

Adjustable link twist angle coupling for reconfigurable manipulator

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Mechanical designs of the robotic manipulators normally have revolute joints or prismatic joints exhibiting single degree of freedom. The relative motion of the joints is exhibited by the sliding of the surfaces one over the each other in prismatic joints. There is a need for keeping relative motions precise and backlash free. Robotic arms having modular construction normally uses twist angle 0° or 90° using fixed angles. To perform robotic actions in variable environment adjustable angle joints have issues like backlash and constraints of variability of twist angles. A coupling is designed and developed for link twist joint which can have relative backlash free positioning at an angle multiple of 15 degrees as well as 7.5 degrees as indexable joint which can be locked at desired location. Moreover, with slight adjustment with the pin it can also be positioned as per desired angle having discrete as well as continuous angle variability other than the fixed angles 0° or 90° .

Keywords: Link twist angle, Revolute joint, Indexable coupling, Manipulator mounting, Modular and Re-configurable robots

1 Introduction

Robotics is trending towards modularity due to its many benefits, which include the capacity to be customised, reconfigurable, and rapid repair or replacement when a portion fails without necessitating the shutdown of the entire system. Robotics modularity includes the creation of basic building blocks known as modules. The robotic system can be created by assembling or combining these elements. Typically, the modules consist of a connecting mechanism, joint modules, and link modules.

According to literature, the majority of robotic arms with modular construction use particular twist angle data, such as 0° or 90° . Moreover, the number of degrees of freedom (DoF) is maintained constant. The solution space for the configuration synthesis problems is reduced as a result of these design parameter constraints, and in a cluttered work-cell, there may be no feasible solution¹. therefore in order to perform the robotic functions in variable environment a adjustable angle resulting in inclusion of extra degrees-of-freedom (DoF), link twist joint with zero backlash is designed to perform the desired twist angle functions. Such couplings have various uses such as in case of vertical farming the variability of the work space and environment due to various

plants type and crop variety the application of such couplings manipulator are very useful for the robotic path defining and calculations. This leads to the efficient use of varied designs in extremely congested surroundings. This link twist angle α is the angle between axes Z_i and Z_{i-1} in a plane normal to X_i . The value is taken positive when rotation is made counter clock wise.

As indicated Acacciaetal.² presented three different types of modules: link modules, revolute joint modules, and prismatic joint modules. Design and control modularity degrees of modularity were displayed. The synthesis of two configurations, SCARA and a 6 DoF robotic arm, was also demonstrated by the authors Guan etal.³ presented "T and I" type joint modules for perpendicular and parallel connection between the axis of nearby joints. Two types of link modules the "T and L" type—were presented by Liu et al.⁴ for various configurations with a single joint module. Although the authors claim to have designed three distinct joint module sizes based on torque, the varying torques are only obtained by changing the gear ratio, thus there isn't much of a difference in size or weight when the torque is reduced. To create the manipulator with fewer modules and with less complexity in its control, it's a goal to find a configuration with the fewest degrees of freedom (DoF). There is no need to totally remove the links of joints in order to reconfigure the

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manipulator thanks to the new configurations, which lead to simpler and more efficient solutions to situations with modest changes in the DH parameters. The ability of the modular reconfigurable robots to adapt both morphological and topology⁵ is a significant advantage.

A reconfigurable manipulator is required when there are no regular set of tasks is to be performed by the robotic arm. For a non-repetitive nature of tasks modularity or adaptive parameters are helpful. There are 4 nos of Denavit-Hartenberg (D-H) parameters consisting of four variables i.e. two variable that are used to represent rotation θ and α two variables for displacement i.e. r & d . These parameters are represented in D-H parameter table for robotic arm with reference frames. Therefore coupling has been designed and developed for module itself gets new configuration by changing rotational angle α . The flexibility of the desired angle for the link is achieved by using this coupling. A designer has to consider many mechanical properties while designing robotic link such as the rigidity, weight, strength, ease of motion, type of joint, link length, economics, shape aesthetics, inertia forces etc. A coupling has been designed and developed for the indexable angle α when required and continuously variable desired angle and with a rigid locking arrangement. The material of the coupling is chosen to be aluminium for light weight and ease of machining. The novelty of this arrangement is that we can either change angle in finite set of multiples of $15^\circ / 7.5^\circ$ or any angle of the desired value without having any backlash.

