A study on customized low degree of freedom hydraulics flexible material handling: Alternatives and limitations

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Abstract: Inventory plays very important role in a manufacturing system. Compare to conventional forklift vehicle, a robotic arm is more efficient and reliable because it requires no human operator. Unfortunately, a robotic system needs high investment and maintenance cost, commonly due to its control system as a consequence of its high Degree of Freedom (DOF). For medium enterprises it is still difficult to find high capacity but affordable system. Customized system with a hydraulic power pack is a considerable alternative solution since speed and accuracy is not a mandatory. Therefore, this paper provide a preliminary study report for a low DOF hydraulic robotic arm. Basically, this is a conceptual product development study. This research used the first 5 activity stages of Concept Development Phase from Generic Development Process. The first stage was Identifying Customer Needs which involved automation experts from academician. The second stage was Translating Customer Needs into Technical Requirement. The third stage was Generating

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PUBLIC INTEREST STATEMENT

Nowdays not only big company may utilize robots in their manufacturing facilities, but also medium and small industries due to robot part customization. This paper show a mechanism to select types of robot structures namely Cartesian articulated and SCARA, for material handling in warehouse area. By using generic product development process, articulated type robot was selected and developed into a material handling robot prototype with hydraulic power pack and independent linkage system.
Concept Alternatives which was more focused on mechanical structure alternatives. The fourth stage was Selecting The Best Concept which was based on valuation with some technical criteria. The final stage was Testing The Best Concept which addressed to evaluate its operational abilities by building a prototype. The development process produce three design alternatives which featured with only three DOF linkage system. A flexible material handling with PRR (Prismatic-Revolute-Revolute) robotic arm then selected as the best concept. The robotic arm was inspired by VANTA MD410ib/300 Palletizing Robot. The arm is actuated with a hydraulic cylinders for each DOF. The system was designed to handle material from or to a graded vertical shelf. A 450 mm sized prototype was building using small plastic hydraulics components. From several trial, we found a critical part on the second link actuator thus an additional counter balance or spring system should take in to consideration.

Subjects: Industrial Engineering & Manufacturing; Production Systems; Manufacturing & Processing; Production Systems & Automation; Computer Integrated Manufacturing (CIM); Flexible Manufacturing Systems; Integrated Manufacturing Systems; Systems & Control Engineering; Automation Control; Robotics & Cybernetics

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1. Introduction

Inventory plays very important role in a manufacturing system. Company try to make their inventory more efficient including its handling devices because in most operations, material handling can account for 30–75% of an item’s total production cost (Kulak, 2005). Forklift is still widely used for material handling in warehouse especially for placing thing from or to vertical shelf storage. Unfortunately, the usage of forklift seems carry safety risk (Chinniah, 2015; Larsson & Rechnitzer, 1994; Saric, Bab-Hadiashar, Hoseinnezhad, & Hocking, 2013). Compare to conventional forklift vehicle, a flexible material handling intelligent system such as Automated Guided Vehicle (AGV) or robotic arm is more efficient and reliable because it requires no human operator (Horberry, Larsson, Johnston, & Lambert, 2004). However, intelligent system, especially for a high capacity lifting and carrying goods, requires high investment which is not affordable for medium to low enterprise. For medium enterprises it is still difficult to find high capacity but affordable system. Even for small system, it can cost thousands dollars (Dai & Lee, 2012). The reason behind the price is their speed, has high DOF(Degree of Freedom), and capability to have accurate movement. Previously, a dexterous manipulator has been built and test for vertical shelf but still need eight DOF (Schwarz et al., 2017). Conversely, high capacity handling which is usually handled by a forklift doesn’t need high speed and accuracy. It is not necessary to have micrometer sensors or ultra fast and precision mechanism to make it works. As long as it powerfull, can reach every place on the shelf, and has several milimeter accuracy, it should do the the handling task. Therefore, customized system with a hydraulic power pack is a considerable alternative solution (Licéaga-Castro, Navarro-López, García-Aguilar, & Andújar-Morgado, 2012).

This paper provide a preliminary study report for a development of low DOF hydraulic robotic arm as flexible material handling. A previous study shows hydraulic articulated type robot has been used as handling devices since long time ago (Hanafusa, Asada, & Mikoshi, 1981). A low DOF hydraulic articulated arm also found to be a didactic system (Gómez-Espinosa et al., 2014). On the other hand, a cartesian robot has known to be the most easy to fit on a flat working range and has been studied to be developed as material handling robot (Gamboa, Miguel, & Dragoljub, 2012). A previous study also shows the usage of hydraulic powered Selective Compliance Articulated Robot Arm (SCARA) robot for laying bricks (Heintze, Teerhuis, & Weiden, 1996). SCARA also widely used for handling device in many industrial fields. It means SCARA may also take in to consideration as handling device
alternatives. However, there are still limited scientific studies in designing or choosing the best concept for low DOF robotic manipulator for flexible material handling purpose. In this paper the three typical manipulator; articulated, cartesian, and SCARA would be simplified into the lowest DOF design they can be built but it still possible to do end effector positioning on a vertical graded shelf. Then we would select the best concept among the three. This paper consist of four parts, The Introduction, Methods, Result, and Conclusions.

