Development of anthropomorphic multi-D.O.F master-slave manipulator

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Abstract- We developed a robotic arm for a master-slave system to support tele-operation of an anthropomorphic robot, which realizes remote dexterous manipulation tasks. In this paper, we describe the design and specifications of the experimental setup of the master-slave arm to demonstrate the feasibility of the tele-operation using exoskeleton. The paper explores the design decisions and trade-offs made in achieving this combination of price and performance. We developed the 6-degree-of-freedom slave arm and exoskeleton master for control of robotic arm.

Keywords- Robotic arm, Human Machine Interface, exoskeleton, manipulator, tele-operated

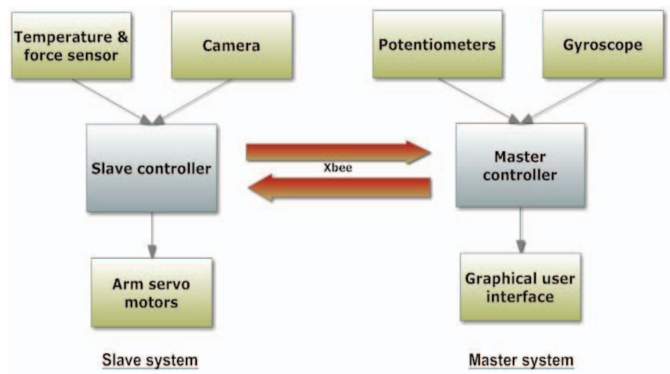

Fig. 1: Block diagram of the Master-slave system

I. INTRODUCTION

Conventional robot arms are typically controlled by pre-programming of the desired paths within the robot workspace. Then the robot arms followed the desired programmed paths. There are some applications which we cannot form the desired paths at the beginning. The manual manipulation is needed to help the operator to control the manipulator arm. In this case the master-slave or tele-operation is required to fulfil the task. In this work we develop a 6 degree of freedom Master-Slave Human-Assisted manipulator arm with relaxation of kinematics closeness. We also bring up virtual guidance to improve the manoeuvrability for the operators. The virtual guidance can be a desired path or a boundary of the desired workspace. And any limited control volume can also be controlled or specified by virtual guidance technique.

In this paper we aim to present the 6-DOF anthropomorphic arm controlled by Human Machine Interface (HMI) which is used by the tele-operator to control "DEXTO:EKA: – The Humanoid Robot"[1], which is a remotely operated anthropomorphic (i.e. appearance like human) robot. Fig. 1 shows the block diagram of the master slave system. It has the Human Machine Interface as the master, which is used for the remote control of the robot. It consists of a gyroscope based interface, joystick and audio-visual system. The mode selection switch enables the tele-operator to select one of the three modes of operation. The anthropomorphic robotic arm acts as the slave, which has six degrees of freedom including the manipulator.

II. RELATED WORK

There are a number of robotic arms that are being used in robotics research today, many with different features and design criteria. In this section, we discuss some recent widely-used and influential robotic arms. The Barrett WAM [2], [3] is a cable-driven robot known for its high back drivability and smooth, fast operation. It has high speed (3 m/s) operation and 2 mm repeatability.

The Meka A2 arm [4] is series-elastic, targeted for interactions with humans; more, custom-made robots with series-elastic arms are Cog, Domo, Obrero, Twendy-One, and the Agile Arm [5], [6], [7], [8]. The Meka arm and Twendy-One[9] use harmonic drive gear heads, while Cog uses planetary gearboxes and Domo, Obrero, and the Agile Arm use ballscrews; the robots use all different mechanisms for their series elasticity purpose. These arms have comparatively low control bandwidth (less than 5 Hz) due to series compliance, yet that did not appear to restrict their use in manipulation research. Several human-safe arms have been developed at Stanford University using a macro-mini actuation approach.

The PR2 robot [12], [13] has a unique system that uses a passive gravity compensation mechanism, so the arms float in any configuration. Because the huge mass of the arm is already being supported, comparatively small motors are used to move the arms and support payloads. These small motors

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render human safety, as the motors can be driven back very easily because of their low gear ratios.

The DLR-LWR III arm [14], Schunk Lightweight Arm [15], and Robonaut [16] all use motors directly mounted on each joint, along with harmonic drive gear heads which provide faster motion with zero backlash. These arms have somewhat higher payloads than the other arms discussed in this section, ranging from 3-14 kg. They are not designed for human safety, having relatively large flying masses (close to 14kg for the DLR-LWR), although demonstrations with the DLR-LWR III have been performed that incorporate a distal force/torque sensor that uses the arm's high bandwidth to quickly stop when collisions are detected.

