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A Non-Axisymmetric Parallel Manipulator for Head Stabilisation in Vitreoretinal Surgery

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***Abstract*—A non-axisymmetric parallel manipulator headrest design was previously proposed to counter patient head motion during ophthalmic surgery, and a non-motorized prototype was built. Custom linear actuators were designed, and installed to the headrest manipulator prototype in preparation for kinematic performance test. An inverse kinematic-based control algorithm was implemented, and initial kinematic testing was done. Finally, the future plans for the research are briefly explained.**

***Index Terms*—parallel robots, medical robots and systems, actuation and joint mechanisms**

I. INTRODUCTION

Involuntary patient head motion is one of the biggest obstacles in achieving efficacy in stem cell implantation [1], [2] and gene vector delivery under local anaesthesia. The precision required to target thin retinal layers, of micrometer dimensions, is several orders of magnitude below the motion caused by patient head repositioning. During anterior segment ophthalmic surgery, for example, involuntary patient head motion can be as much as 11 mm [3]. Most researches that aim to mitigate head movement had focused on how to constraint the head, with examples such as the head fixation device for iRAM!S robot [4] and the Granular-Jamming Headband [5]. On the other hand, other approaches, such as countering head motion, were rarely explored. A non-axisymmetric headrest manipulator proposed for this purpose was in the early stages of research, with a non-motorized prototype alongside its inverse kinematic, statics and performance analysis were presented in [6]. The current paper presents motorisation and control considerations for an updated robot prototype towards evaluating its kinematics performance.

II. MECHANISM DESIGN

We summarise the manipulator design explained in depth in [6]. The manipulator comprised 3 planar linear prismatic actuator pairs, that were arranged in a non-axisymmetric manner. The non-axisymmetric arrangement was used to provide a space for the patient's neck, as the patient's head was positioned within end-effector perimeter to fulfil system height requirement, as mentioned in [6]. Meanwhile, the 6 actuators allow for translation and rotation along all axes. This design allows for easier control, due to the patient's head located closer to the end-effector center of mass. In the current paper, the linear struts embedded in [6] have now been swapped for linear actuators. To fulfil dimensional constraint requirements, 6 custom linear-prismatic actuators with stroke lengths of 150 mm, 160 mm, and 200 mm were used.

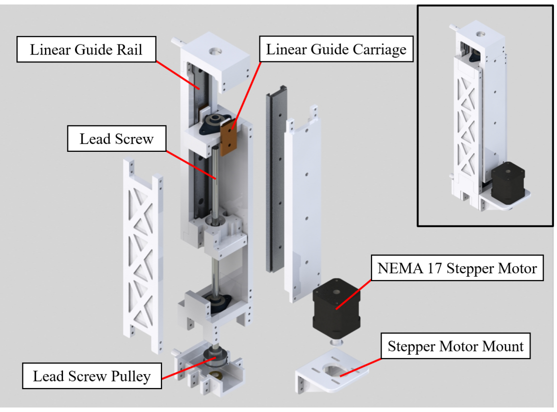

Fig. 1. Custom linear-prismatic actuator construction and final assembly.

Lead screws were used within the custom prismatic actuators to allow actuator extension and retraction motion, whilst linear guide rails were mounted parallel to the lead screw to constraint the actuators from rotational motion. NEMA 17 stepper motors were mounted to the actuator using 3D printed custom motor mounts. The motor mounts feature several slots, which allow the belt tension to be adjusted by moving the motor along the slots. The motor mounts were designed to

