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Design and Implementation of Force Sensation and Feedback Systems for Teleoperation Robotic Arm

Akhtar Un Nisa [1], Saifullah Samo [2*], Raheel Ahmed Nizamani [3], Areesha Irfan [4], Zuha Anjum [5], Laveet Kumar [6]
[1, 2, 3, 4,5] Department of Mechatronic Engineering, Mehran University of Engineering & Technology Jamshoro, Pakistan
[6] Department of Mechanical Engineering, Mehran University of Engineering & Technology Jamshoro, Pakistan
Email: [1] 155.15bme@gmail.com, [2] saifullah.samo@faculty.muet.edu.pk, [3] raheel.nizamani@faculty.muet.edu.pk,
[4] areeshairfan999@gmail.com, [5] zuhaanjum98@gmail.com, [6] laveet.kumar@faculty.muet.edu.pk
*Corresponding Author

***Abstract*—Humans put their own lives aside to save other human's life and perform risky and dangerous activities. The risk can be reduced by using new technologies. This research study focuses on telepresence and teleoperation systems with motion and force control systems that replace humans in hazardous workspaces. In telepresence, the system helps humans to visualize the environment in real-time. In teleoperation, the system provides sensation to assist human beings in performing out-of-reach and dangerous operations safely as in real, providing a shadow hand to the operator. In this study, a system is developed that consists of a slave robotic arm and a master wearable device with bidirectional communication between the robotic arm and operator (master wearable device). It also presents a gesture-controlled robotic arm that uses sensors to read and translate human arm movements as commands. The slave robotic arm, senses applied force on an object and a master wearable device develops the force according to sensed force, in a result operator senses/feels the same object in the control room at distance. The slave robotic arm also mimics the operator arm to reach the proper position of an object. Several experiments were conducted with untrained personnel and satisfactory results were yielded, which showed that the motion and force replication is 90-95% accurate.**

***Keywords*—Telepresence; Teleoperation; Position measurement; Calibration; Force feedback; Force sensation.**

***Abbreviations*—**

μc	Microcontroller
F_{SA}	Applied Force to grip the Object
F_{MD}	Developed Force as per F_{SA}
S_{MD}	Measure Develop Force by Senor
P_{MS}	Measure Position of joints by Senor
S_{SA}	Measure Applied Force by Senor
P_{SA}	Achieve Position as per P_{MS}
P_{SS}	Measure Achieved Position by Sensor

I. Introduction

Human life has threats of death or great bodily harm due to work in hazardous areas. Health hazards are radiations, chemical, COVID19, physical, safety, or biological factors. Robots are being used for performing complex tasks in hazardous environments [1]-[2]. The number of accidents increased day by day, during performing life-saving activities. A huge population of the world is suffering from various kinds of disabilities that make basic daily activities to be challenging [3]. Most systems need a human being to be physically present to perform dangerous tasks. The teleoperation robot systems allow human beings to do physical tasks at a distance in a safe way. It also helps to avoid possible risks and risky situations. The world is moving at a breakneck pace. In this fast-moving era, technology is evolving rapidly, but working with and handling these fast-growing technologies is not always very safe. Every year, millions of employees die or get injured at work because of working in an unsafe and dangerous environment. e.g. Bomb disposal squad jobs are considered one of the world's highest risk and most dangerous jobs. A slight mistake can threaten the lives of the whole squad. Similarly, there are several jobs of inconvenient and unsafe nature. Also, there are jobs where the human hand is a must to complete the required task; however, sometimes, it is impossible to be present on the spot at the time of need. In this study, a teleoperation system is proposed through which humans can perform such dangerous tasks while sitting at a safe distance and experiencing the same force feedback.

Teleoperation systems in the field of robotics date back to the 1950s [1], and still, the field is enhancing in all its possible manner. This human-robot interaction allows humans to perform crucial tasks remotely. The importance of such systems resides in the fact that they are not explicitly programmed to perform a particular task, on the other hand, they are programmed to simply mimic the operator's arm movement. For this fact, the system can serve in a diverse range of scopes including operations in mines, diffusing a bomb, rescue operations, or can be used in the field of medical to perform telesurgery.

