The Design and Evaluation of a Four Degree-Of-Freedom Cooperative Handheld Robotic Device in a Simplified 3D Construction Environment

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Contents

1 Abstract

2 Introduction

3 Handheld Robot Design

3.1 Flexible Robotic Arms

3.2 Design Process of Four Degrees-Of-Freedom Device

- The initial design took direction based on the use of four Hi-Tec MS7980 servomotors to provide a degree of freedom each, driving the arm via some form of lightweight cable.
- A flexible foam tube was provided to act as the arm of the robot with outer diameter 42mm and inner diameter 19mm
- Early design was based around a single solid part, where two servos were mounted at the back and another two slightly offset. A tubular section was also present to attach the foam arm. However, after attempting to 3D print this, the quality was severely hindered by the need for excessive scaffolding to support the overhanging elements of the design
- As a result, the base was designed in two halves, with a separate piece for the tubular mount for the arm. These three parts could then be printed separately in an orientation that didn't result in any overhanging sections. As such, a much higher 3D print quality could be achieved.
- At this point, alternate shapes were explored based around this fundamental design, with compactness being a priority. One such design would entail a cubic section, where all servomotors would be at the same level, reducing the required moment arm to hold the device
- The cable management was then accounted for in order to drive the arm. Tubular linkages are attached to the arm with holes to connect the cables to the servomotors. When connecting the cables from the servomotors to the tubular linkages, the orientation of the cables in 3D space must be considered in order to determine how the arm will move in response to servomotor angle changes. Initially, the cables were planned to be connected in a straight line direct from the servomotor to the arm linkages, eliminating the need to account for friction
- INSERT IMAGE OF THE CAD OF THE CUBIC DESIGN WITH CONNECTING LINES
- However, by connecting the cables directly, in a manner with a relative angle between the axis of the arm, the motion of the arm in response to a servo angle change is unpredictable, and more importantly, a single servo motion may not necessarily constrain the arm to motion in a single degree of freedom. That is, the arm will move in one direction initially, resulting in a different angle between the cable and the arm, and further servo motion will cause movement along the axis of the cable (in a different direction to the initial motion).
- As such, it was decided that a configuration was necessary that routed the cables so that each servo acts solely on a single degree of freedom, with the cables running parallel to the arm. This of course required changing the direction of the cables by passing them through guiding holes, accepting friction where they make contact with the edges of the holes.
- Further iterations of the dimensions in the design were explored in order to find a configuration in which the cables of the rear pair of servos did not interfere at all with those of the front pair. Holes were implemented on the central tube holder pillar so that the cables could pass through in an orientation normal to the servo arms of the rear (so the driving force on the servo arm would be tangent to the radius of the servo arm motion), meaning that motion from the servo would result in the maximum movement of the arm. If it was directed non-tangentially, motion from the servo would have less of an effect on the motion of the arm.
- PUT IN IMAGE OF SERVO ARM WITH CABLE ATTACHED TANGENTIALLY AND MOTION TO SHOW LARGE CORRESPONDING MOTION, AND THEN SIMILAR FOR ATTACHED AT AN ANGLE SHOWING LESS MOTION.
- A similar approach was taken to guiding the cables of the front two servos by passing them

through holes in the base mounting for the tube holder

- Once the cables have been guided in such a way that they are perpendicular to the servo arms, they then required another set of holes in order to guide them along the axis of the arm. Therefore a faceplate with four guiding holes was fitted to the front of the housing.
- A low friction fishing wire was thus selected as the cable material [INSERT REFERENCE TO PRODUCT??], and was found to move freely against the 3D printed PLA plastic with little signs of wear or grazing
- An initial prototype was printed with relatively low percentage infill in order to test the concept. The medium sized servo arms that were supplied with the servo were used, feeding the cables through the set of holes along each side of the arm to lock it in place. Exiting the cable at the outermost hole gave an effective diameter (which acts on the cable) of 45mm, whereas the overall diameter of the servo arm was 52mm. Initially, this prototype was ran with all four servos connected to the respective arm linkages, achieving correct motion. This proved that the friction of the cables was not a cause for concern, and the routing of the cables was successful. However, the range of motion of the front two servos were limited by potential collision with the base mounting for the central tube holder, only affording 35 degrees either side of the neutral position. (the max range of the servos is 70 degrees either side but this should have been mentioned already.
- Another issue found was the inconsistent rate of motion in a given degree of freedom with increasing servo angle, this is for similar reasons as explained earlier in FIGURE X [THE ONE SHOWING THE CABLE ATTACHED TANGENTIALLY TO THE SERVO ARM]. At larger angles, a similar movement of the servo arm results in a smaller response motion from the arm. Hence the effect is an overall reduced range of motion of the arm as high servo angles have minimal effect on the motion as they don't pull the cable further. The other key problem observed was that on the opposite side to the pulling action of the arm, the cable became slack. This is because as the arm flexes, the extra cable available afforded by the forward motion of this end of the servo arm [USE A DIFFERENT WORD TO ARM] is not made up by the increase in arc length on that side of the robot arm as the cable itself does not follow the curve, but takes the direct path between the two linkages, a distance which has actually become shorter as it will always be a maximum when the arm is straight [THE CABLE IS FED THROUGH THE MIDDLE LINKAGE ON WAY TO THE TOP OF COURSE, MENTION THIS EARLIER], [ALSO PUT IMAGE OF THIS EFFECT AND MAYBE REFERENCE AUSTIN PAPER AS SIMILAR EFFECT WAS OBSERVED
- The latter problem was addressed by adding another pair of linkages that merely act to guide the cable, and are not driven unlike the other two. This reduces the relative difference of the distance the cable has to cover in normal and flexed states, thus reducing the amount of slack occurring.
- Pulleys used to address other problem....
- Dimensions changed to afford more room to front servo to allow it to move full range of servo motion.....

3.3 Interfacing With NatNet Optical Tracking System

3.4 Controlling The Device

3.5 Calibrating Device Using Kernel Regression Method

3.6 Response to Required Outputs

4 Experimental Design

4.1 Setup

4.2 Construction Environment Parallels

4.3 Mental Aspect

4.4 Physical Aspect

5 Results

6 Discussion

7 Conclusion

8 References

[1] S.J. Anderson, S.C. Peters, T.E. Pilutti, E.H. Tseng, and K. Iagnemma. Semi-autonomous avoidance of moving hazards for passenger vehicles. In *ASME 2010 Dynamic Systems and Control Conference*, pages 141–148. American Society of Mechanical Engineers, 2010.

9 Appendix

9.1 CAD Drawings