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Re-Design and cost reduction in fabrication of a novel 3 DoF active ankle joint.

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Abstract— The mechanism of active ankle is a novel 3 DoF parallel mechanism that operates in an almost spherical manner. It is a project by DFKI Germany and currently it is being used in medical rehabilitation. The project was re-engineered with techniques like CAD and Rapid-Prototyping to reduce the cost of fabrication. In the present paper, a comprehensive study of the design, and fabrication of the active ankle is provided. Various motions of human ankle joint such as adduction-abduction, inversion-eversion, and plantarflexion-dorsiflexion, was achieved by the prototype. This project was modeled in CAD software like SolidWorks, accordingly mounting were prepared for the available motors. Various parts of Active Ankle prototype was printed using Olivetti 3D printer by feeding the .gcode file created by slicing software Cura. The paper also discuss about the integration of Dynamixel motors with MATLAB for control. Finally, the paper talks about various application of parallel manipulator in the area of medical rehabilitation.

1.INTRODUCTION

Our project is a 3 DoF parallel mechanism. A parallel manipulator (PM) can be defined as a closed-loop mechanism in which the end effector (mobile platform) is connected to the base by at least two kinematic chains. Its geometry provides various advantages like better control and robust construction. Closed chain in each leg offers more stiffness and orientation maneuverability and this is the reason it has many applications. We here have tried to replicate the work by 3D printing the structure and making it more economical in the process.



Fig 1.1: Assembly

There are many other spherical manipulators such as AGILE EYE and AGILE WRIST. Joint axis of these type of manipulator are required to intersect at a single point[2]. However, due to manufacturing and assembling errors, it is difficult to achieve an accurate intersection of all joint axes.

Our prototype version is a 3D printed one and it is firm belief of authors that to really boost exoskeleton technology to a common man it needs to get comfortable, effective and easily replaceable.



The exoskeleton has to have many customizable parts, as inter-subject variability still remains a challenging issue [5]. So, 3D printing could serve a good option. Although it has some limitation discussed in the further section.

Human ankle has 3 DoF. That is rotation in 3 mutual perpendicular axes are possible, namely-inversion, eversion; dorsiflexion, plantarflexion; abduction adduction. An ankle joint in an exoskeleton is very important as it acts as a final interface between ground and body so the complete load transfer occurs through this joint. Also it should be easy to control and rigid enough to let the load get transfer. Hence, we were interested in ankle joint.

Further the section 2 discusses upon set-up of our project, section 3 talks about 3D printing aspects. Section 4 gives an overview of control, and section 5 and 6 informs about the limitations and future works to be done respectively.

2.SET-UP

2.1 Actuators used

Actuators used becomes a major part of your designing process. That is it drives the direction in which the designing is led. We here used Dynamixel AX-12A servo actuator. With fully integrated DC Motor, Reduction Gearhead, Controller, Driver. The Robotics Dynamixel AX-12A handles the sensor management and position control. To strengthen the assembly, horn and nuts are fixed inside. For easier cable management extra holes are given. The new design of this actuator increases the durability and reduces the damage rate. Operational voltage is 9V – 12V. Gear ratio 254:1. Weight is 54.6g.

According to this actuator we had alter the design from the original [1],[2] keeping the basic architecture same. We had design an different structure on the first try and the printer was just not able to print the 3 mm cantilever platform for motor mounting. So we had to design a more solid design as can be seen now.

The current design is made by keeping in mind that the axis of all three motors must be mutually perpendicular, and also by considering the rod and rod end bearing and the distance between the two links attached to same motor.

