International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

A Study on Industrial Applications and Link Designs of Modular Manipulators

Rachit Shukla, Himanshu Gaurav, Aniket Singh, Rakesh Dhiman

Abstract - In industrial robots, there are numerous common kinematic structures, the most popular of which is a six-axis angular structure. Researchers are working with task-based mechanism synthesis, which could result in improved efficiency using custom-optimized manipulators. The most efficient optimization technique for task-based robot manipulators has been the subject of numerous studies. These manipulators, on the other hand, are frequently optimised using simple modular joints and connections rather than more complex modules. We show that link modules with a minimal number of parameters perform better than those with more parameters. We examine three types of manipulator connections: Three different designs are linear links that can be optimized for different lengths, rounded links, and links with a curvature defined by a Hermite spline.

Keywords – Industrial application, Link design, Manipulators.

I. INTRODUCTION

A modular robot is a robotic system that is built from a collection of standard components. Following the product life cycle, we can differentiate distinct levels of modularity: modularity in the design and development phase; modularity in manufacturing; operative modularity; and modularity in retirement (Fixson, 2003).

When it comes to modular robots, operative modularity is important since it allows for a wide range of robot configurations to be created from a limited set of modules in order to meet various operating requirements.

Furthermore, if a complete set of spare modules is available, modularity reduces the robot's time-to-repair and so enhances its total availability; this is a crucial requirement for modern industrial firms trying to maximise resource availability.

For all of these reasons, researchers have been focusing their efforts in recent years on modular robots with the goal of increasing flexibility (Hamlin and Sanderson, 1996; Yim et al., 2000; Jantapremijt and Austin, 2001). Some researchers have attempted to create self-reconfigurable robots capable of autonomously modifying their configuration in order to improve the amount of autonomy of the robots (Murata et al., 2000, 2002; Rus and McGray, 1998). In complicated, unfamiliar surroundings, or in unmanned environments for self-repair, a modular and self-reconfigurable robot is most successful. The drawback of this approach is the lower mechanical performance, because the modules are necessarily more complex and heavy.

Modular manipulators are a new type of manipulator developed to maximise manipulator use by modularizing the architecture. In comparison to conventional manipulators, the effectiveness and functionality of a modular manipulator is simple to enhance.

These manipulators are made up of a variety of separate or identical module types that vary in size depending on the application. Because modular manipulators can be developed with more than 6 degrees of freedom, their architectural structure enables redundancy (DOFs). Modular manipulators have a more complicated control, inverse kinematics, and dynamics programme than typical manipulators. The modules of the modular manipulator can have various cross sections and forms. As the number of modules connected to each other grows, the degree of freedom grows as well. Modular manipulators can be manually or automatically modified to build a new robot that can execute a variety of tasks depending on the working environment.

The most valuable commodity nowadays is time, followed by industry resources. Every company or industry wants to make the most of its time and resources. The modular manipulator is critical in meeting this type of demand. The manipulator is modular.

The difficulty of optimization is determined by the complexity of the modules that make up a robot. In this sense, a module's complexity can be thought of as a set of parameters that describe one module and the various shapes it can take. Liu et al. [19] shown that changing the number and position of connecting faces in a module affects the modular robot's evolvability. Moreno and Faina used the same robotic modules in another study [20] to demonstrate how changing the length of modules influences the resulting robot architecture and performance.

 DOI : 10.35291/2454-9150.2022.0184

The Denawit–Hartenberg (DH) [21] parameters can be optimised to increase the performance of an open-chain manipulator for a specific task. For a certain workspace shape, Ceccarelli tuned the DH parameters of a 3R manipulator [22]. Singla [23] described a method for manufacturing serial redundant manipulators in an environment with obstacles by optimising their DH parameters. Previously, research that used DH parameters to improve task-specific manipulators were mostly limited to predetermined modules or straight modules of varying lengths. Brandstöter [1] proposed a modular robot with curved linkages and a general kinematic structure. We study and compare customizable straight and curved linkages in a single set of motion challenges, unlike earlier work.