2. Methods

Basically, this research is a product development. Many methods were proposed for this kind of activity and this research choose Generic Development Process (Ulrich & Eppinger, 2004), because it can accommodate almost of product design case. This research used the first 5 activity stages of Concept Development Phase which is taken from this development process. The first stage was Identify Customer Needs which involve academicians who major on automation. The second stage was Translating Customer Needs into Technical Requirement. The third stage was Generating Concept Alternatives which was more focused on mechanical structure alternatives. The forth stage was Selecting The Best Concept which was based on valuation with some technical and operational criteria. The final stage was Testing The Best Concept which addressed to evaluate its operational abilities by building a prototype. Before prototype building, we conducting a concept detailing stage using a mechanism simulator. For more detail illustration, you can see the Figure 1.

3. Result

3.1. Customer needs

The main topic that we discussed with the academicians expert is what are the criteria for a flexible material handling system if it will be used as handling device at a warehouse with vertical graded shelf. After consulting and conducting deep interviews towards the two Automation Lecturers and 6 Automation Tutorial Assistants, there can be summerized four identified needs:

(1) The arm should be suitable for hydraulic powered system or hydraulic actuator, which is categorized as linear actuator. All experts recommended hydraulic as the power system because it has high capacity with relatively cheap price compared to other systems.

(2) Suitable for 1 flat faced vertical shelf storing operation include positioning the end effector/fork enter and exit the shelf.

(3) For a simple affordable system, it should have maximum 3 DOF. This consideration was taken because a typical cartesian robot already has only XYZ movement.

(4) Capable in reaching all place in vertical shelf with horizontal end effector/fork orientation. This is very important because carrying things into and out from the shelf must be done with horizontal fork.
3.2. Concept alternatives

Previously, there were so many alternatives which can be generated from these nine technical requirements. Some effort has been done to reduce the alternatives, such as pre-defined the theme. The theme was “handling material from or to a graded vertical shelf with 3 DOF robotic arm”. Instead of palletizing on horizontal surface, this activity looks more unique. Its combine the handling task of forklift with the flexibility and speed of the robotic arm. Finally, the alternatives generation can be focused to the type of the robotic arm as the system manipulator. There are only three possibility of robotic arm type which can perform vertical material handling on a shelf.

The first alternative is a Vertical Cartesian Robot with PPP (Prismatic-Prismatic-Prismatic) joint configuration. Cartesian Robot can easily move the end effector linearly by moving one of its arm. The second alternative is a Modified Articulated Robot with PRR (Prismatic-Revolute-Revolute) joint configuration. This Articulated Robot relatively compact but producing vertical linear movement will require simultaneous movement of the second and third link while linear horizontal movement can easily provide by the first link. In another hand, to fix the orientation of the end effector, there must be an interdependent mechanism. This fixing mechanism was inspired by VANTA MD410ib/300 Palletizing Robot. The third alternative is a Modified SCARA Robot with RRP (Revolute-Revolute-Prismatic) joint configuration. This type of robot is opposite the articulated type in which it is easy to provide linear movement in vertical direction. However, end effector orientation issue is still occur in RRP, which in the typical SCARA, the end effector rotation controlled independently by one more DOF. As the result, we applied similar technique as done in Modified Articulated Robot. The three alternatives can be seen in Figure 2.

Figure 2. Concept alternative 1 (left), concept alternative 2 (middle), concept alternative 3 (right).

A1: Actuator of the first link
A2: Actuator of the second link
A3: Actuator of the third link
L1: First Link
L2: Second Link
L3: Third Link
3.3. Selecting the best concept
The best concept is the one that needs the simplest and cheapest hydraulic system to operate. It was selected based on valuation using 3 technical criteria, they are number of actuator, needs for long stroke actuator, and actuator load. These criteria has been approved by the eight expert who involved in the first stage. Number of actuator directly correlate with system complexity and cost since single hydraulic cylinder should be feed by independent valve. Smaller number of actuators indicate affordability of the system. Long stroke actuators for hydraulic system usually is accommodated by a usage of a multiple telescopic hydraulic cylinder. Since this part cause an extra cost, the existance should be minimum. Finally, the actuator load illustrates the most load by actuators in the system. The maximum load reached by single actuator which endure load from all other link and carried object. Since the load correlates directly to cylinder size and system pressure, lower the load will be better. The valuation was conducted using Pugh Matrix (Ulrich & Eppinger, 2004), with Alternative 1 as the reference with valuation value at “0” for each criteria. Better alternatives would be valuated by “+” while the worse by “−”. The best alternatives is determined by most number of “+” and less number of “−”. The valuation can be seen on Table 1.

