HYDRAULIC AND LINEAR ACTUATOR MOTOR OPERATED 7 DOF HUMANOID ROBOTIC ARM WITH DEXTEROUS HAND

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Abstract—In this research paper, a new way and approach on design and fabrication of 7 axis humanoid robotic arm with dexterous hand (having 16 DOF) is proposed. A methodology to construct a 7 axis (DOF) "HRA" chassis or skeleton chassis with accurate and precise movement with compact construction at very low cost is presented. Hydraulic and linear actuator motor is used to construct an artificial muscle network which is very much similar in function like ‘McKibben’ artificial muscle, a force generator which is a pneumatic based air muscle. Hydraulic system actuated by "Linear actuator motor" is used as a mean to study and search the new possibility and a way to control the “HRA” which is very much analogous to the working of actual human muscles. A commercially available microcontroller is used i.e. "Arduino Uno" with shield and integrated development environment software will be used for controlling the HRA. Further our approach is to create a skeleton chassis with the robust, simple and compact design with some additional feature like mounting panels which can be removed easily for easy maintenance and access to the inner component of HRA for repair purpose.

KEYWORDS- Humanoid robotic-arm, Dexterous hand, Arduino Uno, Artificial Muscles, skeleton chassis.

I. INTRODUCTION

Development of humanoid robotic arm having anthropomorphic nature was started from the year 1990. Ever since a lot of research has been done in the field of a humanoid robotic arm. A human body is a most sophisticated machine with so many complex mechanisms which enable us to do our day to day task and work. Due to the advancement of technology in the field of Mechatronics and Biomechanical engineering, in the present era, it is possible to replicate the human arm using the knowledge of all the distinct discipline of mechatronics that consists of mechanical, electrical, electronic, computer science and control engineering. Using the knowledge of all these disciplines an analogy can be made to study and understand the anthropomorphic nature of human arm in terms of engineering and technology to replicate it.
A human brain is like a supercomputer which controls all the voluntary and non-voluntary function of the body. A similar analogy can be made using the computer science and control engineering to control and study the motion of the humanoid arm. Whenever an individual wish to move a certain muscle of the body, electrical signals generates which transmit from the brain to the targeted muscle through nervous systems. These electrical signals actuate the muscle and thus muscle movement is possible. In biomechanical engineering, a term motorized movement is used to describe the movement of human muscle and its analogy can be made using electrical and electronic engineering to study and understand myoelectric nature of muscle and same can be used to fabricate the artificial network or transmission line and artificial muscle [1] for a humanoid robotic arm. Similarly, the skeleton structure of human arm is very robust and flexible, which consist of several joints that enable 7 degrees of freedom for its movement and additional 21 DOF for hand movement. The human shoulder has 3 DOF which enable it to have abduction-adduction, flexion-extension, and external-internal rotation motion and movement. The elbow joint consists of 1 DOF which enable the forearm to have flexion-extension and wrist consist of 3 DOF that enables it to have flexion-extension, supination and pronation and ulnar deviation and radial deviation movement. Using the knowledge of biomechanical and mechatronics engineering, it is possible to fabricate and design a skeleton chassis that will have 7 DOF arm movement and a dexterous hand (with 16 DOF) that can perform natural arm movement and gesture control.

Although a lot of development has been done in this field of robotics, but still it is not commercially successful and available in the market. A more advanced 7 axis industrial robotic arms are commercially successful and used worldwide in manufacturing industries and are easily available in market having a variety of category to choose from according to the application and structure [13]. At present the demand and applications of humanoid robotic arm/hand is very less due to the fact that they are ineffective and cannot be used up to its full potential unless it is equipped in a full humanoid robot that can do the task that a human being can perform with its body. These types of robots are very useful in an environment which is very hazardous and dangerous to human life [2] [3], thus this type of robots has an advantage over industrial robots. Research and development are still going on to improve the control, flexibility, load carrying capacity, speed, accuracy, and quality of humanoid robotic arm so that it can interact with humans and can work in a normal environment as well, to provide assistance and support to humans that are physically challenged and cannot perform normal day to day tasks. A recent development of artificial intelligence has increased the scope of development in the field of a humanoid robotic arm. Many ideas and methods have been proposed for the 1 DOF [6] 2 axes (Noritsugu, Tanaka and Yamanaha 1996) 3 axis [14], 4 axes (Bridge Corporation 1987; pack Christopher, kawamura 1997) 5 axis Bridge Stone corporation and Taicubo engineering 1993) [1], and 6 axes and 7 axes humanoid robotic arm [7] [17]. In this research paper, we would like to propose a new approach in designing and fabrication of humanoid robotic arm.

