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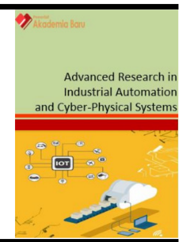

Cooperative Control of Dual-Arm Robot Manipulators

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ABSTRACT

This paper describes cooperative control of dual-arm robot manipulators. With the development of robot technologies, many control algorithms for multiple manipulators have been proposed so far to undertake tasks using manipulators in coordination as humans do using their arms. By using multiple manipulators in a cooperative way, several tasks could be executed which could not be done by a single manipulator in addition to the handling of a single object. The objective for this study is to demonstrate the cooperative control that is implemented involving two KUKA KR 3 robot to balance a tapered beam horizontally in single planar motion. This is achieved by integrating the robots with a tilt sensor via programmable logic controller. Experimental results show that the manipulators succeeded in demonstrating cooperating capability in terms of accuracy of the follower with respect to the leader.

1. Introduction

In the early 1970s where not long after the emergence of robotics technology, research on multi-arm robot systems had already started. Typical limitations in applications of single-arm robots was the main reason of this interest began to crop out. With an appropriately designed control system, multiple manipulators in coordination could handle a large and/or heavy object, which could not be handled by a single manipulator because the load to each manipulator is reduced by distributing it among the manipulators [1].

Most of the existing robots application in manufacturing are of coordinated control of a single arm working on one specific task and are independent of each other [2]. As time moves on, automation is becoming popular in many production lines and traditional construction.

In manufacturing, a product is designed for mass production, whereas construction products (or projects) are usually one-off and unique [3]. Thus the efficiencies achieved through mass production are not easily achieved in construction. In addition, unlike their manufacturing counterparts,

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construction sites are for the most part unstructured, cluttered, and congested, making them difficult environments for robots to operate in. Furthermore, human workers are also present in large numbers on a construction project, making safety a major concern. In order to reduce, if not solved the problems stated above, an external controller is to be designed which integrate the cooperation between the two manipulators to work mutually for applications beyond the capability of a single arm such as manipulation of massive and bulky objects and handling flexible payloads [4-7].

Though a single manipulator could execute such mundane tasks to ensure a consistent work, it does not ensure a flexible and variety of possible applications. In such situations, it is essential to consider the use of multiple manipulators cooperating together. The present work attempts to address this issue. Cooperative manipulators can contribute a major diversity in terms of efficiency, accuracy and task execution that are impossible for a single arm robot [8-10]. In cases where batch of production increases, the existing robot may encounter difficulty of limited load handling capabilities that could be replaced by integration of cooperative robot arms [11]. It is expected that this research will solve existing problems and opening up a new stream of applications in flexible manufacturing systems (FMS) as well as in poorly structured environments in construction engineering.

The objectives of this project are: (1) to demonstrate the cooperative control for two KUKA KR 3 Manipulators using programmable logic controller (PLC) in a leader-follower approach [12]; (2) to test the system to balance a straight beam at a levelled position and compare in terms of the accuracy of the follower with respect to the leader.

2. Methodology

In order to achieve the objectives, the KUKA KR 3 Manipulators are left to where they are; apart from each other. A straight beam will be the contact object between both the manipulators gripped from point A and point B as shown in Figure 1.

Fig. 1. Concept for demonstrating cooperative control

The system has ten predetermined sequences only in the Z-Axis motion or up-and-down motion. KUKA KR 3 robot 1 will stop its motion until it receives input from the PLC to confirm the beam is not tilting. Subsequently, KUKA KR 3 robot 2 will move to level the straight beam. Programming of the follower, that is KUKA KR 3 robot 2, takes into account the Cartesian axis motion when it is triggered by the PLC. Referring to Figure 2, the PLC sends digital input and it is recognized by the KUKA KR 3 robot 2 as either CASE 1 or CASE 2. If it is CASE 1, KUKA KR 3 robot 2 moves Z = +1mm. If CASE 2, KUKA KR 3 robot 2 moves Z = -1mm. KUKA KR 3 robot 2 continues its motion until it is neither CASE 1 nor CASE 2. If TERMINATE input is received, the program stops any motion, releases the beam at initial position and go to HOME Position.

For the PLC programming, the concept is to let the robot move +Z or –Z motion and stop whenever the angle tilt is 0°. It is simpler, more accurate and efficient programming than the specific voltage or resolution for specific angle programming.