2 Materials and Methods

2.1 Requirement of adjustable Link twist angle

One of the applications varying twist angle α in a robotic arm is being used reported work by Dogra *et al*⁶ on the idea of vertical farming for agriculture⁷ since it helps in using less area, which results in compact greenhouses, precision farming, which increases farmer yield, and so on. Robotic intervention would be a practical alternative for the implementation of farming practices on multi layered vertical farms, where human participation is rather tedious. It is possible to prepare for varied robotic aid with agricultural tasks like seeding, transplanting, harvesting, plant health monitoring, nutrient & water supply. The characteristics of various tasks, such as the reach, orientation, payload capacity, and even the kinds of end-effectors needed for each procedure,

varies as per farming processes. In addition, complexity may result from variations in the amount of clutter brought on by different plant heights. Each task would need a unique robotic configuration rather than a single configuration serving all objectives. It is not cost-effective to buy many configurations at once, and doing so will eventually raise maintenance costs as well. Consequently, the issue is to offer a time and economical solution that can be used to complete all required tasks within the necessary time frames. This is connected to the length, order, and other weather-related aspects of each procedure. Modularity and reconfigurability offer the most affordable alternatives for achieving this level of customization. The reconfigurable twist angle proposed coupling is the passive module allowing the user to adjust twist angle mechanically and configure the manipulator for alteration of D-H parameters for achieving new anatomies⁸. This paper proposes the design for a reconfigurable robotic system using rotational parameter α that in a way can meet the aforementioned requirements.

2.1.1 Design of link twist joint coupling

A robotic manipulator has joint modules as well as link modules. A link connects two joints while having certain geometrical relationship between them. The common joints in a robotic manipulator are revolute, rotary and prismatic type⁹. The rotary or revolute joint provide one degree of rotation whereas prismatic joint provide one degree of translation. These parameters are adjusted to reconfigure a robot. Currently the link twist joint angle are varied¹⁰ using a pin and hole arrangement with holes at different angle. A pin is fitted in common hole between two parts of the joint. Due to clearance between the hole and pin there is always a backlash in the joint resulting in the tolerance stacking and desired position is not achieved by the end effector. Therefore this coupling for the joint is designed for flexibility in the manipulator configuration for variable work environment with backlash free locking arrangement in field robots. The coupling consists of two parts, one has a T slot all around and the other one has holes 15° apart as shown in Fig. 1a. The width of the T-slot is just enough to avoid the rotation of the hexagonal head of the bolts. The coupling plate is having the projection and corresponding recess in the other plate for guidance and location purpose Fig. 1b. The plate having the indexable holes is fixed to the robotic arm through the clamping bolts and the other plate is mounted with the

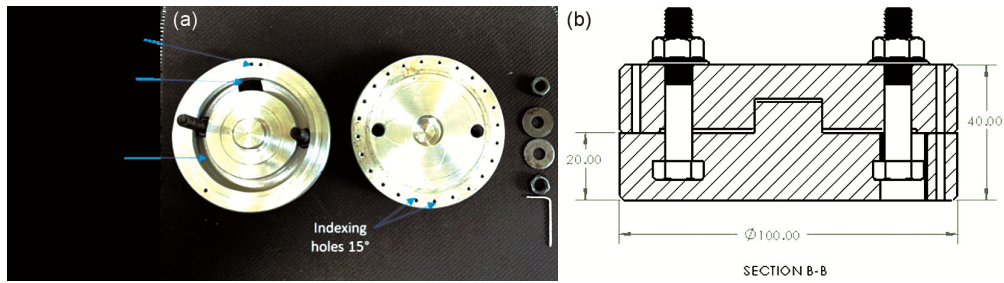


Fig. 1 — (a) Parts of link twist joint coupling, & (b) sectional view 2D.

motors. There is a locating pin which has common locating holes on both plates for indexing of 15° & 7.5°. The unique robotic hardware is capable of carrying out a variety of fundamentally dissimilar jobs through software reprogramming and desired hardware modification, such as altering the twist joint¹¹.

The motor assembly is done with motor holding component by 4 nos of bolts Fig. 2. The plate having slot is assembled with motor assembly through motor holding component with 2 nos bolted joint Fig. 3.

There are two nos. of M8 full thread bolts for assembly of the coupling with the robotic arm. The plate having indexable hole is the fixed one and the one having the slot mounted with motor is indexable.

