# A High Torque Density and Highly Compliant 7-DOF Collaborative Robotic Arm

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*Abstract*— **Robotic arms are essential for many human-robot collaboration and interaction tasks, often relying on actuators with harmonic drive reducers to achieve sufficient torque and precision. However, these traditional solutions require substantial space and weight, resulting in bulkiness and inefficiency. The advent of collaborative robots in shared environments has necessitated the development of smaller robotic arms that offer high torque and compliance to maintain safety. In this abstract, we propose a brand-new Rotary Vector (RV) actuator-based OMNI-3 robotic arm, featuring joint actuators that are highly integrated, including motors, RV reducers, drivers, and encoders with remote control capabilities. This design leverages the benefits of high integration, allowing the OMNI-3 to deliver high torque output with a 3kg payload while maintaining a compact size and high compliance. We compare the RV actuator-based OMNI-3 with various state-of-the-art harmonic drive-based robotic arm solutions. Our findings demonstrate that the OMNI-3 excels in payload-to-mass ratio and compliance, making it an outstanding choice for modern collaborative robotic applications.**

## I. Introduction

As many mechanical tasks require the presence of both collaborative robots and human workers, the market demands more than just large robotic arms that operate in isolated environments. A more flexible, safe, and efficient robotic arm is necessary. In certain applications within the field of collaborative robots, such as circuit board soldering and surgical robots [1] [2], there is a need for not only high precision and flexibility but also strong back-drivability to ensure safety [3], [4]. While many robotic arms on the market attempt to address these requirements, our OMNI-3 robotic arm, based on a Rotary Vector (RV) actuator, stands out. Then, we compared the performance and advantages of the OMNI-3 with other robotic arms in key parameters.

## II. Compact Rotary Vector Actuator with Highly Integrated Motor and Electronics

*RV actuators* are precision components designed for high torque and large loads. At the core, it has a cycloidal gear mechanism that operates within a two-level system. The gear composition at a micro level includes several rolling pins and needle bearings that contribute to its robust performance. Compared to *harmonic drives*, which are very lightweight and compact with low manufacturing costs, RV actuators offer better load handling, long-term precision, durability, and excellent torque-to-weight ratio [5]. Furthermore, RV reducers possess excellent back-drivability that enhances operational safety by improving force dissipation [3].

Traditional RV actuator-based robotic arms have drawbacks such as high cost, insufficient lightweight design, and lack of compactness, requiring them to be separated from humans for large industrial applications. Our robotic arm solved these issues by featuring a fully integrated actuator with a compact motor and RV reducer. This allows for easy use in close-range human-robot collaboration, offering advantages over Harmonic rotary actuator-based robotic arms.

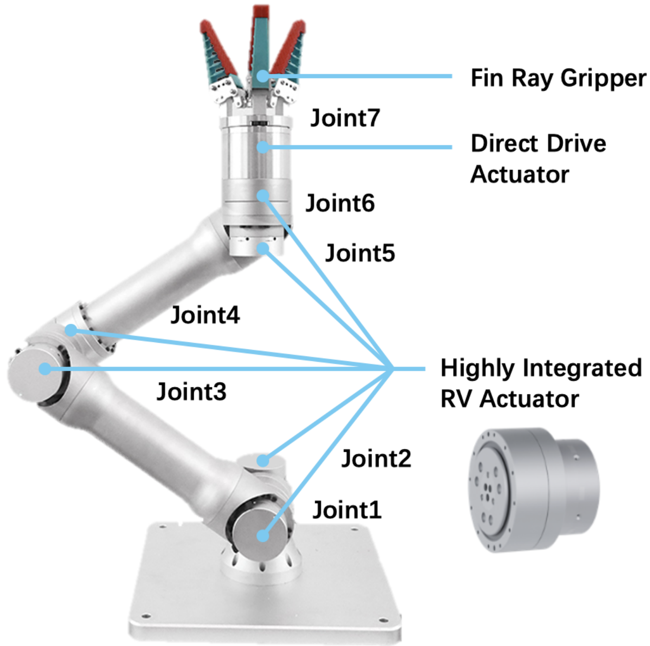


Fig. 1. The 7-DOF OMNI-3 Robotic Arm and its Fin Ray Gripper.

*Modular Design and Fin Ray Gripper*

The OMNI-3 robotic arm features seven degrees of freedom. The former six joints are facilitated with six modular compact actuators. Each actuator is highly integrated by an RV reducer, sensors, motor drives, and a compact brushless motor. The seventh joint features a fin ray gripper controlled by a lead screw and a direct drive brushless motor. Each modular RV actuator ensures consistent performance, reducing the maintenance cost. The fin ray gripper adds versatility, allowing for precise and adaptable gripping applications.

## III. Communication Architecture of 7-DOF OMNI-3 Collaborative Robot Arm

### A. Internal CAN Communication

The OMNI-3 robotic arm utilizes an internal CAN bus for efficient communication between its modular actuators. Each actuator, integrated with RV reducers, sensors, motor drives, and compact brushless motors, communicates over the CAN bus to ensure synchronized movements and precise control.

