A Robotic hand-arm teleoperation system using human arm/hand with a novel data glove

Bin Fang, Di Guo, Fuchun Sun, Huaping Liu, Yupei Wu

Abstract—Data glove is one of the most commonly used techniques in the robotic teleoperation systems. In this paper, we propose a robotic hand-arm teleoperation system with a novel data glove called YoBu, which can acquire human motions from both the arm and the hand simultaneously. The proposed data glove is designed to be stable, compact and portable. It is composed of eighteen low-cost inertial and magnetic measurement units, among which fifteen units are attached to the human operator’s finger joints for robotic hand teleoperation and three units are attached to the palm, upper arm and forearm respectively for robotic arm teleoperation. In the robotic hand-arm teleoperation system, the operating commands generated by the data glove are transmitted to the robot via a Bluetooth wireless communication, which makes the whole robotic teleoperation system simple and user friendly. Finally, several experiments are implemented to verify the efficiency of the proposed robotic teleoperation system.

I. INTRODUCTION

A robotic hand–arm system in which a robot hand is attached to a multiple-degree-freedom arm are considered useful in performing complicated tasks in various environments, e.g. in nuclear power plants, in space, and at the bottom of the sea. One growing application of robot hand manipulation used in everyday life is human-assistive technology. Human intelligence is used to make a decision and control the robot especially when it is in unstructured dynamic environments. Thus, robot teleoperation is necessary in this situation especially when objects are unfamiliar and unknown. There are some human–robot interfaces [1] like joysticks [2-4], dials and robot replicas, and they have been commonly used. However, for completing a teleoperation task, these contacting mechanical devices always require unnatural hand and arm motion. While the wearable device such as data gloves can provide the robot with the most humanlike motions. With the rapid development of the data glove and vision-based technique recently, it is believed to provide a more natural and intuitive alternative to control a robot.

Vision-based approach is often used in the teleoperation system. It is easy for visual systems to capture contours of the human, but the captured images cannot provide enough information for tracking hands in three-dimensional space. It is because the derivation of the spatial position information can lead to multiple 2D-3D mapping solutions. The well-developed RGBD sensors such as the Microsoft Kinect have been widely used nowadays. The Kinect sensor consists of a laser projector and a CMOS sensor, which enables the sensor to monitor 3D motions [5] under any illumination conditions. [6-8] have successfully applied the Kinect sensor to teleoperate the robotic arm. However, vision-based systems are constrained to the volume space in which the cameras are placed. Furthermore, the occlusion of fingers results in a non-observable problem, leading to a poor estimation of the hand pose [9].

Another popular way is developed by the data glove. This method uses inertial sensors, contacting electromagnetic tracking sensors, gloves instruments with angle sensors to track the operator hand or arm motion which completes the required task. Until now, different types of sensory gloves have been developed overtime, both commercial and prototype ones. Among the commercial products we can mention the 5th Glove, the Cyber Glove, the HumanGlove, the PSGlove, and the ShapeHand [10]. These commercial motion data gloves usually use expensive motion-sensing fibers and resistive-bend sensors, and are consequently too costly for the consumer market [11]. Consequently, the prototype data gloves are developed to lower the cost of such equipment. [12] proposed a data glove equipped with considerably resistive bend sensors for assessment of human finger movements in neurophysiological settings. [13] presented a new array of flex sensors which is integrated into a data glove. However, the above sensors only measure the relative orientation of articulated segments by mounting the sensor on the angle joints of interest. This requires an accurate alignment of sensors with particular joint. Moreover, re-calibration during utilization is necessary to reduce estimation errors due to sensor displacements. The general disadvantages of data gloves are the lack of customization for individual hands and the absence of tactile sensing from the palmar surface of the hand. Often this is because the spare place of the data glove to embed sensors is limited. To overcome this disadvantage, the inertial and magnetic sensors are emerged. The availability of Micro Electrical Mechanical Systems (MEMS) technology enables the inertial sensors integrated into single chips. It has made inertial sensors so small and low-power that they have already become a common practice in ambulatory motion analysis [14-15]. Meanwhile, the magnetic sensors are used together with inertial sensors for accurate and drift free orientation estimation [16]. Inertial and magnetic measurement unit (IMMU) has been proved to be an accurate approach in estimating body segment orientations without external actuators or cameras [17]. It is non-obtrusive, relatively cost effective, and easy to setup and use. It demonstrates higher correlation and lower error estimation compared with a...
research-used visual motion capture system when recording the same motions \cite{18}. The low-cost and small wearable inertial and magnetic sensors are becoming increasingly popular for the development of the data glove. To the best of our knowledge, a data glove that can simultaneously capture the motion of both the arm and the hand in a robotic arm-hand teleoperation has never been proposed. Currently, either the robotic hand or the robotic arm is only tele-operated by a data glove separately \cite{19-21}. Hence, it is necessary to develop a teleoperation method based on data glove for the robotic hand-arm system.