Figure 4 (a-b) shows the complete Assembly of the coupling with Robotic arm and motor Assembly. The Fig.4c represents another similar design of the reconfigurable joint that can be mounted directly on the motor with indexing and joint locking as described above Fig.4d. For illustration purpose two positions of the coupling as demonstrated with joint having twist angle as zero Fig. 5a and another configuration a 45° Fig. 5b.

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3 Results and Discussion

The Fig. 6a illustrates that how a twist angle¹² α_i in link_i between joint_i and joint_{i+1} is achieved by the use of the developed coupling which is rotation¹³ α_i about x_i axis Fig. b. Through development of the coupling for the mounting of the motors with different configurations, the experimentation & the process of converting typical robotic parameters (DH convention) into a modular sequence is illustrated in Figure 6c. This might be useful in providing integrated modular answers to the issues of task-oriented manipulator design synthesis¹⁴. The motor mounting in a manipulator without any backlash

joint is

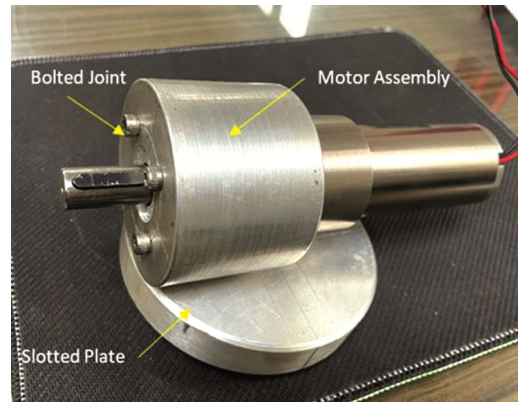


Fig. 2 — Assy of link twist joint.

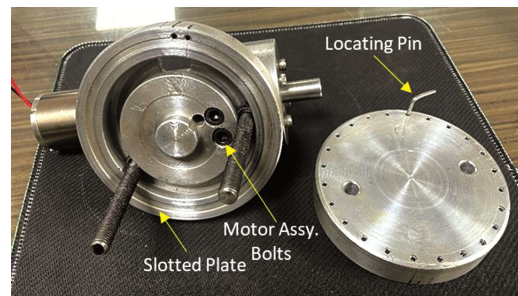


Fig. 3 — Assembly details of the coupling.

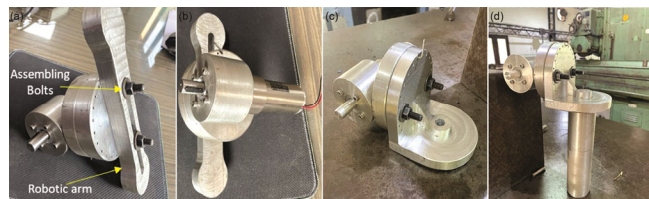


Fig. 4 (a-d) — The complete Assembly of the coupling with Robotic arm and motor Assembly

possible through this design in a cost effective and economical way. Designers may quickly and easily test out various manipulator configurations and validate them utilising the established coupling. The error due to the backlash in the joint due to the tolerance stacking is avoided and a rigid joint is achieved.

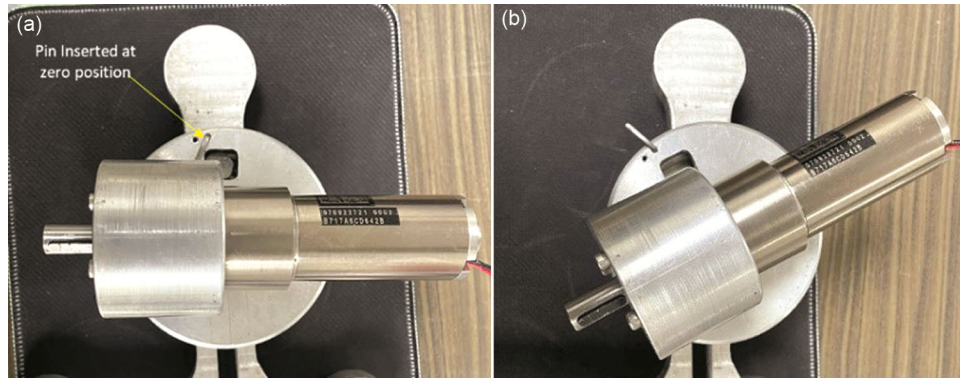


Fig. 5 — (a)-Assembly of the motor at Vertical position indicating the zero, (b) Assembly of the motor inclined at $\alpha=45^\circ$ the pin is inserted at third indexing hole from zero.