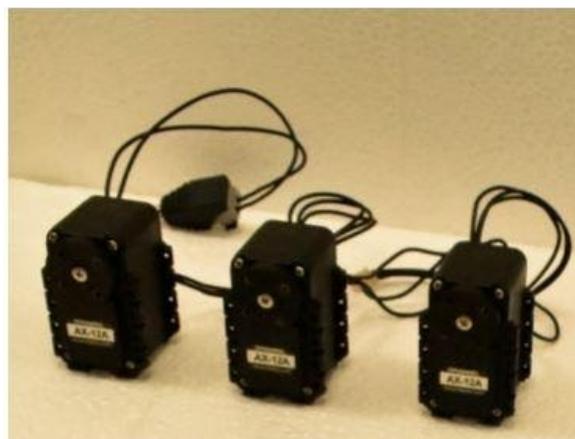


Fig 2.1: AX-12A

1. Dimensions of actuator:

- 32 X 40 X 50 (mm)

2. Various features of motors:

- Easy to track its shaft position, speed, temperature, voltage and load.
- It also let us control the speed and strength of the motor's response based on the control algorithm used to maintain the shaft position.
- It can also be used as a wheel so that you can create a robot with a combination of wheel type and joint type in a single module

2.2 Actuators used

There were total five, 3D printed parts, one base, one end effector and three couplers. In future we also want to increase the count of 3D printed parts used. More on 3D printing is given in further section.

2.3 SMPS



Fig 2.2: SMPS

The figure of SMPS is shown in Figure 2.2 .A switched-mode power supply, is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently [3]. It transfers power from a AC source mainly mains to a DC supply in our case it was 12 V.

This was the voltage rating of actuator used. It provided a stable power source for our experiment.

2.4 U2D2

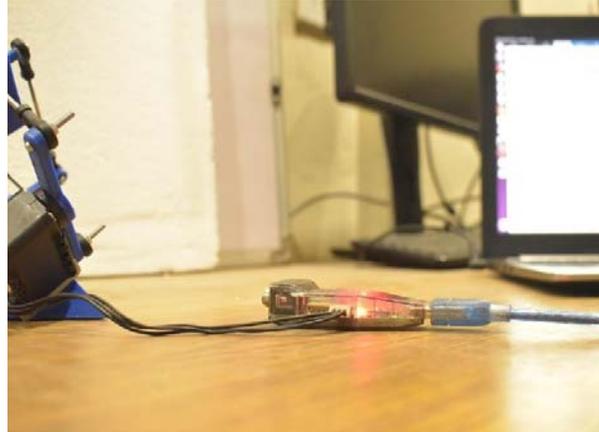


Fig 2.3: U2D2

U2D2 is a small size USB communication converter that enables to control and operate DYNAMIXEL with PC, this is the interface between laptop to communicate with the motors. It basically sends and reads position of motors as shown in Figure 2.3. Figure 2.4 shows the setup of the system

Laptop (For control)

Intel - Core i7 3.16GHz 8Gb Ram Linux 16

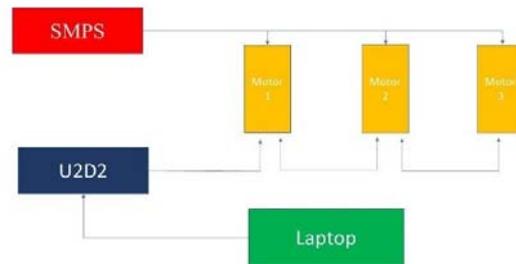


Fig 2.4: Setup of the system

3. 3D PRINTING

3D printing is a manufacturing process where a 3D printer creates a three-dimensional object by depositing material by depositing material layer by layer in accordance to the object's 3D digital model.[3] In recent years this technology has gained momentum and future is definitely looking bright for it. This significantly reduced cost of manufacturing compared to when machining metals. But the question of strength perpendicular to layers still remains.

