should be able to carry a stack of bricks (about 10) and mortar (mixture of cement, sand and water) during the activity.

Objective

- Select serial kinematic chain to perform the desired task effectively. Justify your selected kinematic chain with strong arguments for selected task. Provide the sketch of kinematics chain model. In addition, mention the joint limits for all joints.
- Solve Forward Kinematics for the kinematic chain. Suggest, an Inverse Kinematic solution for the kinematic chain.
- Compute velocity kinematics model for the kinematic chain.
- Give the sketch of the workspace of the kinematic chain.
- Propose a control architecture along with necessary components like sensors, actuators, controller to perform the desired task effectively.

Introduction and Background

When it comes to worker productivity, the construction industry is one of the slowest. As a result, building projects take longer and cost more to complete. New technology is being developed. adopted to boost worker productivity in the construction sector It is getting increasingly common. It is even more crucial for the industry to adapt to this new technology. Robots are among them. The SAM100 (Semi-Automated Mason) is a brick-laying robot that can take the place of the majority of a project's masonry staff. Utilizing On masonry-heavy projects, this technique might be quite beneficial.[1]

Figure 1: SAM100 Construction Robot

Construction Robotics has taken a somewhat different strategy than FBR. Instead of automating manual process, the SAM100 (Semi-Automated Mason) collaborates with a human to assist reduce part of the manual effort. The SAM100 can lay up to 3,000 bricks per day, completing the construction six times quicker than a mason working alone. This robot takes the bricks, applies mortar to them, and then places them on the wall. After that, the mason who is working beside the robot smooths off the extra mortar. This significantly speeds up the laying process while also enhancing worker health and safety by decreasing manual handling. [1-2]

These steps are briefly explained below in the form of flowcharts and block diagrams, following figure shows the basic model for the construction process. The above mensioned steps are based on the following model. This technique is commonly used while working with the construction robots.

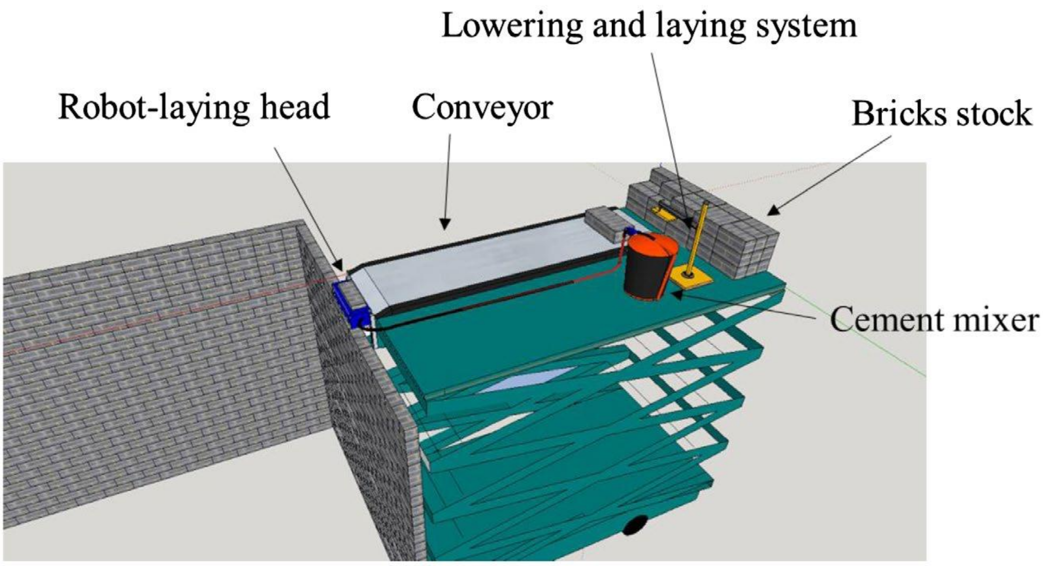

Figure 2: Model for the Working of SAM

The above shown mechanism is used by the SAM100 the robot is fixed on the platform so that its height and longitudinal position can be adjusted in the space as the wall is being constructed. We know that the robot is completing the wall quickly by placing the bricks in a line one by one. So, the robot must move forward to complete the line of the bricks according to the length of the wall. As the robot is constructing wall, the wall is also increasing the height as the lines of bricks are being placed on one another one by one thus the robot should increase its height too to achieve the height to continue constructing the wall. For that purpose, the above mechanism is being used.[2]