Of the robotic arms discussed previously, those that are commercially available are all relatively expensive, with enduser purchase prices well above $100,000 USD. However, there are a few examples of low-cost robotic manipulators used in research. The arms on the Dynamaid robot [17] are constructed from Robotis Dynamixel robotics servos, which are light and compact. The robot has a human-scale workspace, but a lower payload (1 kg) than the class of arms discussed previously. Its total cost is at least $3500 USD, which is the price of just the Dynamixel servos. In videos of it in operation, it appears to be slightly underdamped.

The KUKA youBot arm is a new 5-DOF arm for robotics research [18]. It has a comparatively small work envelope over 0:5 m3, 0.1 mm of repeatability, and 0.5 kg of payload. It has custom, compact motors and gearheads, and is priced for 14,000 Euro at time of writing itself.

III. ANTHROPOMORPHIC ROBOTIC ARM

The following requirements were chosen to ensure the arm would be useful for manipulation research:

- Human-scale workspace
- 6 Degrees of freedom
- Payload of at least 1.5 kg
- Human-safe
- Maximum speed of at least 1.0 m/s
- Zero backlash
- Low cost

The main advantage of tele-operation is that human beings are adaptive and so are better able to deal with unregulated or disorderly environments. Specifically, this is a human scale robotic arm with 6-DOF (degree of freedom) [19]. The 6-DOF covers the major and most common arm movements to cover a large area, and it also helps the arm in easy manoeuvrability to lift and move objects in any direction. It is almost a replication of the human arm with respect to the number and position of the joints.

Out of the six degrees of freedom, four are for positioning and two for orientation. If the joints are seen with respect to their human equivalent, then the robotic arm can be said to have the following joints: abduction (shoulder sideways), shoulder back and forth, elbow, wrist up and down, pivot (wrist rotation), and gripper (hand). The actuators for all of these joints are servo motors. There are in total ten servo motors used. The gripper is a two-finger construction; each finger with two parallel links. Fig.2 shows the 3D model of the anthropomorphic arm.

Fig. 2. 3D model of 6-DOF anthropomorphic arm

Sensors are mounted between the joints of the manipulator for force sensing. These sensors measure the amount of strain exerted on each and every joint. The greater the strain, the larger is the amount of force that the joint is exerting [20]. The main advantages of this system are that it measures actual forces and that the measurement does not affect the operation of the joints themselves. It is therefore relevant, for the gripper joint, to use a force sensor to measure the amount of force the slave is exerting on an object in its grip.

To measure the force, a sensor is attached to the inside of one of the gripper prongs. When the gripper closes around the object, the sensor is contracted between the object and the gripper prong. From this the force can be measured. These sensors are mounted on a flexible circuit board and have a small circular dot of force-sensitive ink. The resistance of this ink increases as the force applied is higher. By adding a simple operational amplifier based circuit this force can be converted into an analog voltage that can be fed into one of the ADC inputs of the microcontroller.

DS18S20 one wire digital thermometer is also attached at the gripper to measure the temperature of the object and surrounding. DS18S20 digital thermometer provides 9-bit Celsius temperature measurements and is displayed at the GUI (Graphical User Interface) at the controlling end. It has an operating temperature range of -55°C to +125°C and is accurate to ±0.5°C over the range of -10°C to +85°C. The slave also has two 10mm LED to provide light for working in dark environment.

Table 1 show the range of each servo motor and number of servo motors used for all the six joints if the arm.

TABLE 1

Joint ranges and Number of servo motor

S. No.	Joint	Range (degrees)	No. of Servos

1.	Abductio n	120	2
2.	Shoulder	130	2
3.	Elbow	125	2
4.	Wrist	180	2
5.	Pivot	180	1
6.	Gripper	NA	1

The specifications of the gripper used in the arm are-

- Gripping size: 50mm
- Gripping force: 1500gms (Maximum)
- Length: 110mm (When fully closed)
- Weight: 157gms (Including 2 NRS-585 servo motors for gripping and twisting)

Fig.3 show the actual developed 6-DOF anthropomorphic robotic arm for Dexto:Eka:. The frame of the robotic arm is made up of aluminium alloy and servo motors are used for actuation. The arm is being powered by a Lithium Polymer 2 Cell, 5000mAh, 7.4V, 30C discharge Battery.