3.1 Fused Deposition Modelling (FDM)

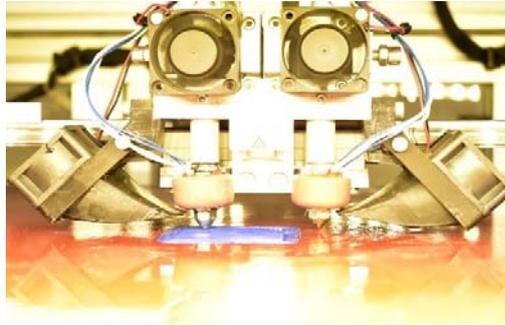


Fig 3.1: FDM

In FDM, an object is built by selectively depositing melted material in a predetermined path layer-by-layer. The materials used are thermoplastic polymers and come in a filament form of melted plastic. FDM Technology works with specialized 3D printers and production-grade thermoplastics to build strong, durable and dimensionally stable parts with the best accuracy and repeatability of any 3D printing technology. FDM is the most widely used 3D Printing technology it represents the largest installed base of 3D printers globally and is often the first technology people are exposed to. FDM have many advantages few of them are the technology is clean and simple-to-use. Supported production-grade thermoplastics are mechanically and environmentally stable. Complex geometries and cavities that would otherwise be problematic become practical with FDM technology. Our printer used this 3D printing technique and was quite effective, as final assembly was done by using that parts itself.

3.2 Slicer

Cura slices 3D models. It translates the 3D STL, OBJ or 3MF file into a format that the printer can understand. Fused filament fabrication (FFF) 3D printers print one layer upon another to build up the 3D object. Cura takes the 3D model and works out how those layers are placed on the print bed and creates a set of instructions for the printer to follow layer by layer.

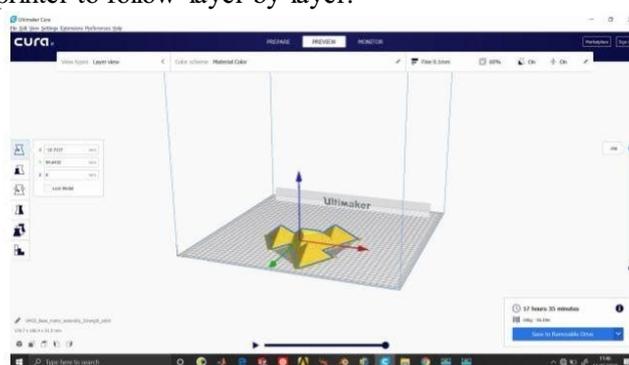


Fig 3.2: Cura

Cura generates instructions for your 3D printer. They are called G-Code, a text document that ends with the file extension. gcode. By opening the file and we can actually read through quite a bit of the code and understand what it's telling the printer to do.

Infill density: It's the amount of plastic that is being used on the inside of the print. More infill density means that there is higher amount of plastic on the inside of the print, making it stronger. And for the end use parts, higher densities can be used. We used 60% infill density

Infill pattern: Ultimaker cura also have settings to change the pattern of the infill structure of printing parts. These patterns are selected accordingly it's uses. Here are some pattern options available in Cura:

- Grid: strong 2D infill
- Lines: quick 2D infill

- Triangles: Strong 2D infill
- Zig-zag: a grid shaped infill, printing continuously in one diagonal direction.
- Cross: Flexible 3D print.

The settings which worked for us was infill pattern zig-zag, wall thickness 0.8mm nozzle temperature 210 degrees Celsius, with printing speed to be 60mm/s and build plate adhesion type to be Raft. It took around 14 hrs. to print the base part. [4]

3. *Filament*

PLA and ABS are two commonly used filament/material in 3D printing. Not having much difference but certain factors that separate these materials in terms of performance, quality, process etc.

Like PLA is used for higher strength [6], higher rigidity and strong layer bond while ABS is considered for higher impact resistance, higher flexibility and higher temperature resistance (T_g) in terms of performance. PLA filaments gives sharper details (features, corners, surfaces). In terms of process, PLA is taken for lower warping, better odor, and less particle emissions while ABS is taken for lower risk of jamming.

4. CONTROL

4.1 Kinematics

Kinematics of this architecture is done earlier in the papers [1],[2]. The basic idea being that the distance between the end effector points and the coupler point remains same as the length of the rod. Writing position vector of the 12 points mentioned above and subtracting it gives us the required equation. Then eliminating $\sin(q_x)$ and $\cos(q_x)$, q_x being the angle made by motor whose axis is in x direction half angle substitution and latter solving a quadratic equation to get the angles.



Fig 4.1: Schematic of control

finally test on a human subject this paper serves more as an overview of our work until now and journey of our first working prototype.

8. REFERENCES

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