The most critical element in such remote operations is the force feedback which allows the operator to feel the force with which the robotic arm grasps any object. The current and hot issues are teleoperation and telepresence in research. Many systems used various grounded device like space balls or joystick to control the operation of the robotic arm [5]-[6], some uses sensors [7] whereas some systems imply artificial intelligence-trained models to mimic the operator's arm positions [8], different approaches have been used for the realization of force feedback using SMA clutch mechanism on distal finger segments[9] and through spikes generated through a neural spiking model on receiving force signal via load cells mounted on the robotic end effector [10]. A power assist system is a human-robot cooperation technology and is mostly used in the rehabilitation and healthcare of disabled or older people [11]. The robotic arms for teleoperation tasks are difficult tasks and require training [12]. The bilateral teleoperation with haptic devices has attracted much attention in robotics and other fields [13]. There have been substantial developments in these fields including haptic feedback integration, human motion capture, and finger tracking [14]-[15].

Teleoperation is an important research area in robotics, as it can complete tasks that are safe or dangerous for human beings [16]-[18]. The camera was used to create a virtuality system to observe the human hand for teleoperation [19]-[20]. The motion capture devices were also utilized to study the human body motion for teleoperations [21]-[22]. A cost-efficient and highly efficient robotic arm can be built using artificial intelligence techniques, and its position can easily be controlled [23-24].

The research contribution is to reduce life risk by using telepresence and teleoperation techniques. Also, to develop a master-slave system that stimulates the senses of touch and mimics motion, so the human can feel the same force as the robotic arm touches or grasp any object. The motivation behind this research is to assist humans to work in hazardous areas without physical presence. The whole research is divided into 5 sections: section 2 presents an overview of the whole system, the working of the system is explained in 3rd section, experiments and results are presented in section 4 and the last section presents the conclusion.

II. Material and Methods

The proposed system consists of two parts i.e. a wearable master device, a slave device robotic arm, and a communication channel, as shown in Fig. 1. The master device is used to control the position and motion of the slave robotic arm which mimics its actions with active force feedback. The two calibrated FSR sensors of the same configuration are used. One FSR sensor is mounted in the master to sense the developed force. The other FSR sensor is mounted in a slave device to sense the applied force. The communication channel is between both devices.

A. Master Device

Master device couples the robot and human to accomplish a task. The coupling between robot and human is a complex activity, which may cause the system unstable [25]. The robot's psychomotor skills can be integrated with human experience and cognitive skills [26]. The master device is a wearable device made with the idea of sensors on arm to make the whole system compact and portable. Different types of microcontrollers are available that help to design and develop low-cost robots [27-29]. The environment can be visualized on screen. The master device avoids the risks of work-related musculoskeletal disorders. a lot of research has been done on work-related musculoskeletal disorders [30]-[31]. The master device is further divided into two parts i.e. (a) the arm wearable device and (b) the haptic data glove.

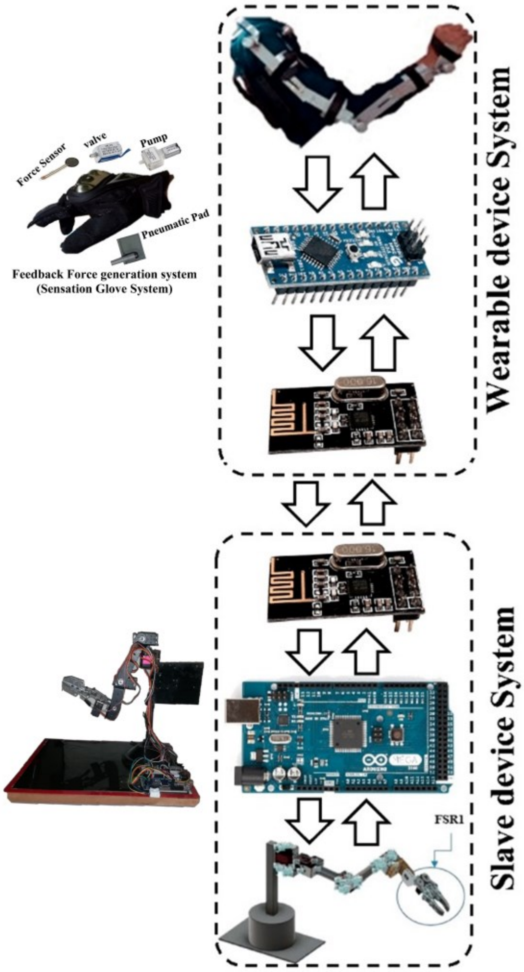


Fig. 1. Master and Slave devices communication system.

a) Arm Wearable Device: The master arm wearable device is made by position sensors embedded on each joint of the arm i.e. wrist, elbow, and shoulder joint as it can be seen in Fig. 2. The device is made of aluminum strips separately for wrist, forearm and upper arm and fixed on the operator's arm using tightening belts on the device. Aluminum is chosen out of its properties which made the device lighter weight, durable, and flexible for the comfort of the operator.