The goal of this research is to show how module complexity influences total robot kinematics optimization results. We show this by optimising a manipulator made up of varied complexities of connection modules for two different jobs. The simulation of the manipulator, joints, and various sorts of linkages is described first. The optimization procedure and tasks are then outlined, followed by the outcomes.

II. Outline of the Design Methodology

Our research was carried out using the following steps based on these assumptions:

1. 1 Conceptual design of a robotic module library capable of meeting the needs of common industrial applications, taking into account the requirements listed in the previous section.
2. Architectural synthesis of several sorts of modules
3. Concurrent engineering method to detailed module design, incorporating FEM analysis and multibody simulation

Modular Design

The proposed modular approach entails the creation of a library of modules that can be used to construct a generic serial robotic architecture; this library is divided into two categories:

1. *Joint modules.* A joint, its accompanying actuator (motor and gearbox), a drive unit, and a motion control processing unit.
2. *Link modules.* They can be inserted between two joint modules, between the base and the first joint module, and between the last joint module and the end effector (two joint modules can be connected without the use of link modules if necessary).

There are two layers of modularity in this robotic library:1

1. **Mechanical modularity** is number one. The library's elements can be used to build a variety of serial robots.
2. **Control modularity** An embedded distributed control system governs the constructed robot; more specifically, each joint module is supplied with a local processing unit for appropriately driving its motion.

Mechanical modularity is a property that is independent of control modularity, and mechanically modular robots are controlled by a centralised control unit. The suggested distributed control solution has the advantage of not requiring the control unit to be programmed according to the kinematics of the specific built serial chain.

The library's multiple joint modules have varying mobility (revolute or prismatic); also, each form of mobility has different diameters, allowing:

1. Robots with a variety of size and functions

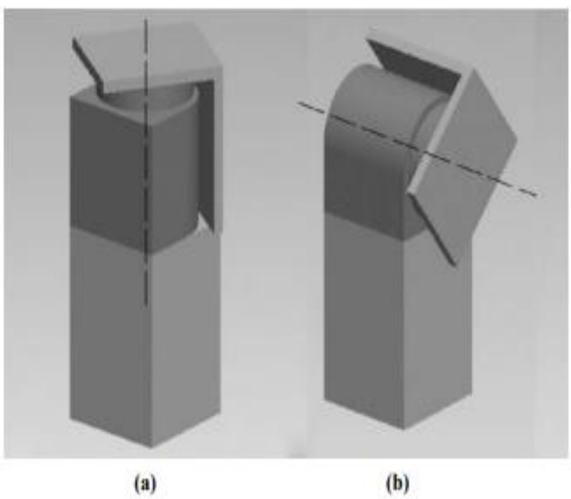
2. Different sizes of modules are incorporated within the same robot to account for gravity influences.

Revolute joint modules can be constructed in several orientations with regard to the remainder of the chain in a generic serial robot; typically, only two orientations are possible:

1. Axial. As shown in Figure 1(a), the joint axis is parallel to the previous link's longitudinal axis (a).

2. It's cross-sectional. As seen in Figure 1(b), the joint axis is orthogonal to the prior link's longitudinal axis (b).

Figure 1



To improve the modularity of manipulator by reducing the number of elements of the library revolute joint modules are designed in such a way that it can be assembled both in axial and in Page 16 transversal configuration. Therefore,

 DOI : 10.35291/2454-9150.2022.0184

ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

they proposed library composed of four sets of modules: link modules (Figure 2.6) and three types of joint modules:

1. Revolute joint module (Figure 2(a));
2. Prismatic joint modules (Figure 2(b); and
3. Wrist modules (Figure 2(c)).

The design of the revolute joint modules has been modeled in such a way that mechanical features (torque, angular speed and structural strength) of the revolute joints of a wide range of medium-small general purpose serial robots. On this basis, it was decided to design,as first step, three sizes of revolute joint modules (small, S; medium, M; large