In section [1], we have presented the methodology of design and fabrication of skeleton chassis with 7 DOF arm and a dexterous hand. Section [2] elaborate the method to create an artificial muscles network architecture for actuation of all the motions and joints of 7 DOF skeleton chassis precisely whose kinematic and dynamic characteristics is based on currently available research [7]. A commercially available microcontroller i.e. Arduino UNO with a shield (L293d) and integrated development environment (IDE) software will be used to construct the control unit for a humanoid robotic arm.

II. DESIGN AND FABRICATION

The methodology of design and fabrication of HRA is discussed in three sections
1. Design of skeleton (in three sections).
2. The layout of artificial muscle network.
3. Control system for motion and movement control of HRA.

1. DESIGN OF SKELETON CHASSIS

Design of skeleton chassis is divided into 5 segments namely.

1.1 Dexterous hand (16 DOF).
1.2 Forearm and wrist (2 DOF at the wrist).
1.3 Elbow joint (having 2 DOF).
1.4 Upper arm (having 1 DOF).
1.5 Shoulder (having 2 DOF).

1.1 DEXTEROUS HAND

The design of dexterous hand is very much similar and a follow up of [5], there are other alternative methods for constructing dexterous hand with new bending mechanism [4] [18]. But in our approach, we will add closed helical spring over the fingers to control tension force and if possible, spring adjuster will also be used to vary the tension force as per the requirement. Further, steel wires/cables will be used as a linkage for assisting the push-pull motion that will be actuated by linear actuator motor and to transmit force through the hydraulic system instead of using servo motor directly [5]. 5 hydraulic cylinders will be used and placed in the palm to which the steel wires will be attached and 1 additional cylinder will be placed for thumb's abduction-adduction movement. This hydraulic network with steel wire and spring combination will smooth out the motion and movement of the dexterous hand and will reduce the possible jerks that will occur during operation. A schematic diagram is given in figure :(3)

1.2 FOREARM & WRIST

The forearm here will provide housing for 6 hydraulic cylinders and 10 LAM, a layout of which is discussed in section [2.3]. This design of forearm is quite simple which will consist of two end plate (wrist plate and elbow side plate). A central rod that will connect both the plate will be used that will provide strength to the forearm. Further, steel wires will be used to form a cage-like structure or frame for a forearm, these steel wires will be connected from one end plate's outer periphery to another end plate periphery (elbow side plate). This wireframe will create outer surface of the forearm where the mounting clip will be attached for attachment of mounting panels to give it more aesthetic look and easy access to the components of the forearm. A schematic diagram is shown in the figure (4).

![Figure 4: Fore-arm section](image)

![Figure 5: Wrist section layout](image)

For wrist flexion-extension motion and ulnar deviation–radial deviation motion, a hoop joint will be used to replicate this movement of the wrist that will have 2 DOF. And it will connect the forearm’s central rod and dexterous hand. 4 push-pull rods will be used as a linkage, directly attached to respective LAM that will motorized the wrist motion/movement and transmit force. Further, spring adjuster will be used and will be placed on the rod that will reduce jerky movement and smooth out the operation. To simplify the design of wrist, it’s supination and pronation movement will be added to lower section of elbow. Working layout of this is discussed in section [2.2] A schematic diagram of wrist is given in figure: (5).

1.3 ELBOW JOINT (HAVING 2 DOF)

Elbow joint of human has 1 DOF that allows it to have flexion-extension movement.

A knuckle joint will be the most suitable joint to replicate the flexion-extension of Elbow joint. Moreover, we are adding supination-pronation movement of wrist to elbow that will provide one additional DOF to elbow section. A DC servo motor will be used that will be placed at the lower section of the elbow which will attach to the forearm through the lower section of an elbow. A schematic diagram is given in the
Figure 6: Sectional view of elbow

1.4 UPPER ARM (HAVING 1 DOF)

The upper arm of human usually has 1 DOF that allow it to have external – internal movement but the shoulder muscles and joints are involved for actuating and causing this motion thus this DOF is a part of the shoulder in general. But in our design, we will place this movement in the upper arm to reduce the complexity of shoulder since it is the most complex part of the human arm. A similar mechanism that we are using for elbow’s supination-pronation motion will be used for the external – internal movement of the upper arm. Another central rod will be used that will connect the upper section of elbow to upper arm. A DC servo motor will be used for replicating and motorizing the external – internal movement of the upper arm. And a similar cage-like frame that is used for forearm will be used for constructing upper arm where the mounting panel will be attached to give HRA a more human arm like look and structure.

1.5 SHOULDER (HAVING 2 DOF)

The shoulder is the most complicated part of the human arm [17]. A lot of research has been done for the analysis of shoulder characteristics [10] based on this analysis we are designing a shoulder with 2 DOF that will replicate the flexion-extension movement and abduction and adduction movement of shoulder. For the abduction-adduction movement a knuckle joint will be used whose one side will be attached to the shoulder and the other side will be attached to the circular disk platform where the upper arm will be connected. The circular disk platform will provide the flexion and extension motion and movement to the whole arm. A DC servo motor will be used to replicate the angular motion of the arm. The working and operational layout is given in section [2.4], where the lifting mechanisms and flexion-extension mechanisms of the shoulder is discussed. A schematic diagram is given in figure (7).