Fig. 2. Arm wearable device (Master). The research team member has worn the device.

b) Haptic Data Glove: The haptic data glove is mainly served to generate and provide force feedback (sensation) to the operator's thumb and index finger. The haptic data glove consists of a force sensor, pneumatic pump, pneumatic valve, and pneumatic pad, shown in Fig. 3(a). the assembly is shown in Fig. 3(b). The operator wears it and the force feedback is provided to 2 fingers only in this project. The force feedback system implanted on the glove consisted of FSR underneath the pneumatic pads placed at the fingertips of the glove to impose pressure on the operator's mentioned fingers whenever the robotic arm touches any object, driven by a mini air valve attached at the back of the glove. The linear control system is used after the calibration of the FSR sensor. The whole force feedback system is programmed on a relay that switches the air valve as programmed. The microcontroller and radio frequency communication modules are also attached to the same glove.

a) Haptic Glove Components b) Haptic Glove Assembly

Fig. 3. Haptic Data Glove

B. Slave Device

The end-effector gripper with 2-fingers or 3-fingers is capable to perform the tasks as a human hand [32]-[39]. The research is going on the end-effectors for proper gripping, assembly, and surgery [40]-[44]. The pneumatic pressure is necessary to maintain the grip in end effector to avoid any mishap [45]. A slave device is a robotic arm with two fingers gripper as shown in Fig. 4. For telepresence, a camera is mounted on a robotic arm to capture the environment. The motion control of the robotic arm with the gripper performance is of ultimate interest. The robotic arm mimics the movement of the operator and communicates the gripping force to the operator, by which it touches any object. It produces a sensation by which the operator feels the object at distance and applies proper force. The robotic arm is a 5-DOF device, and the clamper consisted of two fingers only. It consisted of 20 kg-cm servo motors at each joint as it provides close loop control and FSR (force-sensitive resistors) at the jaws of the gripper. The microcontroller and radio frequency communication modules are also attached to the same platform.

C. Communication Channel

Since the telepresence and teleoperation systems need to operate in remote areas, the system is made wireless using radio frequency-based communication. A radio transceiver module is used for bidirectional communication i.e., the same module can be used to transmit as well as receive data at the time. The module is utilized for its transceiver and easy program properties.

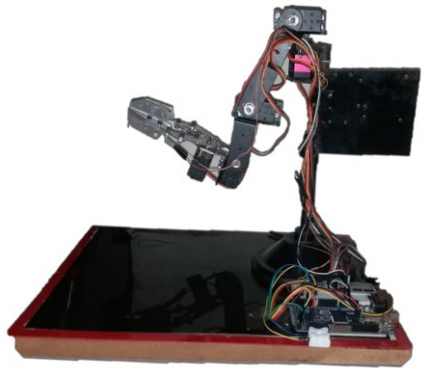


Fig. 4. Slave Device

D. Working Principle

The whole operation of the built system consisted of two parts i.e. i) the gesture mimicking operation and ii) the force feedback system. The operator wears the master device and moves his arm to perform any operation virtually and the slave device (robotic arm) will do the rest of the work. The functional diagram is shown in Fig. 5 and the control diagram is shown in Fig. 6. The master controller controls the sensation force by taking input from the slave device, and the slave controller controls the position of joints by taking the input from the master device.

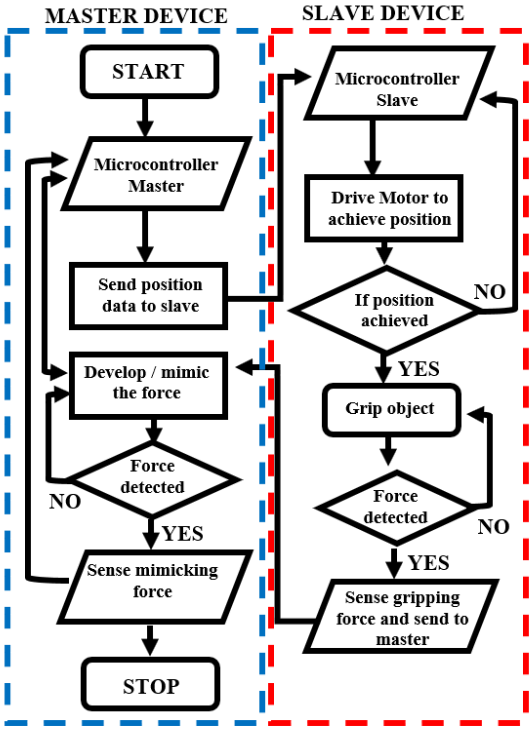


Fig. 5. Functional Diagram

E. Gesture Mimicking Operation

The system is designed to provide a shadow hand to the operator. It mimics the movement of the operator's arm to the extent such that if he moves his shoulder up and down, the slave device would do the same. To make it possible for each joint, the position sensor is placed at each joint of a wearable device and mapped to the corresponding joint motor in the robotic arm, and the system is then programmed accordingly.