In terms of number of actuators, Alternative 1 using more actuators than Alternative 2 and 3 since it needs 2 actuators for moving the first link. Then, for the needs of long stroke actuator, only Alternative 2 which consider doesn’t need any of the parts. For actuator load, Alternative 2 better than the other since the vertical load at link 1 is already detained by the slide rail. Finally, the result is alternative 2 was selected as the best concept. The best concept valuation and summary are shown in Table 1.

3.4. Testing the best concept
Conducting the operational ability test require a prototype, but the prototype cant not be built without detailing the concept first. We used A mechanism simulator to simulate our concept. We only focused on link 2 and 3 and the orientation fixation mechanism. We plan our prototype to be capable for 250 mm vertical storing. In the real world the size can be easily upscaled. For this initial study, we used equal length for link 2 and 3, then we gave them equal mass of 0.5 kg. We set link 2 at 135° and link 3 at 45° as initial condition that considered to be a default position. We have tested 3 models with 150, 175 and 200 mm link length. To achieve balance condition, a 1 kg load was attached 53.33, 61.87, 70.71 mm respectively for each link length. For the result, we found 175 mm to be shortest length which can easily reach 250 mm vertical shelf (283.82 mm on simulation). Maximum load for link 2 actuator (A2) reached at lower end effector position by 334.4 N. The simulation result can be seen on the following Figure 3.

For prototype building, we used transparent prototype as our design direction. This direction was choosen to minimize technical problem and to be easier for troubleshooting, consider hydraulic is working based on fluid. Firstly we chose colored water as hydraulic fluid compare to oil. Water is more safe, non-toxic, non-flammable, and cheap. For the valve and actuator, we use a ∅20 mm plastic

Table 1. Alternative concept valuation

| No. | Criteria                        | Alternative 1 (Ref.) Cartesian PPP | Alternative 2 articulated PRR | Alternative 3 SCARA RRP |
|-----|---------------------------------|-----------------------------------|------------------------------|-------------------------|
| 1.  | Number of actuator required     | 4 (2 for link 1, 1 for link 2 & 1 for link 3) | 0 | + | + |
| 2.  | Needs for long stroke actuator  | Yes (link 1 and link 2)           | 0 | 0 | No | + |
| 3.  | Actuator load                   | 2 actuators at link 1 endure load of link 2, link 3, and carried object | 0 | 1 actuator at link 2 endure load of link 3 and carried object | + | - |
|     |                                 |                                   |                              |                         | The best alternatives | No (3x“0”) | Yes (2x“+” and 1x“0”) | No (2x“+” and 1x“−”) |

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transparent tube. For the first link actuator which needs longer stroke, we use longer tube instead build it as multiple telescopic cylinder for manufacturability reason (Figure 4).

A 10psi nylon micro gearpump with integrated 6 V DC motor has been selected as the fluid prime mover. The pump cases is transparent so that we can see the gear rotating while fluid is pumping. 1 gear pump is more than enough to operate all actuator which max load of 350 N, require 0.02 N/mm or ~3psi. However, we used 2 gear pumps with serial configuration (20psi) to make sure it can works because hoses, valves, and cylinders has their own friction. The robotic arm is made of acrylic sheet. It is easy to shape by machining and has very good optical properties. Transparent robotic structure will enable us to see how the cylinder rod lengthen and shorten while it moving the arm.

An acrylic was also used as tank material. The hoses are made of small poly propylene transparent hoses. The illustration of detail concept is in the following Figure 5. All components were assembled with non-permanent mecanical fitting to ensure its maintainability. All of the component was installed on 45 × 45 mm (L × W) wooden box as the system platform.

The prototype are tested and it was able to operate completely. However, to move up form lower end effector position, the system running very slow. This indicate the link 2 actuator still endure very high load eventhough the pump theoretically can supply twice pressure than required. Our
suggestion for the real system is using additional mechanism such as counter weight or spring. The pictures of the prototype can be seen in Figure 6. It also has been tested for its capability to endure continuous operation in Automation Tutorial Class (Laksono, Priadythama, & Azhari, 2015).

4. Conclusion
This paper has shown alternatives of low DOF flexible material handling and their limitations. 3 DOF is considered as the simplest manipulator linkage system to achieve handling flexibility for storing task in shelf type storage. PRR Articulated Robot was selected for the best alternative concept. However, link 2 actuator (A2) is suffer the load due to link 3, end effector, and external weight, thus additional mechanism such as counter weight or spring are required. In the real system, more reliable components can be utilized so that many technical issue of the system can be eliminated. Eventhough the speed is still low, the system is fully worked and ready for automatic controlling such as by adding a programable controller. In the market, there are many type of controller available, and some of them consider very cheap but more than enough for controlling some actuators. Finally, this paper is already shows a base reference concept alternative of next generation material handling system which can reduce handling risk due to human factor.
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