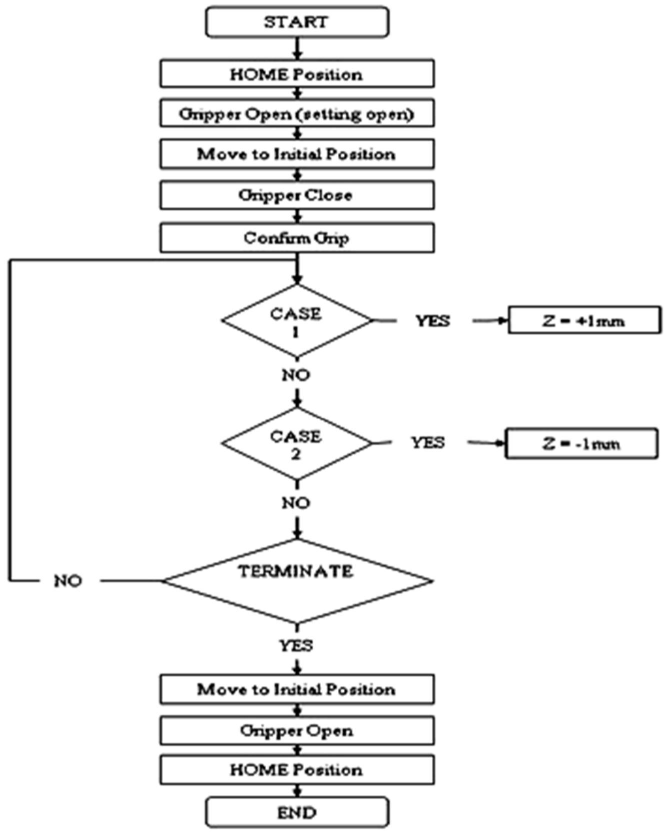

Fig. 2. Process flow of programming of KUKA KR 3 robot 2

Figure 3 shows the control method approach uses tilt sensor (ADXL202JE by Analog Devices, Inc.) to detect the beam's inclination [13-15]. KUKA KR 3 robot 1 moves according to a motion assigned. Using the tilt sensor, any inclination angle is made into analogue output receives by the PLC. The controller then sends the digital output to KUKA KR 3 robot 2. Afterwards, KUKA KR 3 robot 2 actuates its motors according to the input signal. Analogue output from the tilt sensor will continuously give feedback to the PLC until the tapered beam is levelled (perpendicular to the gravity vector).

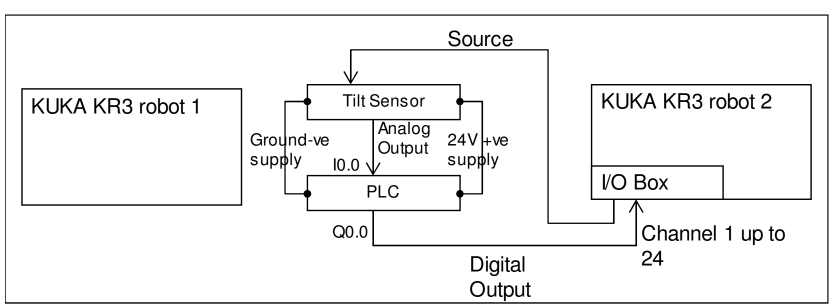

Fig. 3. Schematic diagram of the concept for demonstrating cooperative control

3. Results

Figure 4 shows the full assembly of the demonstration. The setup uses a 1" x 2" x 20" aluminium square hollow bar and attached with a modified car coupling at both ends in order to level freely at any robot's grip configuration. The robots are able to grip the coupling and perform the sequences.

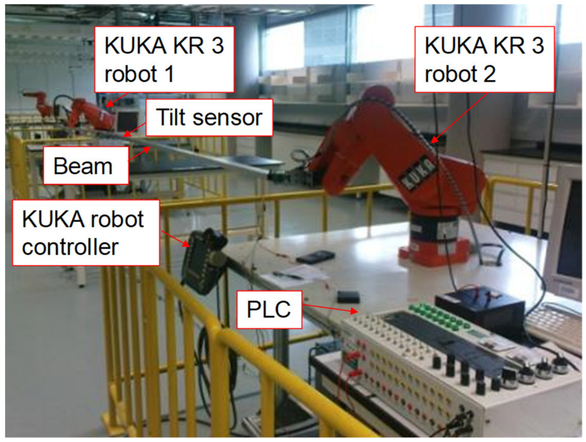

Fig. 4. Full assembly of demonstration

Accuracy is the degree of conformity of a measure to a standard or true value. It is the ability for the robot or follower specifically to accurately level the beam exactly the same as the predetermined position of the leader. The accuracy of the system to level the beam is summarized in Table 1.