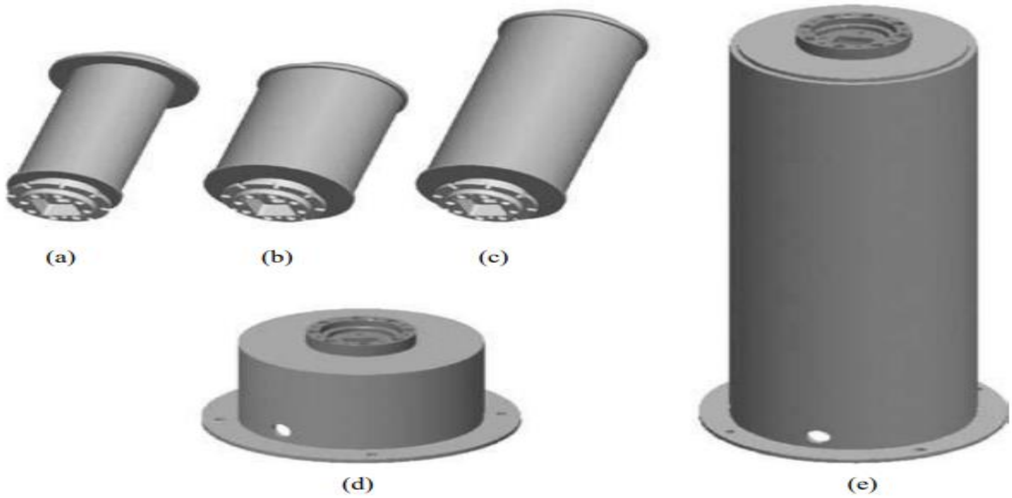


Figure 2 Link modules: connections between link modules (a,b,c) and robot bases (d,e)

Wrist modules are two-degree-of-freedom devices with two revolute joints with orthogonal axes; they are excellent for adding two rotations to the end effector. Assembling wrist module with revolute joint module in axial configuration results in three degree of freedom wrists with three intersecting axes and spherical motion, as shown in Figure 4.

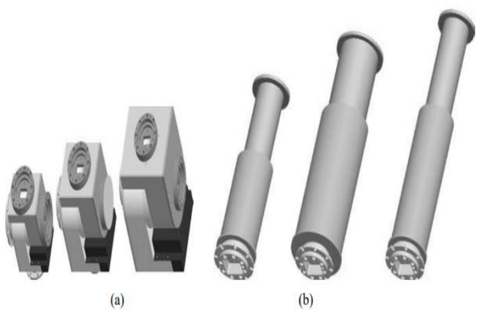


Figure 3 Joint modules: (a) revolute joints; (b) prismatic joints; (c) wrists

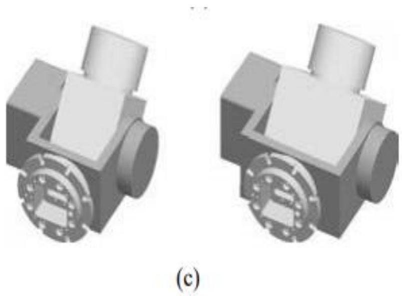
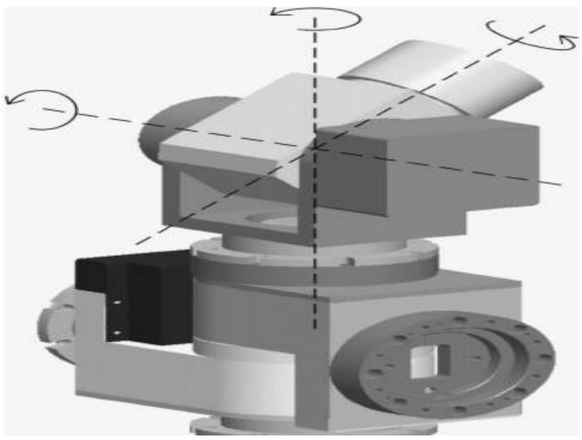