The SAM100 use three steps to construct the wall and these steps are mensioned below: -

- Stock Processing
- Construction
- Material Deposit

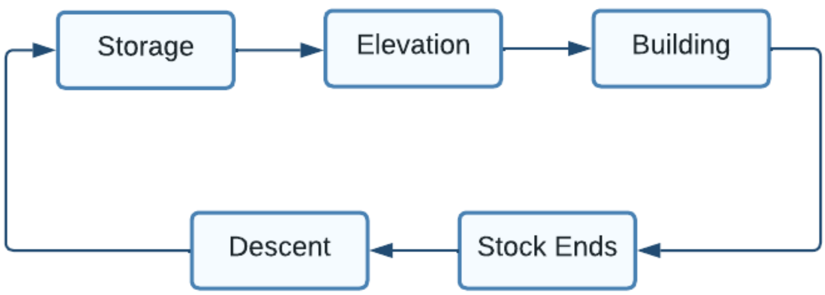

Figure 3: Stock Processing Block Diagram

The stock processing unit is used to keep an eye on the stock present at the working point of robot here according to the block diagram the robot is constructing the wall which is represented by the building block. The robot is in building state and the stock ends and consider the robot is 2m above the ground then the robot will descend and the stock will be loaded on the elevator of the robot from the storage then it again elevates to the 2m height and continue its construction.[1]

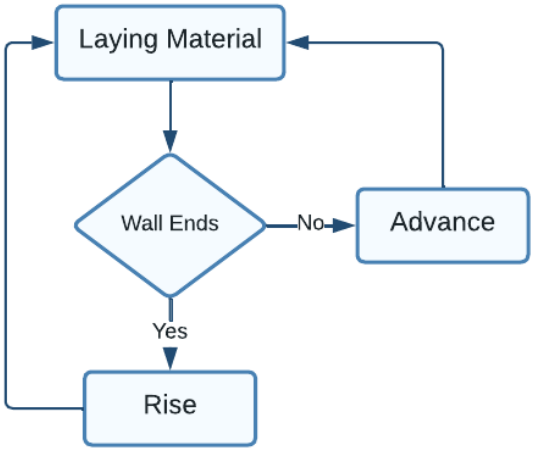

Figure 4: Construction Process Block Diagram

This block shows the construction process according to this the robot is constructing the wall and let say the wall is of 15m then it is obvious the robot has to move placing the bricks along the wall. So, the robot will lay the material and if the wall is not yet ended the robot will move forward otherwise it will rise for the next line of the brick to increase the height of the wall. So, the rise and advance processes are very important in working of the manipulator in this case. [1]

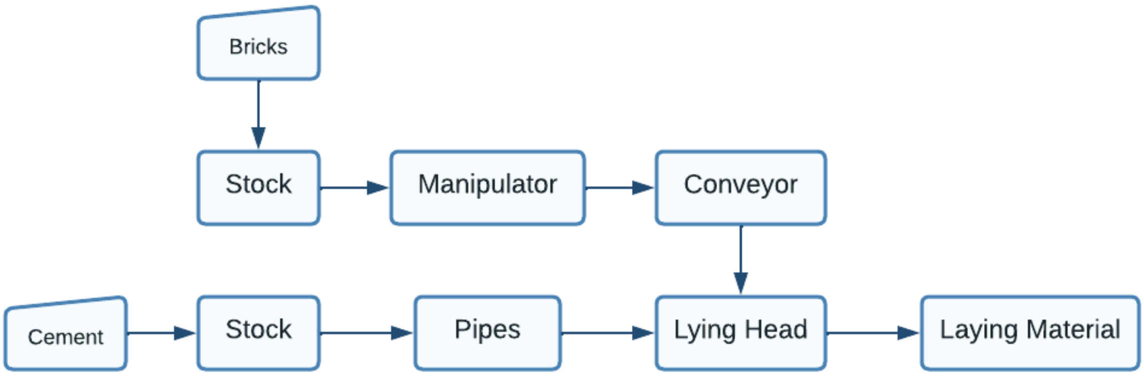

Figure 5: Material Deposit Process Block Diagram

This is important block here the block will give complete information about the laying process of the robot. Here the bricks are loaded on the robot from the stock and then the bricks will go to the robot manipulator and then to conveyor. Similarly, the cement will go to the pipes through stock present for the robot. Both the objects (the brick and the cements) will go to the end effector which is laying head and material will be placed on the right position which will be computed by the controlled or the robot. The robot will first pick the brick from the stock and then it will apply the cement from the pipe which is located at the bottom of the robot (at its base) after that it will place the brick on the right position. [1-3]