Table 1
Accuracy of the system to level the beam

Sequence	Position of KUKA KR 3 robot 1 in Z-axis (mm)	Position of KUKA KR 3 robot 2 in Z-axis (mm)				Percentage error (%)	Range (mm)
		1	2	3	Average		
1	241.00	245.15	240.97	242.86	242.99	0.8271	1.9933
2	341.00	346.19	344.53	338.89	343.20	0.6461	2.2033
3	441.00	440.92	443.71	445.12	443.25	0.5102	2.2500
4	541.00	542.37	541.10	538.00	540.49	0.0943	0.5100
5	521.00	524.48	519.11	522.92	522.17	0.2246	1.1700
6	541.00	537.77	542.63	539.95	540.12	0.1633	0.8833
7	521.00	519.99	523.73	524.87	522.86	0.3576	1.8633
8	541.00	545.75	538.42	542.93	542.37	0.2526	1.3667
9	441.00	437.44	435.53	435.40	436.12	1.1058	4.8767
10	341.00	336.48	338.70	336.90	337.36	1.0674	3.6400

A total of ten sequences were carried out. Each time the leader reaches the checkpoint, it will wait for the beam to level itself. During that time, the position of the follower will be monitored from the KUKA robot controller in Cartesian coordinates. From there, the value of z-axis position of the robot that is in motion is recorded. Three readings at the same checkpoint were taken as it is fluctuating. The average value of the z-axis position is then compared with the leader to obtain the percentage difference between them. Meanwhile, the range from the three readings was also taken that is the subtraction between the maximum value and the minimum value at each checkpoint.

The testing conducted to the levelling system yield interesting results on its accuracy and precision. The accuracy is 98.89 %. From Table 1, the highest percentage error is 1.1058 % while the lowest percentage of error is 0.0943 %. Figure 5 shows how accurate the position of the leader and follower. Minimal error could be visualised.

Careful observations were done, taking every sequence into account. As the robot proceeds lifting the beam, the percentage error between the leader and follower is small in magnitude and almost negligible. Towards the end, however, as the beam begins lowering down, the percentage error increases considerably as huge gaps of the range could be observed. This is due to the additional gravitational force that exerts on the beam thus affecting the force/moment applied to the load and distracting the cooperative control undertook by the follower.

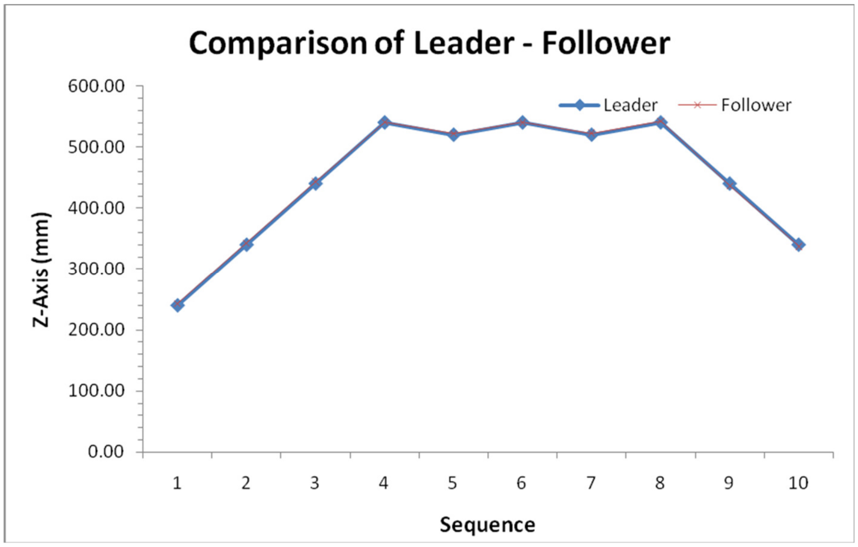

Fig. 5. Comparison of position between leader-follower

4. Conclusions

Cooperative control for two KUKA KR 3 Manipulators using PLC in a leader-follower approach was successfully demonstrated. The result of the accuracy of the follower with respect to the leader was presented thoroughly.

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