Figure 4 Assembly of a three-degree-of-freedom spherical wrist



Different materials were explored in this study for module joints and linkages. The material's strength, stress resistance, lightness, and production cost were all taken into account. Because of its high manufacturing cost, carbon fibre was rejected. FEM analysis was used to compare the structures of titanium and aluminium alloys from a list of lightweight metal alloys (Figure 5). According to the findings, using titanium instead of aluminium can lower the mass of the inlet and outlet bodies by 5-7 percent, but using aluminium reduces the overall mass of the module by 30 percent. As a result, aluminium was chosen since it is less expensive and easier to machine.

Figure 5 FEM analysis of the revolute joint module: (a) von Mises stress of the inlet body (b)

 DOI : 10.35291/2454-9150.2022.0184

ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

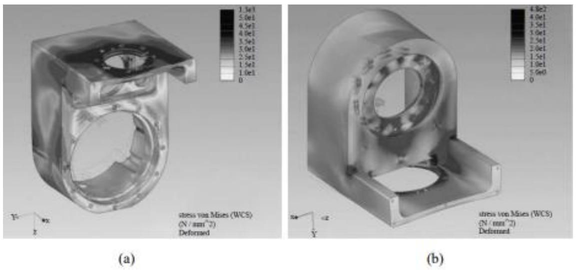
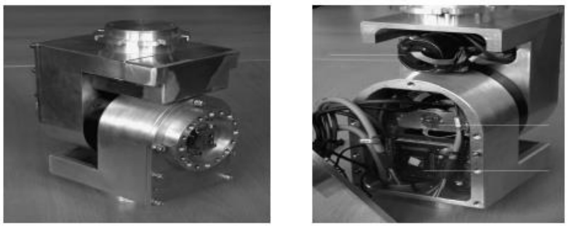
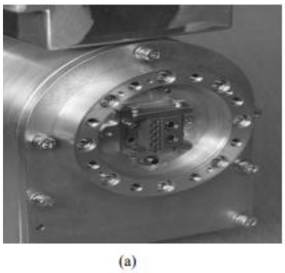


Figure 6



The prototype of the revolute joint axis, size M, has been realized (Figure 6). Figure 7 shows the female interface (a) and the male interface (b). Figure 8 shows the internal view of the module.



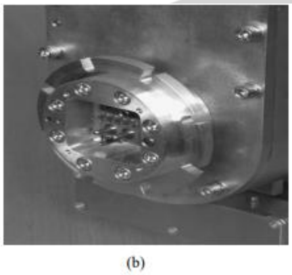


Figure 7 **Figure 8**

III. MANIPULATOR JOINTS

We limited the number of joints to three in this research because we were concentrating on manipulator linkages. Only those three joint modules were used to construct all manipulators (Table 1). In Coppeliasim, we built equivalent models (matching in size, weight, inertia, and torque) for joint modules manufactured by Schunk (production versions PR70, PR90, and PW70) . Only rotating joints were evaluated for the sake of simplicity. Two of the joint modules contained a single rotational joint, while the other had two. All joints in a manipulator can be instances of one joint because the modules can be reused an endless number of times. The joints were implemented as genes in the genetic algorithm, with three parameters: joint type (ID), orientation between the previous link and the joint (ora), and orientation between the joint and the following joint (orb) (orb).

The modules can be connected in four different orientations, as shown by the four orientation values space.

Table 1. Joint module physical parameters.

Parameter	PR 70	PR 90	PW 70 (axis1, axis2)
Maximal torque	46 Nm	145 Nm	24 Nm, 4 Nm
Weight	1.7 kg	3.6 kg	1.8 kg
Maximal current	8 A	12 A	8 A, 6.5 A
Flange size	70 mm	90 mm	70 mm
Type ID (in the program)	0	1	2

Table 2. Joint module parameters used for optimization.