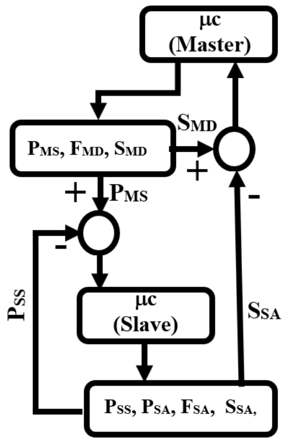


Fig. 6. Control Diagram

F. Force Feedback System

The focus of this research is to achieve effective force feedback, so the operator may feel the same force as the robotic arm whenever it touches or grasps any object. For this, the FSR at the clamper is coupled with a relay at the data glove which turns on whenever the FSR experiences any force. This relay turns on the air valve which is connected to the pneumatic pads at the fingertips and feedback begins to develop. This feedback terminates as soon as readings of both force sensors (FSR at the clamper and FSR at the glove) become equal. Hence the same force is felt by the operator by the application of pneumatic pressure.

III. Experiments And Results

To verify and validate the proposed system, several experiments are conducted. Two types of experiments are performed on the developed system: one is to test the gesture mimicking the operation of the robotic arm whereas the second is done to test the extent to which the achieved force feedback is comparable to the actual force.

A. Gesture Mimicking Operation Experiments and Results

The system is tested on a completely naive operator after giving him 5 minutes of instructions and training for different positions of the wrist, elbow, and shoulder joints. The operator is asked to slowly move his joints inward, upward, and downward directions. The operator performed this task 3 times and each time the results are satisfactory with 0.2 seconds of delay.

The results are captured for different positions of each joint as shown in Fig. 7, Fig. 9, and Fig. 11. Also, for each test, the position of the robotic arm is plotted against the position of the human arm (the sensors embedded in the wearable device) as shown in Fig. 8, Fig. 10, and Fig. 12 to ensure the active response of the gesture mimicking system.

(a) (b) (c)

Fig. 7. Wrist motion mimicking operation test

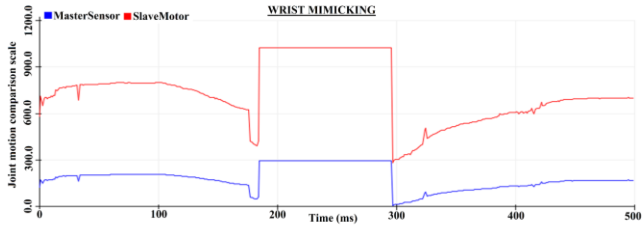


Fig. 8. Master and slave comparison of wrist joint motion during wrist mimicking

(a) (b)

Fig. 9. Elbow motion mimicking operation test

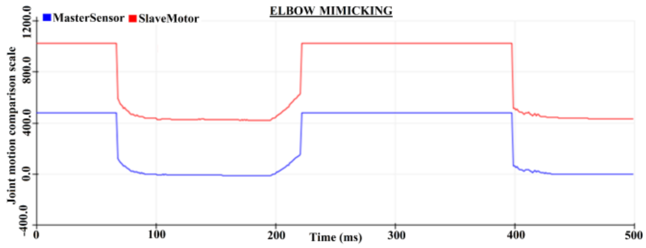


Fig. 10. Master and slave comparison of elbow joint motion during elbow mimicking

(a) (b) (c)