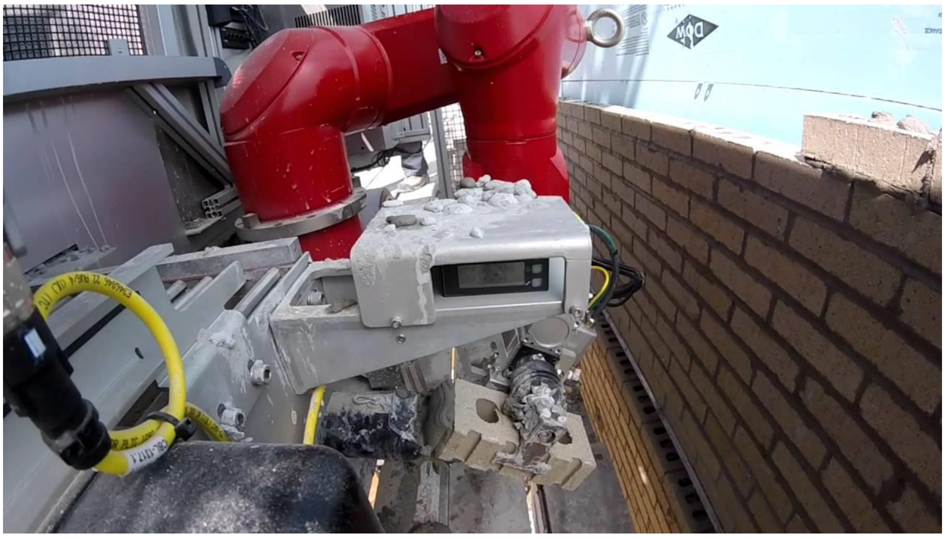

Figure 6: SAM100 Applying Cement on the Brick

Figure 7: Placing of Brick on the Desired Position by SAM100

Figure 8: A View of End Effector of SAM100

Kinematic Chain

So, a kinematic chain with 6 DOF (Degree of Freedom) is being selected for this problem here the first three degrees of freedoms are for the arm and next three for the spherical wrist. The kinematic chain is shown in the figure below draw using the RVC toolbox MATLAB.

Here the specified kinematic chain is selected to achieve the desired position and right orientation for the end effector. The so called 6 DOFs are required to reach any point in the space in desired orientation. If degrees of freedom are less than 6 then the robot will not reach each of the point in the space. The arm is required to place the brick or the clay on the wall at a specific point and wrist is required to put the two objects at a specified point in desired orientation. Both the arm and wrist make the total 6 DOF of the robot.