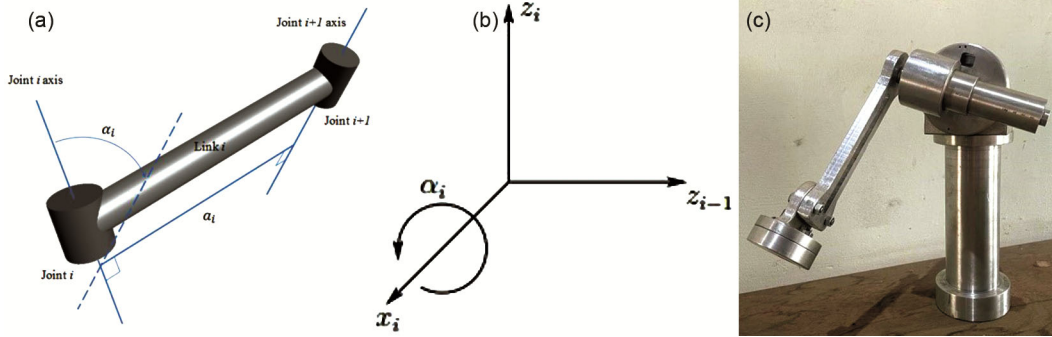


Fig.6 — (a-c) Twist angle α_i between Z_i and Z_{i-1} , about X_i .

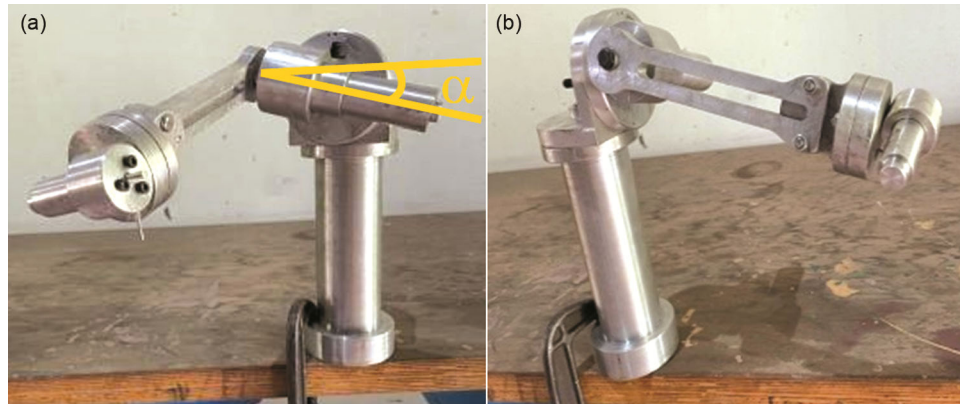


Fig.7 — (a) Twist angle α , and (b) Side view of link twist angle α .

4 Conclusion

A new mechanically reconfigurable passive joint has been developed, which facilitates the changing the one of the D-H parameters leading to a simpler & cost effective design compared to the conventional reconfigurable robots that are comparatively have complex locking mechanisms. The configuration change of twist angle can be performed reliably and mechanically in very less time having no joint backlash issues. Another advantage of the developed coupling is the reconfiguration of the twist angle in

discrete and continuous mode. The automation of the angle movement using stepper motors and other devices may have future scope of work in this direction.

Figure 7 a shows link twist angle α adjustment using two nos of couplings in a manipulator. The one attached with vertical motor is showing use of coupling with 90 degree joint and is mounted on the motor and the one at the link end shows a smaller coupling mounted directly on the link & is smaller in size. The Fig. 7b shows the mounting details of small

coupling on the link itself with two nos of bolts. This shows how two different twist angles can be given to the links by installing the motors at different angles as shown. This variability in robotic design parameters due to link twist angles increases the possibility of better designs even for highly unapproachable workspaces¹⁵.

The advantages achieved by adjusting the link twist angle; one can avoid singularities issues, cope with a variety of objects and actions in work space, avoid collisions and improve overall robot stability, favorable joint torques by reducing energy requirements to robotic movements and aligning the robot joint axis with desired motion requirements, applications and task a robot intend or need to perform.

The another advantage of this design is that the link twist angle can be changed as per task based environments just by loosening the two bolts and desired link twist angle can be set without disassembling the whole joint¹⁵.

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