Parameter	Range (Limits for Optimization)
ID	{0, 1, 2}
or_a	$\{0, \pi/2, \pi, 3\pi/2\}$
or_b	$\{0, \pi/2, \pi, 3\pi/2\}$

Manipulator This research concentrated on the manipulator's linkages. In the investigation, two different types of linkages were used. Table 3 lists the many parameters that determine each type of manipulator link. Each parameter is an integer that is supplied to the simulator at the start of the simulation. The comparison of all link types is shown in Figure 3.

Table 3. Link parameters.

Modular Link Type	Parameter/Parameters	Range (Limits for Optimization)
Rounded	Circumferential length (L)	{35, 500} [mm]
	Turn radius (R)	{10, 500} [mm]
	Turn direction angle (α)	{0, 180} [deg]
Hermite spline	Normal 1 (n_1)	{1, 300} [mm]
	End X (p_x)	{−500, 500} [mm]
	End Y (p_y)	{−500, 500} [mm]
	End Z (p_z)	{−500, 500} [mm]
	Bend (γ)	{−90, 90} [deg]
	Twist (β)	{−90, 90} [deg]
	Normal 2 (n_2)	{1, 300} [mm]

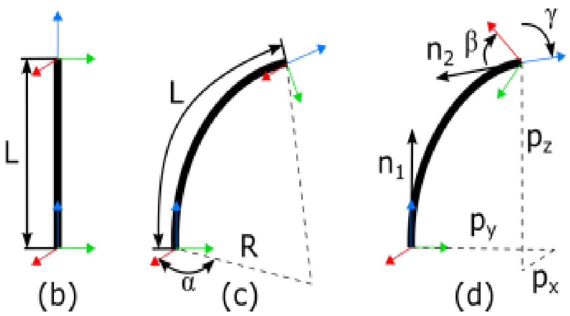


Figure 8. Types of (a)Linear ; (ded (c)Hermite Spline.

 DOI : 10.35291/2454-9150.2022.0184

Each sort of link is constructed differently. A simple straight connection is the most basic link type, and it is chosen from a list of predefined links . A single parameter ID is the sole thing that determines which link module to utilise. One of the modules

(ID 5) is formed at a 90-degree angle to allow for greater solution diversity. The modules are equipped to terminate with 70 and 90 mm flanges on one or both sides because the joint modules have two flange sizes available (70 and 90 mm).

The semicircular shape of the rounded link type is defined by three factors. Because the links in this sort of link module can bend and twist, the joint axes do not have to be orthogonal, and novel kinematic structures can be achieved.

A Hermite spline is used to create the Hermite link type. This gives you more control over the shape of the link than the other varieties, and it should help you avoid self-collisions. The disadvantage of this form of link is that it is described by seven parameters, making optimization methods computationally demanding.

As with basic links, flange diameters for linear, rounded, and Hermite links are not created in advance. Instead, based on the flange size, the thickness of the created connection object in the simulation is modified accordingly.

These four varieties of manipulator links include rounded and curved versions of the typically utilised straight links. They also point out the differences between fixed-length straight links and variable-length straight links.

IV. CONCLUSION

We established a method to optimise and measure the performance of various mechanical links of an open-chain manipulator in task-specific settings in this survey, which presents an analysis of architectural designs of links of modular manipulators and their industrial applications. Two different types of mechanical linkages were used to preconfigured links as well as links of varying length and curve were offered. Task-specific manipulators were built using the linkages, which were optimised for three different tasks with increasing degrees of geometrical complexity.

The experiments disproved our initial hypothesis that links with more customizable characteristics would be better able to adapt to the job trajectory. The simpler Hermite spline links performed much better in every task than the more sophisticated Hermite spline links. The performance of the various simple links (predefined basic links, linear links with changeable length, or rounded links with adjustable length and curvature) was usually similar, with noteworthy variances depending on the task.

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ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

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