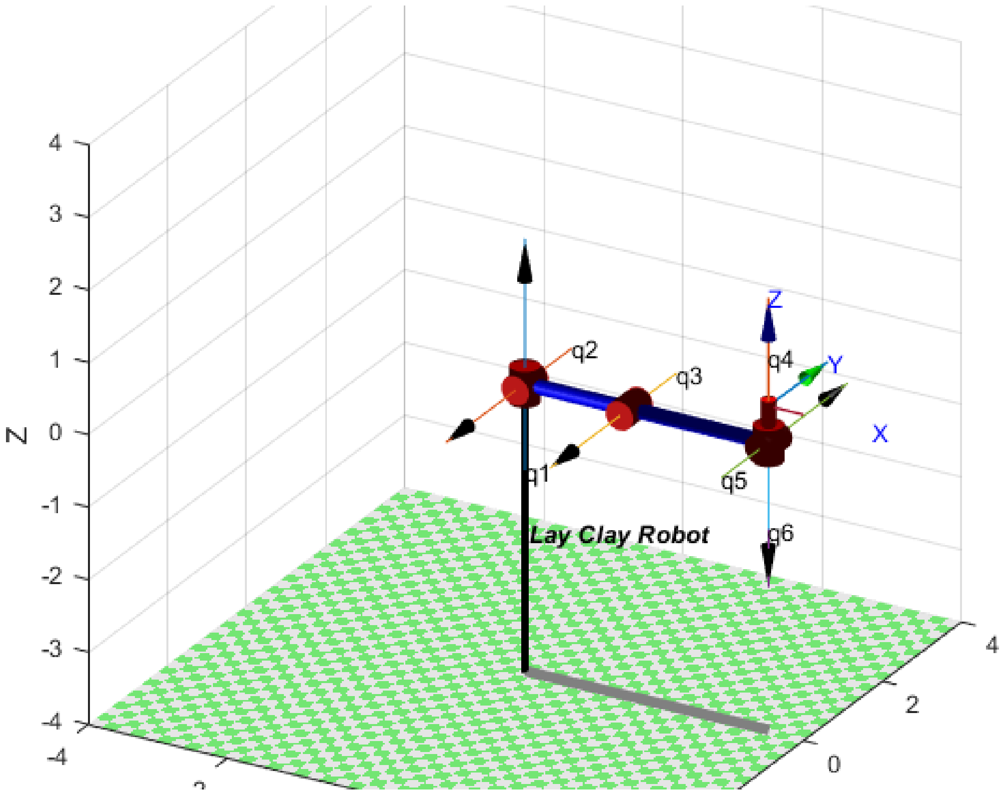

Figure 9: Kinematic Chain for the Lay Clay Robot (Home Position)

Joint Limits of the Robot

Table 1: Joint Limits of the Robot

Sr. No.	Lower Limit	Upper Limit	Home Position
1.	-90	+90	0
2.	-60	+60	0
3.	-90	+90	0
4.	-90	+90	0
5.	0	+180	0
6.	-90	+90	0

