Computer-Aided Manufacturing and Dynamic Analysis of a Six Degree of Freedom Stewart Platform Manipulator

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Overview

This project will be focused on developing the neck system of a humanoid robot, Athena. The neck system will perform movements similar to the human neck: yaw, pitch, and roll. The robot neck will be manipulated by 6 degrees of freedom Stewart platform (as shown in figure 1). Stewart platform will be assembled in between Athena's upper body (as shown in figure 2) and head to move together to perform a simple neck motion. This project will involve design, manufacturing, and kinematic modeling.

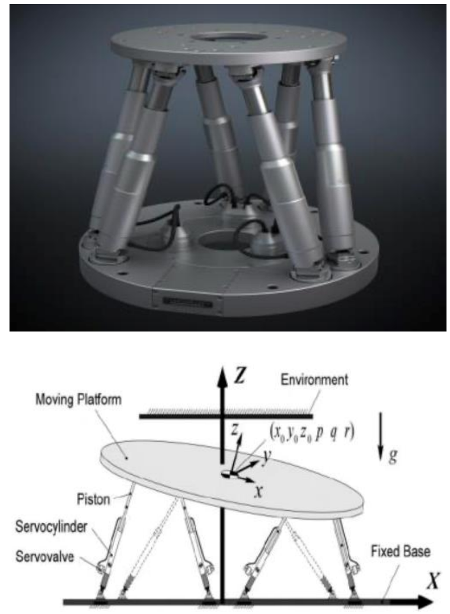

Figure 1: The Stewart Platform

Motivation

Humanoid robots are developed to perform humanly tasks to assist our society with various applications. The ongoing research in the LIDAR lab proposes to make a robot called Athena that mimics human behavior and achieves human-level agility. The team has been working on Athena's upper body and needed a neck platform that connects the upper body and the head. Based on biomechanical research, it was decided that the manipulating structure that uses 6 degrees of freedom Stewart platform [1] is suitable for the humanoid neck movement. Robot manipulators that keep actuation in parallel are rigid and feature excellent positioning capabilities such as yaw, pitch, and roll [2]. The final goal for the Stewart platform is to interact with other parts of the robot. For example, the neck must move in the direction that the robot sees or that the robot holds an object. Furthermore, the developed Stewart platform is applicable not only in robotics application but also in other fields that require sophisticated 3D movement such as in aircraft simulators [3]. The problems that the proposer faces are (1) how to design and manufacture a Stewart platform prototype with design constraints, and (2) how to check if the Stewart platform prototype is reliable using kinematic analysis, from which kinematic equations are derived to precisely manipulate the platform.

Related Work and Background

Traditional robots have used serial manipulators, and their load-carrying capacity was rather poor because of the cantilever structure [2]. They tended to deform under heavy load, vibrate at high speed, and have poor dynamic precision [2]. The six degrees of freedom Stewart platform is suitable for a high load carrying capacity, and it performs stable and precise positioning - a perfect alternative to conventional serial manipulators [2]. The kinematic study is an important analysis to simulate if a dynamic model can be used for a robotic system without testing the actual system [4]. The development of dynamic analysis makes it possible to achieve higher performance by incorporating more structural system information [4].

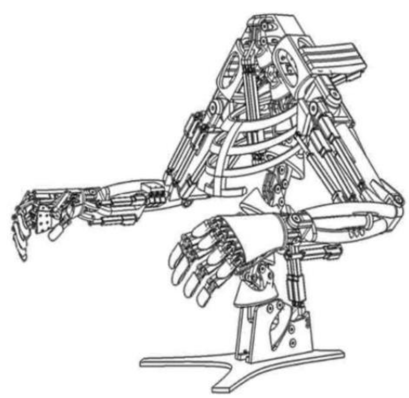

Figure 2: Athena Upper Body Manipulator

3D printing is an additive manufacturing (AM) process that facilitates the design and manufacture of complex components from computer-aided design models [5]. Since 3D printing does not require a complicated and high cost manufacturing process, it satisfies the needs for producing the Stewart platform prototype. In contrast to the conventional manufacturing processes, the material properties of AM depend on structural and process parameters such as infill rate and infill patterns [5].

Objectives
The project will follow two main objectives.

1. Computer-Aided Manufacturing of the Stewart platform prototype
   - Motion study
   - Finite Element Method
2. Dynamic analysis
   - Inverse kinematic analysis
   - Dynamic study and simulation

In order to achieve the first goal, the Stewart platform should be designed with realistic dimensions that meet the design constraints. Specifically, the neck system has to be connected to other parts and fit the size of the P16 Actuators. Design optimization is needed to reduce the manufacturing time and cost. In addition, the design should be simplified to facilitate modification of the dimensions if needed by using SolidWorks. The design changes will be simulated using MATLAB's Stewart platform simulator to check if the design is feasible. The purpose of the Stewart platform is to make Atehna's head move; therefore, each part of the Stewart platform must be designed to resist the stress caused by the dynamic movement of the head platform. Furthermore, since the prototype will be manufactured with an additive manufacturing (AM) process, the material properties will vary depending on the infill rate of the 3D printer. The second goal is to derive kinematic equations from the Stewart platform prototype referencing the conventional mechanism used in the six degrees of freedom manipulator. The kinematic equations should confirm that the desired yaw, roll, and pitch movements can be obtained perfectly. Through dynamic analysis, the dimensioning and tolerancing of the links, joints, and actuators must reveal all the reaction forces and moments.

Methods
The Stewart platform will be modeled in Computer-Aided Design (CAD) using SolidWorks with design constraints, allowing it to be connected to other parts of Athena. The design will be based on the existing design of the traditional Stewart platform and simplified for easier and quicker manufacturing. The rough dynamic simulation (yaw, pitch, and roll motions) in the CAD of the Stewart platform will be performed using the motion study function in SolidWorks. SolidWorks' Finite Element Analysis (FEA) will help verify that the parts of the Stewart platform are safe to support the load caused by the dynamic movement of the head. In addition, the FEA will examine the effects of different infill rates and filament materials on the system. The safe factor will be computed based on the von Mises yield criterion. The kinematic analysis will focus on confirming that the platform is reliable and able to achieve desired movements. Also, it will show the limitations of amplitude, which means that the movement of the platform becomes restricted when any one platform support point is coincident with the axis of freedom of any one leg system. Furthermore, the simulation and kinematic analysis will reveal if the design should be modified. The modified design can be confirmed with the use of a 3D printer that can immediately print the model. Dynamic analysis will follow the procedure of forward kinematics, applying the combination of the Newton Euler method with the Lagrange formulation.

Relation to Past Experience
The proposer is currently a fourth-year Mechanical Engineering major student, pursuing a minor in Computing & Intelligence. Since September 2019, he has been engaged in this project, leading the design process for the Athena robot's head sub-team. He has contributed to the following 3 major tasks in the LIDAR lab: (1) Creating a Stewart Platform simulation using SimMechanics, (2) Developing PID controllers for the actuators that are applied to Athena, and (3) Completing computer-aided designing and FEA for Athena. Furthermore, he conducted an internship at Korea Institute of Machinery and Materials (KIMM) where he contributed to developing new agricultural technology. At KIMM, experience with C programming and numerical analysis from MATLAB to manage signals from environmental recognition sensors and learning to develop control algorithms used in autonomous tractor driving later helped him manage the LIDAR lab projects.

References

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