Research and implementation of a new 6-DOF light-weight robot

Zihang Tao1,2, Tao Zhang1,2, Mingzhong Qi2 and Junhui Ji1,2
1School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, China
2Institute of Plasma Physics Chinese Academy of Sciences

Abstract. Traditional industrial robots have some weaknesses such as low payload-weight, high power consumption and high cost. These drawbacks limit their applications in such areas, special application, service and surgical robots. To improve these shortcomings, a new kind 6-DOF light-weight robot was designed based on modular joints and modular construction. This paper discusses the general requirements of the light-weight robots. Based on these requirements the novel robot is designed. The new robot is described from two aspects, mechanical design and control system. A prototype robot had developed and a joint performance test platform had designed. Position and velocity tests had conducted to evaluate the performance of the prototype robot. Test results showed that the prototype worked well.

1 Introduction
In 1962, the first industrial robot was born in America. Since then, robots have been widely used in factory automations and auto-production systems. In the new century, robot applications have been expanded from automotive industry to rescue, anti-terrorist, service, surgery, medical, rescue and some other special applications. However, in these application scenarios, some drawbacks of the industrial robots are obvious: high power consumption, low payload-weight ratio, bulky structure and complex auxiliary system. In order to overcome these shortcomings, research efforts have dedicated to development of light-weight robots. Some remarkable examples of light-weight robots include the LWR developed by German Aerospace Center[1], the ROBONAUT for space experiment developed by NASA[2], the light-weight actuator designed for mars exploration by JPL[3]. Other examples of light-weight robots include the RPL light-weight robot, the UR light-weight robot series[4], the KUKA LBR iiwa[5], YuMi light-weight robot developed by ABB[6] and so on. These light-weight robots have some common characteristics, namely compact construction, light weight, high pay-load ratio, more sensors and easy installation.

This paper introduces a new light-weight robot. The robot was designed and developed based on modular joints and modular connections. Some performance tests had conducted to the prototype robot. The tests validated the feasibility of the new robot system.

2 Design requirements analysis
Industrial robots are designed with rigid links for high-precision movement in a known application scenario. Usually no more sensors (such as force/torque sensor, additional position sensor) are needed. Normally some auxiliary systems are applied to ensure safety.

In contrast, light-weight robots, for which a high payload-weight ratio is desirable, are built with relatively compact joints and high-reduction ratio.
To get an overview of the light-weight robots, some notable light-weight robots are compared, as showed in the Table 1. Most of these robots have six joints, some of them have seven joints. Their payload-weight ratios are quite better than traditional industrial robots. Some of them install extra torque and position sensors to detect possible collisions. So these light-weight robots can work association with people.

From the comparison, it is seen some common features are desirable for light-weight robots:
- High payload-weight ratio.
- Low inertia.
- Position and force/torque sensors.
- Compact structure.
- Convenient construction and maintenance.

Table 1: Comparison of typical light-weight robots

| Robot | UR-5 | LWR-III | iiwa | OUR |
|-------|------|---------|------|-----|
| Total weight | 18.4kg | 14kg | 23.9kg | 19.5kg |
| Payload | 5kg | 14kg | 7kg | 5kg |
| DOF | 6 | 6 | 7 | 6 |
| Position control | Yes | Yes | Yes | Yes |
| Kinematics | Serial | Serial | Serial | Serial |
| Maximum reach | 0.85m | 0.9m | 0.8m | 0.917m |

3 Mechanical Design

The joints of light-weight robots are normally designed by two approaches. One approach is to separate the motor and the joint. The motors are allocated in the base, their motions are transmitted by rope pulley or chain drive structure. The typical light-weight robot is WAM[7], designed by Barrett Technology. This type of design has advantages such as zero backlash, low friction, and faster response time than traditional manipulator. However, as all driver units are located in the base, this type of robot has a large base. Moreover, it is very complicated to install the rope pulley structure inside the robot link. And this type of robot is hard to gain a large reduction. The WAM is shown in the Figure 1.