Workspace of the Robot

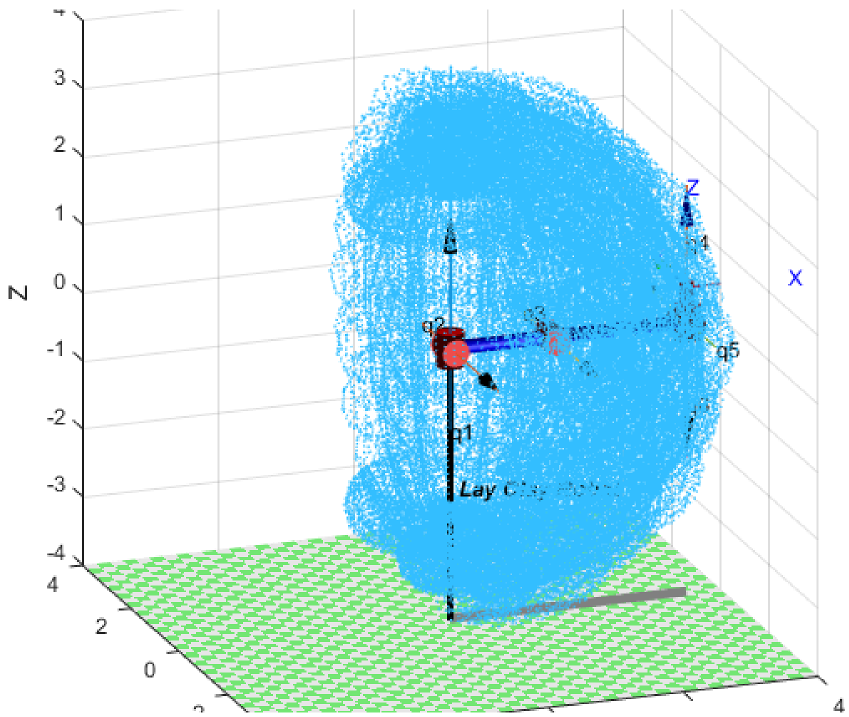

Figure 10: Isometric View of the Workspace of the Robot

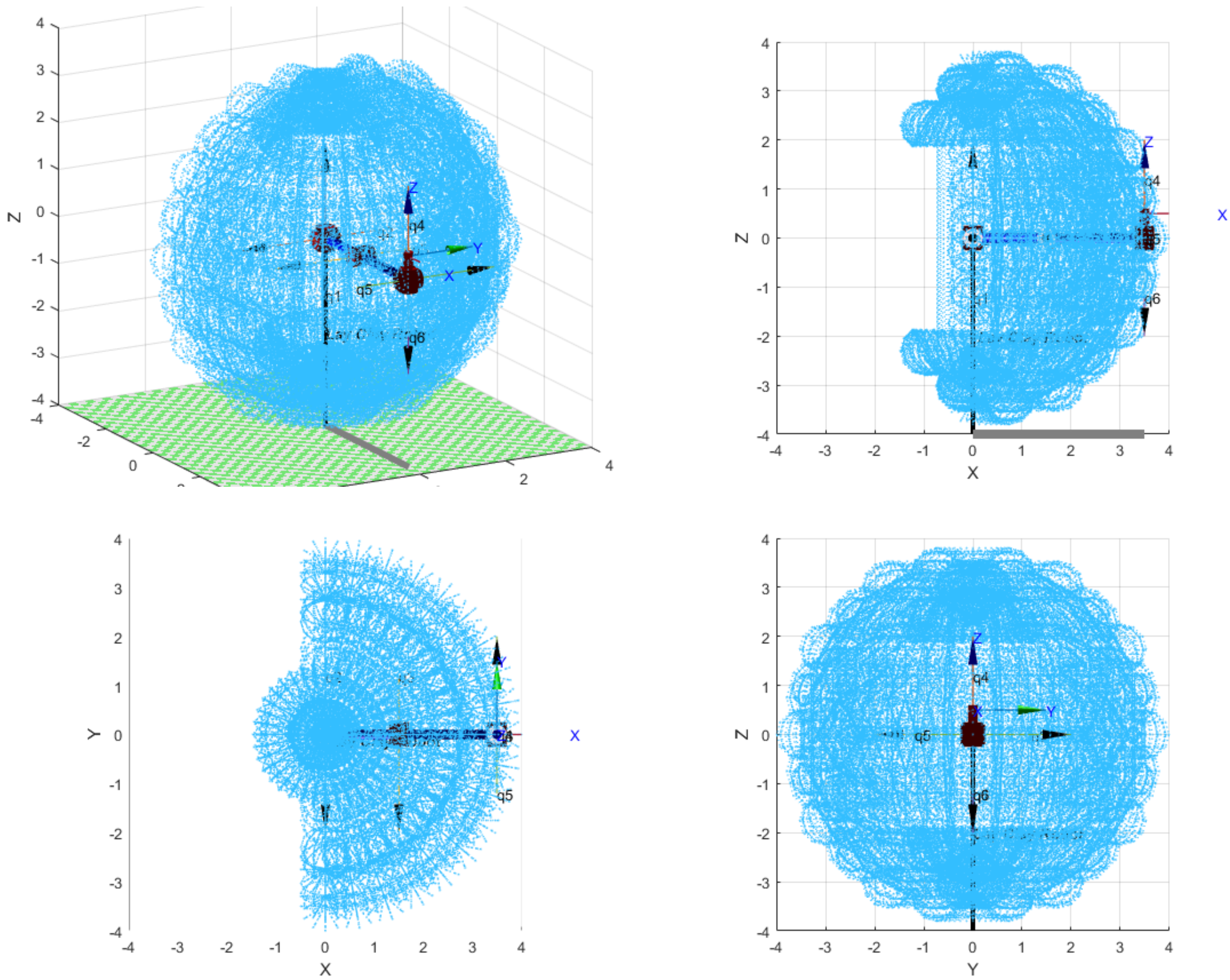

Figure 11: Isometric, XZ, XY & YZ Views of the Robot Workspace

Control Method

The goal of the design is to select a compensator that allows the plant output to follow or track a desired output determined by the reference signal. However, the control signal is not the system's only input. Disturbances, which are essentially uncontrollable inputs, have an impact on the output's behavior. As a result, the controller must be constructed in such a way that the impacts of disruptions on plant output are minimized. The plant is thought to reject the disruptions if this is achieved. Any control system must priorities tracking and disturbance rejection.[4]