In this paper, a robotic arm-hand teleoperation system using human arm-hand with a data glove is presented. A novel low-cost data glove is firstly described that use inertial and magnetic measurement units placed on various arm, hand and finger segments. Fifteen units are attached to the operator’s fingers to detect the movements for robotic hand teleoperation. Three units are separately attached to the palm, upper-arm and forearm to capture the motion for robotic arm teleoperation. It promisses that the robotic arm and robotic hand can be tele-operated simultaneously. The real-time experiments are implemented to verify the performance.

II. PROPOSED DATA GLOVE

A. Design of the data glove

Here, we used the MPU9250 \cite{18}, which deploys System in Package technology and combines 9-axis inertial and magnetic sensors in a very small package. This results in the design and development of low-cost, low-power and lightweight IMMU. This again enables powering of multiple IMMUs by micro control unit (MCU), which reduces the total weight of the system. Moreover, small IMMU can be fasten to the glove, which makes it more appealing and easier to use. Then a cascaded wiring approach is proposed and developed by exploiting the master SPI bus of each IMMU. This approach simplifies wiring without any need for extra components. Since data reading from a string of IMMUs, the MCU does not switch to all the IMMUs to fetch the data, which results in a lower power consumption. In order to increase the flexibility, textile cables are used to connect the IMMU to each other and to the MCU. Here the STM32F4 microcontroller is used to develop the MCU. There are eighteen segments of the arm and hand, hence eighteen IMMUs are used to cover the all segments. Each string deploys three IMMUs, one for corresponding segment. Six strings are used, five ones for five fingers, the other one for palm, upper-arm and forearm. IMMUs’ data is sampled, collected and computed by the MCU and subsequently transmitted via Bluetooth to the external devices. The proposed data glove named YoBu data glove, whose diagram is shown in Fig.1.

The YoBu data glove is designed based on the low-cost IMMU, which can capture the more information of motion than the traditional sensors. The traditional sensors of data glove like fiber or hall-effect sensor are frail. Nevertheless, the board of inertial and magnetic sensor that is an independent unit. It is more compact, more durable and more robust. Commercial data gloves are too costly for the consumer market, but the proposed data glove in the paper is low-cost. Moreover, the proposed data glove can not only capture the motion of hand but also capture the motion of arm, and the estimated results of motion are outputting real time.

B. calibration

In order to improve the accuracy of the IMMU, calibration is a necessary procedure. The typical calibration principle is to subject the inertial sensors to a known angular velocity and linear acceleration and choose the calibration parameters such that the observed sensor output becomes as likely as possible. The method normally need complex equipment, such as a turntable. Here a simplified calibration is used, which only consider the main calibration parameters including the bias and scale of accelerometers and magnetometers, and the bias of gyroscopes. The calibration is divided into offline procedure and online procedure. The offline calibration is implemented to determine the bias and scale of the accelerometers and magnetometers. The ellipsoid fitting method \cite{21} is used to estimate the calibration parameters by rotating the IMMUs in various orientations. The online calibration is implemented to remove the gyro bias. The data glove keeps stationary for a while before used and the bias is the mean value of the measurements. After the calibration is implemented, the orientations and positions are estimated by the measurements.