Figure 7: Sectional view of shoulder

2. ARTIFICIAL MUSCLE NETWORK

Artificial muscle is a term that arises from the Mckibben artificial muscle or air muscle [1]. It is an air powered, a force generator, whose structure and function of extension and contraction that resembles the actual human muscle. The scope of this air muscle is very large in the field of humanoid robotic arm and the whole humanoid robot as well. But the fact that the design and fabrication of material and structure of this air muscle are quite complex and impossible for current material fabrication technology. Moreover, it has a very limited pressure range up to which it can perform the function without any failure. In our approach, we are using a DC servo motors and linear actuator motors as actuating sensor and hydraulic system to replicate a human muscle network of the whole arm, which will perform the exact and precise motion and movement just like human muscle thus the term artificial muscle network is given [8] [11]. In the following section, the layout and functioning of this artificial muscle network are discussed.

2.1 ARTIFICIAL MUSCLE NETWORK OF HAND

As discussed before, the hand or palm will have 6 hydraulic cylinders, 4 cylinders for 4 fingers & 2 cylinders for a thumb. One side of the cylinder will have a push-pull rod that will be connected to the steel wire which in turn will be attached to the finger joint & act as a linkage to transmit actuating force to fingers. The other side of cylinders will have tubes attached to them and the other end of the tube will be attached to another 6 hydraulic cylinders placed in the forearm section. Another side of these 6 particular cylinders will also have a push-pull rod that will be attached to the linear actuator motor that will motorize linear push & pull motion and will actuate & control the fingers, thumb motion/ movement. Further, it is
to be noted that mechanical tuning, timing adjustment, accuracy & positioning are required to precisely replicate the fingers motion with precise angles. This depends on the size, shape, dimension of structure & linear actuator motor & linear displacement, torque, load capacity & positioning of linear actuator motor that will be done in our further research & studies (after constructing an actual working model) the electrical wiring of these 6 particular linear actuator motor will be laid & pass from forearm section to elbow section from elbow to upper arm section and then to shoulder section at last and will be connected to Arduino board, placed in control unit box (CUB).

2.2 WRIST (AMN)

As discussed before, the wrist section is comprised of a knuckle joint which connects both the hand & forearm & 4 push-pull rods with spring adjuster which will be attached to 4 LAM respectively placed in forearm section. Due to space limitation in wrist section no hydraulic cylinders will be placed in this section of arm. Since, these 4 linear actuator motors will be sufficient to cope up with the load requirement for the wrist. For replicating the flexion-extension motion of wrist two linear actuator motor will be placed opposite to each other on the back & front side of the forearm that will actuate simultaneously in opposite direction. This motion is very much similar to the human wrist muscle motion/movement where simultaneously one muscle contracts while the other extents & vice-versa.

Similarly, two other linear actuators will be placed at the opposite sides of wrist that will perform the ulnar deviation – radial deviation motion & movement of the wrist. The Arduino board will control the actuation timing & linear displacement of linear actuator motor.

2.3 EXTERNAL-INTERNAL MOTION OF FOREARM & UPPER ARM

A forearm has an angular rotation motion which is termed as supination-pronation movement and motion. A DC servo motor will be used & placed in the lower section of elbow, a common central rod that runs throughout the forearm will be attached & held by two bearing journals placed at the two sides of lower elbow section. A part of a central rod in lower elbow section will have a spur gear, so will the motor place in lower elbow section. Through these gear meshing, the power will be transmitted from motor to the central rod and to the forearm to provide angular rotation up to certain range & limit. The required angular rotation of the motor will be controlled by the Arduino board. A similar mechanism will be used for the upper arm as well where another central rod that will connect the upper section of elbows and upper arms. A motor that will be placed in the upper arm will have similar control, functional & operating method as discussed for the forearm to replicate the angular rotation motion of upper arm. A schematic diagram is given in the fig. (8)

![Figure 8: Sectional view of fore-arm](image)