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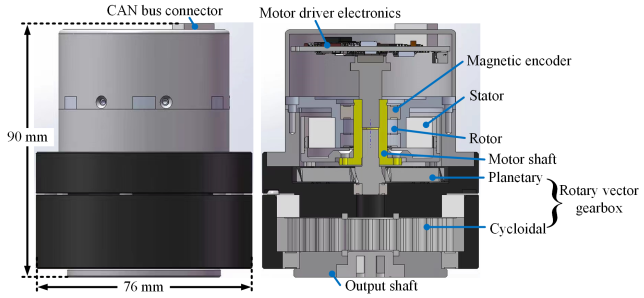


Fig. 2. Rotary Vector Actuator Inside our OMNI-3 robotic arm

### B. Wireless Control Communication

The OMNI-3 robotic arm can be wirelessly controlled using an ESP32 microcontroller. The communication setup involves connecting the computer and the ESP32 microcontroller to the same local area network (LAN) established by a WiFi generation device. The ESP32 microcontroller interfaces with the robotic arm via the CAN bus, enabling robust and real-time communication. The computer, equipped with a graphical interface sends commands over the LAN, which are then relayed by the ESP32 microcontroller to the robotic arm. This setup allows seamless control and monitoring of the robotic arm, enhancing its usability in various applications.

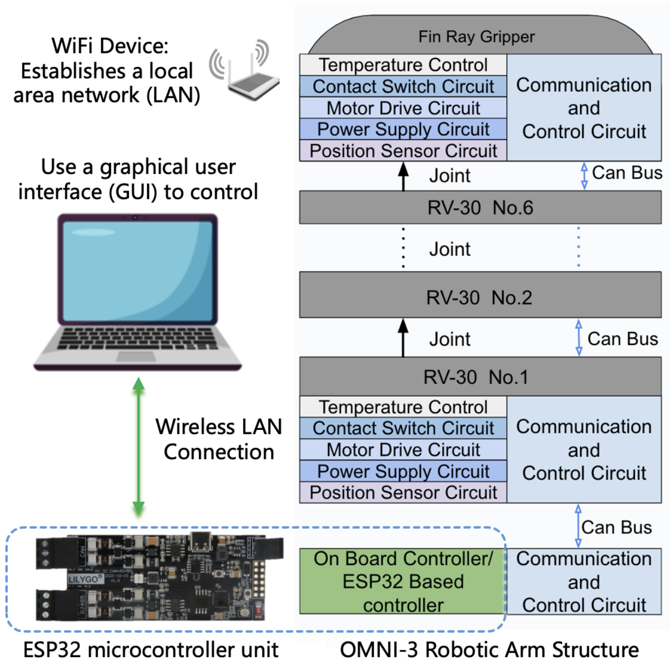


Fig. 3. OMNI-3 Internal and External Communication System - The OMNI-3 robotic arm's wireless control setup uses an ESP32 microcontroller unit and CAN bus communication for robust, real-time control of modular RV 30 actuators and the fin ray gripper. Internal communication is via CAN bus, while external communication between the robot and the computer is through WiFi.

## IV. Comparative Study

The OMNI-3 robot arm is compared with existing robotic arms including Universal *Robots' UR-3E, Kinova Robotics' Kinova, Elephant Robotics' Mycobot, RealMan's RML63-B, igus GmbH's Rrbel*, and *UFactory's xArm*, as shown in Table 1. The characteristics of our OMNI-3 robot arm can be summarized:

TABLE I
PERFORMANCE COMPARISON BETWEEN VARIOUS ROBOTIC ARMS

| | Mass (kg) | Payload Limit (kg) | Payload to Mass Ratio | Working Radius (mm) |
|---|---|---|---|---|
| **OMNI-3** | **6.5** | **3** | **0.4615** | 630 |
| UR-3E | 11.2 | 3 | 0.2678 | 500 |
| Kinova | 5.2 | 1.3 | 0.25 | 900 |
| Mycobot | 8.8 | 2 | 0.2273 | 630 |
| RML63-B | 10 | 3 | 0.3 | 900 |
| ReBel | 8.2 | 2 | 0.2439 | 664 |
| xArm | 12.2 | 5 | 0.410 | 700 |

- **High payload to mass ratio**: The payload to mass ratio of 0.4615 is the highest, indicating superior load handling relative to its weight.
- **High compliance**: The OMNI-3 robotic arm exhibits exceptional compliance, significantly enhancing safety during human-robot interactions by providing a more responsive and adaptive behavior.

## V. Conclusion

The OMNI-3 robotic arm demonstrates significant potential in industrial applications, safety, and human-robot collaboration. The OMNI-3 robotic arm excels with its high payload-to-mass ratio and exceptional backdrivability, allowing smooth and safe interactions. Furthermore, its remote control abilities allow for excellent control over the robotic arm and make it a promising choice for precision tasks in shared confined spaces.

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