C. orientation and position estimation

Based on the measured 3D angular velocity, acceleration and magnetic field of one single IMU, it is possible to stably estimate its orientation with respect to a global (gravity and magnetic north aligned) coordinate system. For this, angular velocity is integrated to obtain absolute orientation. Due to noise and offsets present in the sensor measurements, the resulting orientation exhibits strong drift. Accelerometer and magnetometer measurements are therefore used to counteract this drift. By assuming negligible body acceleration, the accelerometers can be modeled as inclinometers (measuring only acceleration due to gravity) providing absolute information about two angles, i.e. pitch and roll. By assuming local static magnetic field homogeneous throughout the whole
arm, the magnetic field measurements, projected into the horizontal plane, provide absolute information about the heading direction. By fusing all the measurements, a drift-free and long-term stable orientation estimate can be obtained. The above assumptions and principles have been formalized in a nonlinear state-space model for estimating the IMU orientation and kinematics within an extended Kalman filter. After the orientations of the each arm-hand segment are determined, the positions can be derived using forward kinematics. Hence, the stable orientations and positions of human arm and hand are estimated by the YoBu data glove.

C. Data glove system

The proposed data glove system is also included a PC. After the calibration, the MCU of the data glove processes the measurements and estimates results, encapsulates them into a packet, and then sends the packet to the PC by Bluetooth. The baud rate for transmitting data is 115200 bps. By using this design, the motion capture can be demonstrated by the virtual model on the PC immediately. The interface is written by C#.

The flow diagram of the system is shown as Fig.2.

III. SYSTEM ARCHITECTURE

A. Robotic arm/hand

The robot used in the remote site is the core of the teleoperation system. The robot we use consists of a 7 DOF robotic arm and a 4 DOF dexterous robotic hand. The robotic arm (Figure 3(a)) is produced by SCHUNK with 7 force-torque modules that can rotate around its axis. The orders of the modules of the robotic arm is 1 to 7 from base to the end joint.

The three-fingered mechanical hand is made by Barrett (Figure 3(b)). The position of one finger usually called thumb is fixed and the other two can spread synchronously and symmetrically about the palm up to 180 degrees. The spreading action allows for the hand to grasp objects varying from different sizes and shapes. Besides the spreading action, each of the three fingers has two coupled joints. Internally, the hand is of four degrees of freedom actuated by four motors. The orders of the motors is also shown in the Fig3.b.

B. Teleoperation scheme

The traditional teleoperation scheme is based on a few types of fixed gesture mode to operate the robotic arm or robotic hand. This way is lack of flexibility, and it is difficult to achieve real-time smooth teleoperation. Therefore, we will propose a new type of teleoperation scheme.

The movement information flow of the hand and arm is directly converted into the control instruction flow of the robotic hand-arm. Moreover, the robotic arm is teleoperated by the arm and hand, the robotic hand is teleoperated by the fingers. The seven postures of the arm and hand is used that included 1DOF of the body rotation, 2DOF of the shoulder, 1 DOF of the elbow joint, and 2DOF of the wrist. These 7 angles...
are respectively corresponding to the mechanical arm of the 7 joints. Meanwhile, the robotic hand has only 4 degrees of freedom, so we only select the index finger, middle finger and ring finger for the three fingers of the robotic hand. The second joints of the index finger, middle finger and ring finger are respectively corresponding to the bending of the mechanical hand, and the opening angle of the index finger and middle finger is corresponding to the fourth rotation of the robotic hand. The teleoperation scheme is based on the data packet received from the data glove and the commands separately accepted by the robotic arm and robotic hand. A one to one relation between those two sets is established in such a way that a natural movement from the user is required. And specific relationships are shown in table 1.