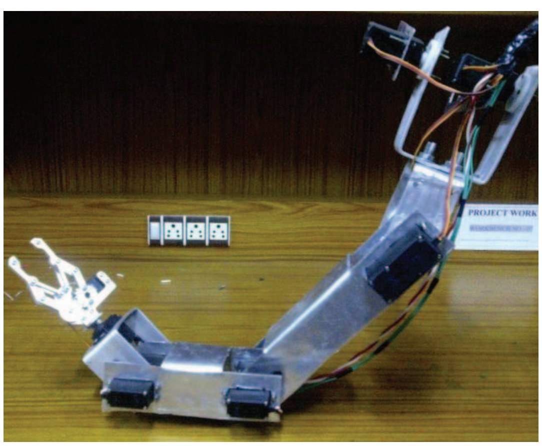

Fig. 3: Developed 6-DOF humanoid arm

IV. HUMAN MACHINE INTERFACE

Special emphasis has been given to the ease of operation with the correct position sensing using gyroscope and potentiometers in the control rig. The control rig is fitted to the user's arm. Use of a 'wearable' rig in a bilateral master slave control setup has been introduced to simplify the HMI (Human-Machine Interface). The design of the master unit, shown in Fig. 4, is an aluminium frame which the operator straps onto his/her arm.

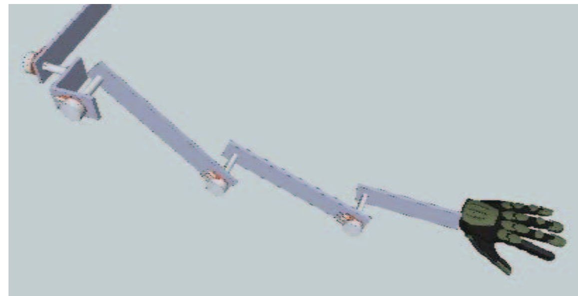

Fig. 4: Design of the HMI

The proposed sensing mechanism is cost effective, accurate and has been easily implemented. In HMI control methodology, which has been used in our work, the slave robot exactly mimics the movements of the operator. Four potentiometers (resistance of 10k ohm and of single turn) are placed on the master robot, one each at the wrist, elbow, abduction and shoulder joints. The movements of the operator rotate the potentiometers' shaft, relative to human joints. The voltage signals from the potentiometers are fed to the transducer unit where their values are sampled and measured by an analog to-digital (ADC) converter. The converted values are mapped with the corresponding servo angles which are sent to the slave robot through Xbee module. The voltage is thus a measure of the angular position of the robot joint.

Fig. 5: Human Machine Interface

Fig.5 shows the developed Human Machine Interface for the control of the robotic arm. This arrangement includes the mounted potentiometers and the gyroscope module on the glove. A joint is commanded to move to a certain angle, and the voltage from the corresponding potentiometer is read. The 3 axis gyroscope in addition to it gives the correct orientation of the arm and hence helps in error correction. Using the principle of inverse kinematics, we have developed an algorithm which gives an accurate position using the value from potentiometers and gyroscope. A relevant GUI (Graphical User Interface) has also been developed to visualise the current status/positions of the robotic arm, at the controlling end. The GUI also has the ability to show the real time video and thus acts as a virtual guidance in the system.

V. EXPERIMENTS

We performed various experiments to check the performance and the accuracy of the MMI.

- The gripper accuracy test was performed using various objects and it was determined that the maximum gripping size and force of the gripper was 50mm and 1500gms respectively.
- The 10 bit ADC on the Atmel 2560 mega maps the analog input into 10 bit digital data (i.e.1023 levels of resolution). Since the servo motors used in the robotic arm have a maximum operating range of 180^o, only 512 levels are sufficient to map the entire range of the servomotor.
- It has been found that with the joint angles computed, the robot achieves position precision within ±0.5cm.
- The current flowing into the servomotors on the arm was determined and the result is recorded in the table below.
- The torque produced by each servomotor on the arm was determined and the result is recorded in the table below.

TABLE 2

Joint servo motor current and torques

S. NO.	JOINT	TORQUE (Kg-cm)	CURRENT (amps)
1.	Abduction	52.3	3.7
2.	Shoulder	47.7	3.2
3.	Elbow	32.6	2.4
4.	Wrist	13.1	1.9
5.	Pivot	8.4	1.2
6.	Gripper	3.2	1.5

Fig.6 shows the master slave system under test. The tele-operater is controlling the anthropomorphic arm using the human machine interface.

Fig. 6: Master slave system under test

VI. CONCLUSION

In this paper, we presented the dynamical analysis and development of a 6 DOF slave anthropomorphic robotic arm of a dual-arm telerobot system to perform telerobotic assembly. The presented model of the robot has also provided correct joint angles to move the manipulator to any position and orientation within its workspace. The human machine interface has been implemented on the real robotic platform. Results obtained from the model have been compared with the actual performance of the robot in accomplishing a task e.g. pick and place. It has been found that with the joint angles computed, the robot achieves position precision within ±0.5cm.This little deviation is because of many reasons namely, mechanical coupling of the joints, non-linearity in mapping angles to low-level encoder ticks. The designed arm is cost effective arm as it has been developed only in 80,000 INR.

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