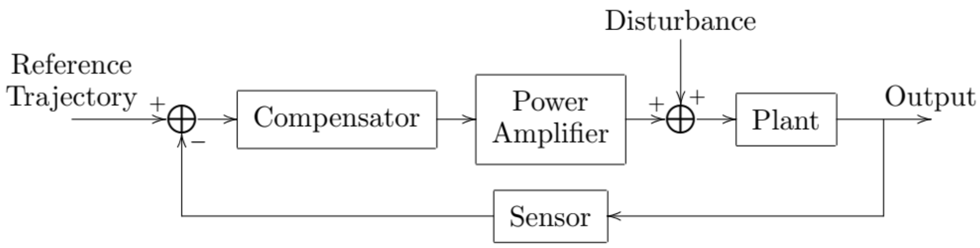

Figure 12: Close Loop Control System

Here we have to use the position control to track the position provided by the path planner, the path planner will provide a track on which robot will move and place the bricks and cements on the right position. Thus, to track the position the position controller is needed in this situation. The aim of the position control is to minimize the error between actual the position provided by the path planner. It also minimizes the disturbance output which could be the friction, environmental conditions and other factors present in this real world that will make the system non ideal and nonlinear.

Now as the robot will carry some mass of bricks and the cement and it had to apply the brick at the exact position by carrying it so force control is also needed here so that the robot can do precise motion while carrying the brick and while moving freely without any brick or object. Hence here force control will also be implemented for precise and error free path tracking. Thus, the force and position control are applied simultaneously for the robot which is called hybrid control. In hybrid control method robot’s position and force and controlled at the same time.

Actuators & Sensors

Actuators

As the robot is 6 DOF thus 6 actuators are needed to move each joint of the robot independently and precisely in the space of robot’s workspace. Here the BLDC (Brushless Direct Current) motors can be used for precise control and to provide high torque to the robot. These BLDC motors are used at every joint and will power each joint with enough torque so that robot moves precisely and without any jerks in the motion.

For the stock processing mechanism simply DC motors with high torque can be used or hydraulic actuators can be used to provide very high torque so that the whole compartment along with the robot can be moved forward and elevated in upward direction to finish the construction. As the robot is fixed on a platform and the whole platform will move in according to the stock processing mechanism explanation explained in above text. Thus, the hydraulic actuators are good option here as stock processing actuation system due to high torque requirement of this mechanism.


Figure 13: BLDC Motor and Hydraulic Actuator for the Robot

Sensors

Here following sensors can be used in the robot to achieve the desired results from the system.

Table 2: Description of the Sensors used in the Robot

Sr. No.	Sensor Type	Description
1.	Quadrature Motor Encoders	Quadrature is used to find out the position and speed of the DC motors and this speed and position is then used to control the motion of the robot. These sensors play important role controlling the motors of the robot.
2.	Force Sensor	The force sensors are used to record the amount of the force required so that the force control can be applied on the robotic manipulator. This is an integral part of the force control unit of the robot.
3.	IMU (Accelerometer + Gyro)	This is very important sensor here it will track the whole compartment position in the space along with the robot. The robot has to move forward and upward while construction so the sensor will keep an eye on the forward and the upward motion of the robot. Sensor fusion can be used to get a precise reading from the accelerometer and the gyroscope.
4.	Loadcell	This sensor is used to find out the number of bricks available in the robot's stock. The mass of the bricks is measured to check the number of the bricks if the bricks are low in number let say less than 5 the more bricks will be sent automatically to the robot.
5.	Flow Rate Sensor	The flow rate sensor will keep track on the cement, sand and water mixture it will tell the robot how much mixture should be applied on the brick and will command the robot to stop the application of the mortar when certain volume has been applied on the brick.

References

[1] Madsen, A.J., 2019. The SAM100: Analyzing labor productivity.

[2] Araya, F.D., 2019. Role of Industrial Robotics Automation Systems (Doctoral dissertation, WORCESTER POLYTECHNIC INSTITUTE).

[3] Gandhi, S.J., 2019. Design, simulation and testing of a controller and software framework for automated construction by a robotic manipulator (Doctoral dissertation, Arizona State University).

[4] Pham, H.L., Perdereau, V., Adorno, B.V. and Fraisse, P., 2010, October. Position and orientation control of robot manipulators using dual quaternion feedback. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 658-663). IEEE.