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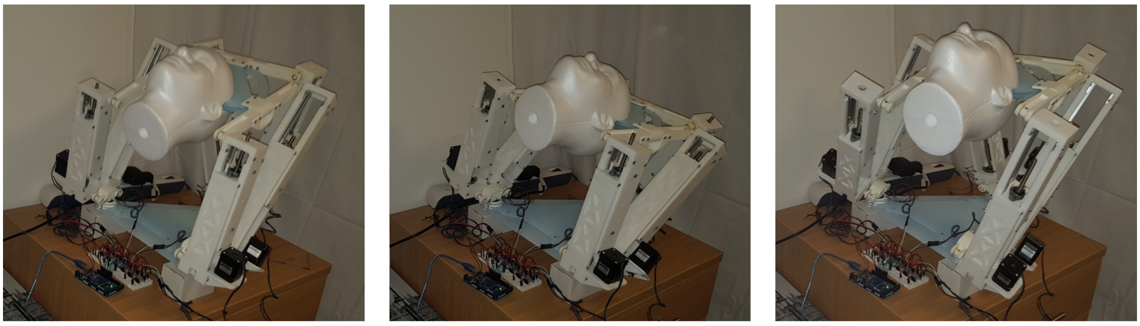

(a) (b) (c)

Fig. 2. Manipulator prototype, with the end-effector positioned in several different positions (X, Y, Z) and orientations $(\theta_x, \theta_y, \theta_z)$ relative to the origin, (a) $[0, 0, 320, 0^\circ, 15^\circ, 5^\circ]$, (b) $[-50, 50, 290, -5^\circ, -5^\circ, 5^\circ]$, and (c) $[50, 50, 360, 5^\circ, 5^\circ, 5^\circ]$.

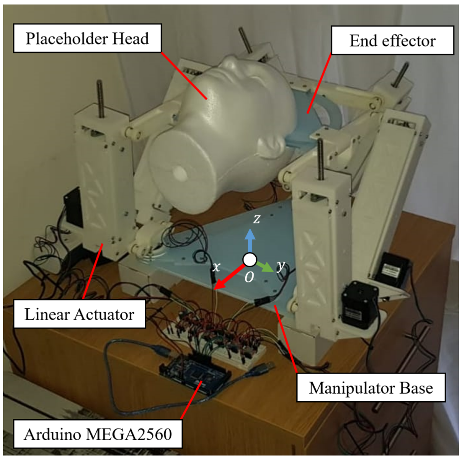

Fig. 3. Manipulator prototype, with a proxy head on the end-effector.

be replaceable, to account for the need to use motors with different specifications in further steps of the research. The stepper motors were connected to the lead screws via belt-pulley system with $2:1$ reduction ratio. Lead screw and motor position within the actuator were arranged to give minimum actuator height when the actuator is in fully-retracted state. Fig. 1 shows the construction of the linear actuators.

Six A4988 stepper motor drivers were used to control the stepper motors, and Arduino Mega2560 was used to provide input to the motor drivers. The manipulator inverse kinematic model, which was briefly explained in [6], was implemented in MATLAB to compute the length of each actuator when provided the desired end-effector pose. The resulting actuator lengths were then compared with the current actuator lengths, and the actuator value differences were sent to the Arduino through serial communication using Simulink.

To avoid the risk of damaging the manipulator, each of the parallel manipulator actuator needed to be associated with specific actuator values. Therefore, the manipulator prototype was tested by positioning the end-effector on random combination of positions and orientations within the manipulator workspace. The position and orientation of the end-effector were expressed in mm and degrees respectively, relative to the global origin located at the manipulator base.

III. RESULTS

The assembled manipulator prototype, equipped with motorized linear actuators, is shown in Fig. 3, with point O being the manipulator global origin.

The actuator setup mentioned in Section II was proven to be able to move the end-effector to several different poses. In addition to positions, these poses can also include orientations relative to all 3 Axes. Some of these poses are shown in Fig. 2. Furthermore, the manipulator did not break when the end-effector moves, which proved that inverse kinematic based control system works well. The prototype manipulator also fulfilled the workspace requirement mentioned in [6].

IV. FUTURE WORK

This paper detailed the initial steps taken to prepare the non-axisymmetric headrest manipulator prototype for kinematic performance test. The next step of this work will be to evaluate and quantify the performance of the motorized headrest manipulator using optical tracking of the end-effector. Closed loop control will be implemented in a patient-head motion simulation scenario, and the end-effector design will be updated to accommodate a surgical pillow.

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