<table>
<thead>
<tr>
<th>TABLE I. TELEOPERATION COMMANDS</th>
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<tr>
<td><strong>Robotic arm</strong></td>
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<td>Data glove</td>
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<td>forearm</td>
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<td>upperarm</td>
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<tr>
<td>palm</td>
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<td><strong>Robotic hand</strong></td>
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<td>index</td>
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<td>middle</td>
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<td>ring</td>
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<td>Index-middle</td>
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C. Architecture

Two different levels of communication are used in our system: a standard RS-232, and a network communication to transmit the commands. Therefore, two communication subsystems are involved. The network communication subsystem is based on the client/server network architecture. For simplicity, the server and client components were integrated to the glove and the robot’s communication subsystem, respectively. This integration scheme allows to create the master and the slave control stations of the system. Both stations are running on standard PCs. The network communication technique is based on sockets and the software for the system was written in Microsoft Visual C++. Figures 5 and Figure 6 illustrate the functionality associated to the master and the slave control stations. The master control station initializes the server to accept valid connection requests. When a connection is accepted, the glove is activated and data packets are periodically read from the glove. If a valid command is defined, it is sent to the robotic arm and robotic hand. The slave control station begins with a connection request. If the connection is accepted, the robot is initialized and a session is started. During the session, commands are continuously received from the master control station and divided into the robotic arm’s commands and robotic hand’s commands. Only if the command does not exceed its operation limit, it is separately sent to the robotic arm and robotic hand.

Figure 5. Master-staion’s flow diagram

Figure 6. Slave-station’s flow diagram
IV. EXPERIMENTAL RESULTS

The robotic hand-arm teleoperation system consists of data glove, PC (master control station), robot control station, robotic hand and robotic arm. The diagram of the experimental platform is shown in Fig.7.

The first experiment is implemented in order to confirm the effectiveness of the data glove. To verify the effective of orientation estimation algorithm, the real three orientations of the IMMU are evaluated in the experiment. The results of the unit of forearm are shown in Fig.8. The IMMU stays static firstly, and then turns into dynamic. We can find that the curves of the yaw, pitch and roll are smooth. The root mean square errors (RMSE) of the three orientations are less than 0.5°, which proves the accuracy of the data glove. Then the robotic arm-hand teleoperation experiments are implemented. Fig.9 shows the process of robotic hand teleoperation. In the Fig.9 (a), the robotic hand is in the initial state, and it is bent real time with the bending of the operator’s fingers by the teleoperation. The effect is shown in Fig.9 (b). Moreover, the experiment of simultaneously teleoperation of robotic arm and robotic hand is implemented. Two different states of robotic hand-arm are shown in Fig.10. We can find that the robotic arm has fluent movements following the motion of arm, and the robotic hand and robotic arm can be operated simultaneously. From these experimental results, the robotic hand-arm can be teleoperated as imitating the movement of the human arm and hand. Thus, the operator can teleoperate the robotic hand and robotic arm by the proposed teleoperation system.

V. CONCLUSION

The robotic teleoperation provides an efficient approach to apply the human intelligence to the robotic operation. In this paper, a robotic hand-arm teleoperation system using a novel data glove is proposed. The novel data glove is designed to be stable, compact and portable. It is made up of eighteen inertial and magnetic measurements units. Superior to other data gloves, it can not only capture the motion of the hand and also the motion of the arm simultaneously. Also the proposed data glove is fully mapped to a robotic hand-arm system so that it can well teleoperate the robot in a natural and intuitive manner easily. Several experiments are conducted to demonstrate the efficiency of the proposed robotic teleoperation system.

For the future work, we plan to combine multimodal sensing information into the data glove to achieve a more precise robotic teleoperation. For example, tactile sensing is critical in distinguishing among objects of different materials. With the feedback of the multimodal sensing information, the
robot can implement more tasks such as object recognition and classification.

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