2.4 FLEXION –EXTENSION MOTION OF ELBOW AND ABDUCTION – ADDUCTION MOTION OF SHOULDER

The elbow of the humanoid robotic arm will be comprised of knuckle joint that will connect both lower and upper section of the elbow and replicate the flexion-extension motion and movement of the human elbow [16]. Two linear actuator motor will be placed in the upper section of the elbow in the same position where the bicep and triceps are located in the human arm. A rotor disc will be attached to a part of knuckle joint that will connect the lower elbow section. A linkage mechanism shown in fig (9) will be used to connect the rotor disc and the push-pull rod of the linear actuator motor. When actuated simultaneously the two linear actuators will move in opposite direction based on their initial position and will move the forearm section up and down to create flexion-extension motion. This type of movement is quite analogous to the bicep and triceps muscle movement to move arm and thus this mechanism is the most suitable for elbow flexion-extension movement. A similar mechanism will be used for shoulder abduction-adduction movement whose characteristic will be based on currently available research [10] [16] [17] but the angulation will be quite different. Since the shoulder takes up a great amount of load therefore 3 linear actuator motor instead 2 will be used. In addition to that hydraulic cylinder and system will also be used for force amplification, in case the linear actuator motor mightn't be able to take up the load capacity of shoulder alone. A schematic diagram of shoulder mechanism is shown in fig (10)
For the flexion-extension movement of shoulder a disk-type platform where the upper arm central rod will be connected to it for the angular rotation. This disk will be attached to the shoulders knuckle joint that will lift the disk platform along with the whole arm a DC servo motor will be placed in the disk platform, two bevel gears will be used, where one will be mounted on upper arm central rod end & the other will be attached to the motor to transmit motion and force at 90. Alternatively, two spur gears may also be used instead of bevel gears by changing the position of the motor in disk platform. But in this case, a spur gear has to be mounted on another short shaft (spindle) whose axis will be perpendicular to the axis of upper arm central rod.

3. CONTROL UNIT BOARD (CUB)

For control system we will use commercially available Arduino UNO board which will act as a brain for the humanoid robotic arm [12]. In this particular case, 15 linear actuator motors and 3 dc servo motors will be used in total.

![Diagram of Control Unit Board](image)

<table>
<thead>
<tr>
<th>Actuator Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 LAM</td>
<td>4 Fingers</td>
</tr>
<tr>
<td>2 LAM</td>
<td>Thumb</td>
</tr>
<tr>
<td>4 LAM</td>
<td>Wrist</td>
</tr>
<tr>
<td>1 DC Servo Motor</td>
<td>Elbow Rotation</td>
</tr>
<tr>
<td>2 LAM</td>
<td>Elbows Joint</td>
</tr>
<tr>
<td>1 DC Servo Motor</td>
<td>Upper Arm Rotation</td>
</tr>
<tr>
<td>1 DC Servo Motor</td>
<td>Shoulder Rotation</td>
</tr>
<tr>
<td>3 LAM</td>
<td>Shoulder Lift</td>
</tr>
</tbody>
</table>

Arduino Uno is a very versatile, easy to use and commercially successful microcontroller board.

Its input & output power supply is limited to only 5v which is sufficient enough to power LEDs & other small sensors but
not sufficient enough to power DC motor which requires more than 5v, beyond that and it might burn its component. Another limitation is that it has only 14 digital input pins which are not sufficient, to run 18 motors simultaneously.

To overcome this problem, a motor driver known as a shield (L298d or L293) will be used to drive motors. Even after using the shield or motor driver, only 2 motors can possibly be attached to a single shield and only 3 Shield can connect to Arduino Uno and thus 6 motors can be run by a single Arduino board. Therefore, 3 Arduino boards with 9 shields will be used for controlling the humanoid robotic arm.

A Schematic diagram of the layout is given in fig. (11). As shown in figure Arduino board A1, which will have 3 shield A₁D₁, A₂D₂ & A₃D₃ to control 6 DC motors (or LAM), for hand namely F₁, F₂, F₃, F₄, and T₁& T₂. Board A₂, will also have 3 shields that will control motor W₁, W₂, W₃, W₄ for wrist, and bicep & triceps motor (or LAM) for elbow joint movement. Shoulders motor S₁, S₂, S₃ will be controlled & connected to board A₁ & elbow section motor R₁, upper arm motor R₂ & shoulder section motor R₃ will be connected to board A₁ as well. Using the Arduino IDE software in window OS, all 3 Arduino will be controlled simultaneously to operate the humanoid robotic arm and control its motion & movement.

III. CONCLUSION

In this paper, we have successfully elaborated our approach of designing and fabrication of humanoid robotic arm with 7 DOF and a dexterous hand based on the currently available research and studies done in this field and general electronics. Further, we have discussed the constructional and structural layout with function and operation methodology which will act as a foundation for our research work for developing and modelling of a robotic arm in the near future. This research work has also shown the possibility of using a combination of the hydraulic system for force amplification and the linear actuator motor for actuating and controlling the motion of several joints in a humanoid robotic arm.

In future research, we can use valve and valve automation technology to reduce the number of hydraulic cylinders and linear actuator motors to increase the flexibility, control and speed etc. and to reduce the weight, complexity, and number of the component to increase the overall performance of the humanoid robotic arm. We can also use new sensors for sensing surface orientation as well [9]. This type of architecture of HRA will show new possibilities in development of giant robots larger than the normal human size.

References