![Figure 1: The WAM robot and rope pulley structure](image)

The other approach is to design with highly integrated components. The most notable structure is the LWR modular joint. The LWR joint is designed to integrate electrical devices and mechanical components. The electrical components include position sensor, electrical braking unit, communication unit and control unit. To gain high pay-load ratio, customized motor and harmonic
drive are used. Moreover, composite materials are used for the robot links to further reduce the arm weight. The design of the whole system (mechanical structure and control system) is selected to reduce the weight of the robot. This type of robot has advantages such as small size, light weight, easy and convenient installation, and interchangeability. However the transmission mechanism of the robot has low transmission efficiency, and usually has driving backlash. So this type of robot is not as precise as traditional industrial robot. The LWR is shown in Figure 2.

Figure 2: The LWR robot and modular joint

In the proposed design of robots, we aimed to design a robot with modular joints which has better interchangeability, smaller size, lighter weight and higher payload-weight ratio. A designed modular joint is shown in Figure 3. The components of the joint are indicated in the picture. The motor adopts high power-density brushless DC motor with hollow shaft. Within the hollow shaft, the communication cables and power cables are routing. So the joints can move more than 360 degrees, and the communication signals are more stable.

Figure 3: Modular joint and components.

Based on the designed modular joints, a 6-DOF lightweight robot is further designed, as it is shown in Figure 4. Some primary parameters are listed in Table 2.
Figure 4: Six-DOF robot

Table 2: Primary parameters of the robot

| DOF | Maximum reach | Total weight | Designed payload |
|-----|----------------|--------------|------------------|
| 6   | 1200mm         | 28kg         | 5kg              |

4 Control System

The control system was designed to have two parts, which are the low-level control and the high-level control. In this project the Elmo Gold Twitter Digital Drive is the controller of the motor. Elmo Gold Twitter is a highly integration motor driver, which has tiny size and high power density. The controller supports many control modes, including current control, velocity control, position control, advance position control and filter design. Moreover the Gold Twitter supports the CANOPEN protocol. So all servo drivers can be connected to the CANOPEN bus serially with two communication cables.

The high-level control is an industrial computer. The computer is the controller of the whole motion of the robot. As the computer doesn’t have CAN interface. A peak is adopted to connect the low-level controller and the high-level controller. The structure of control system is shown in Figure 5.
5 Robot testing

In order to evaluate the single joint performance, a test platform had designed. The component of the test platform are shown in Figure 6. Several testing of the robot have been conducted. At first, single joint was tested, include load test and position accuracy test. Then position controls were carried out with the robot.

At single joint motion test, a position command is sent to the joint, the high resolution sensor in the test platform detects the accuracy of the joints. In the steady-state, the position error is 0.0001 degree. The figure 6 shown the test platform. The robot prototype is shown in figure 7. The test results are shown in figure 8 and figure 9.

Figure 5: The frame of control system.

Figure 6: Testing platform
Figure 7: Robot prototype

Figure 8: Position error

Figure 9: Position Curve
6 Conclusion

In this work, a new 6-DOF light-weight robot was designed and developed. In order to gain high payload-weight ratio and reduce the robot’s weight, modular joints were designed. Based on the modular joints, a 6-DOF light-weight robot was developed. A prototype was fabricated, some tests were conducted to evaluate the performance of the robot. The results showed that the robot worked well. The next step is to optimize the design for better reducing the weight of the robot.

References

[1] Hirzinger. G., Albu-Schaffer, A., Haahnle M., Schaefer I., Sporer N.: On a new generation of torque controlled light-weight robots. In: IEEE International Conference on Robotics and Automation, pp. 3356–3363 (2001).

[2] Bluethmann, W., Ambrose, R., Diftler, M., Askew, S., Huber, E., Goza, M: Robonaut: a robot designed to work with humans in space. Auton. Robot. 14, 179–197 (2003)

[3] Stieber, M.E.: Vision-based sensing and control for space robotics applications. IEEE Trans. Instrum. Meas. 48(4), 807–812 (1999)

[4] http://www.ur5.cc
[5] http://www.kuka-robotics.com
[6] http://www.abb.com.cn
[7] Townsend, W.T., Guertin, J.A.: Teleoperator slave—WAM design methodology. Ind. Robot. Int. J. 26(3), 167–177 (1999)