Fig. 11. Elbow motion mimicking operation test

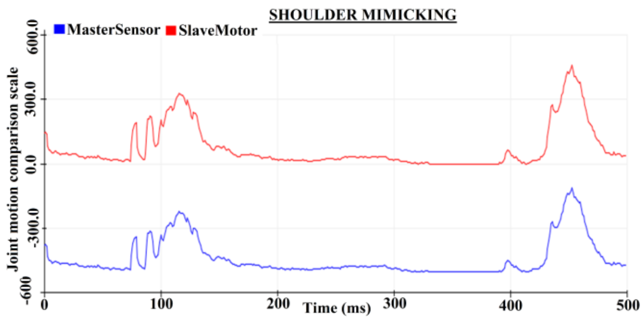
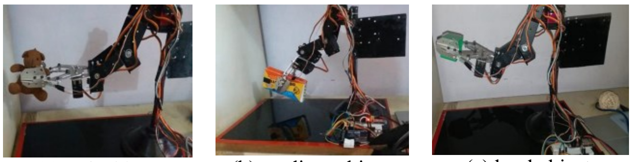


Fig. 12. Master and slave comparison of shoulder joint motion during shoulder mimicking

B. Force Feedback Test and Results

In telepresence, the proper force feedback improves the precision for performing the tasks for teleoperations, grasping, surgery, or tactual exploration [46]-[48]. The force for different textured and different types of objects is different. For example, the force applied to hold a bottle is more than the force exerted to hold a toy that is lighter and softer. The system is tested using the same approach. It is tested separately for soft, medium, and hard objects as shown in Fig. 13. For each test, results are plotted to compare the experienced force at the robot clamper and data glove in the human hand. It can be seen from the graphs (Figs. 14-16) that the magnitude of force feedback expectedly varies according to the object type, reaches the original value within a few seconds, and becomes equal to the actual force. Hence, the force feedback system served acceptable and satisfactory results.



(a) soft object (b) medium object (c) hard object

Fig. 13. Gripping force test

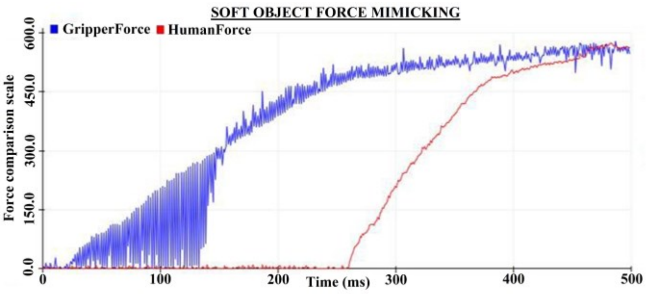


Fig. 14. Gripper vs Human force for soft object

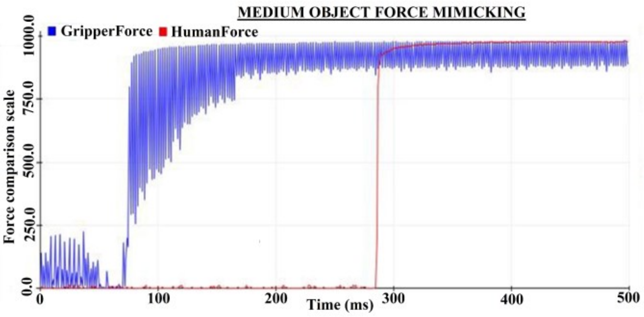


Fig. 15. Gripper vs Human force for medium object

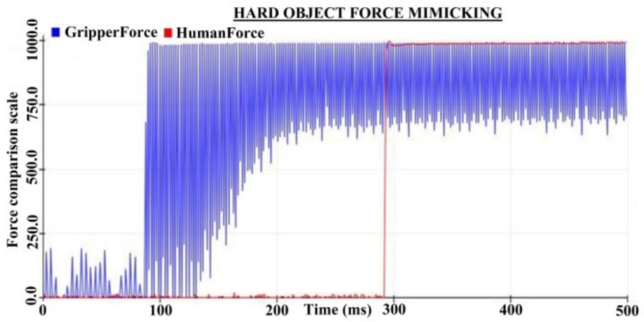


Fig. 16. Gripper vs Human force for hard object

IV. CONCLUSION

In this paper, the proposed telepresence system with force sensation and force feedback using a linear control system is implemented to make the human task easier. It is also tested on real physical systems. This system provides the facility for the operator for performing the tasks in hazardous and remote areas from a distance, without being physically present at the place. Furthermore, the force sensation system enables the human to feel the gripping force, by which the robotic arm grasps or touches any object. Various experiments were conducted for different positions of the operator's arm and gripping force for different types of objects. The experiments have shown the effectiveness of the proposed system and are capable to perform various manipulation tasks. The experiments yield satisfactory results with 0.2 seconds of delay when comparing both master and slave devices. In future work, the most beneficial improvement would be to update the robot gripper to hold the tools (e. g. scissors, pliers, cutters, etc.) to apply proper force.

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