Mech Master: Smart Shoe Cleaning Device

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***Abstract*—This report describes the process of designing and fabricating a smart shoe cleaning device that can automatically cleans the sides of a sneaker and achieves the whiteness of range between 1 to 6 according to the Von Lusmans chromatic scale within 90 seconds. The smart shoe cleaning device also incorporated Internet of Things (IoT) technology which enabled Alexa to activate the operation of the device. The device included mechanisms like foot autofitting and cleaning agent dispersion and they were made happen with the combination of mechanical and electronic components. This semester long project put 6 undergraduate mechanical engineering students in their senior year into a challenge of mechanical knowledge application. In the final test run, the device did not manage to operate as expected due to mechanical components faulty issues.**

I. Introduction

For Mech Masters semester long project, the team decided to pursue with the idea of making a shoe cleaning device that can clean the sides of a sneaker automatically.(see Fig.1) The device later became a smart device because it was incorporated with Internet of Things (IoT) technology which enabled Alexa voice command to activate the operation of the device. The device was initially inspired by the automated car washing service which saved car users time and effort to clean their car regularly. Sneakers have become one of the most important accessories nowadays and it is hard for the users to keep them clean regularly. The device aimed to clean the sides of a sneaker and achieve whiteness between the range of 1 to 6 according to the Von Lusmans Chromatic Chart. In the final testing, the device did not work due to a several mechanical components faulty issues.

A. Functional Requirements

The requirements were:

- Supports at least a 350Ibf person
- Cleans the sides of a shoe within 90 seconds
- Whiteness of the shoe should be in the range between 1 to 6 based on the Von Lusmans Chromatic Scale
- Shoe remains dry after cleaning
- Cleaning process should be fully automated

II. Concept Generation and Evaluation

Before moving to fabricating the alpha prototype of the device, there were 2 sketch model that were being made. The first sketch model aimed to show a prove of concept and get a general idea of the devices structure. (see Fig.3)The

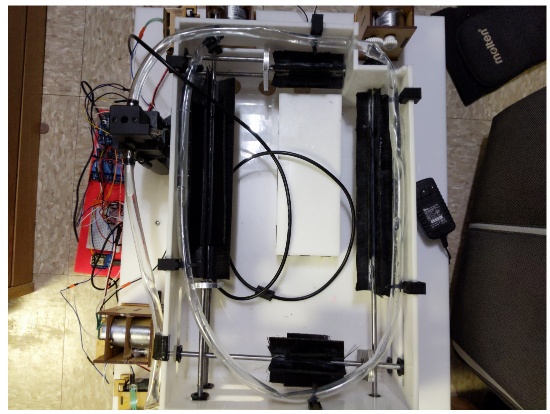

Fig. 1. Alpha Prototype

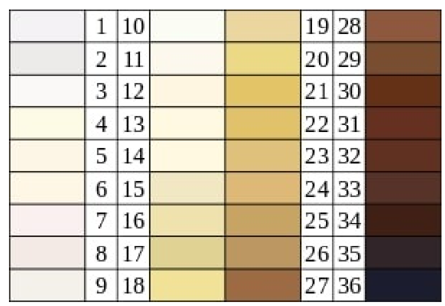

Fig. 2. Von Lusman's Chromatic Chart

material that were being used were and easy to work on, such as card boards, acrylic rods, wood and sponges. In the first sketch model, the features that were tested were foot auto fitting mechanism with linear actuator, bristle shafts on four sides, bristles and gears placement. After collecting feedback from professor and group discussion, linear actuator would be replaced with a lead screw mechanism because it is more economically friendly and achieve the same function.

In the second sketch model, the objective was to test the critical functions of the device. The critical functions that we were testing included foot auto-fitting mechanism with lead screw, spur gear and bevel gear sets, bristle shafts with bristles, and water pump.(see Fig.4) Through this sketch model, we found out that there was an excess of axis freedom in the slots for U-joint and the lead screw set up. A force sensor that

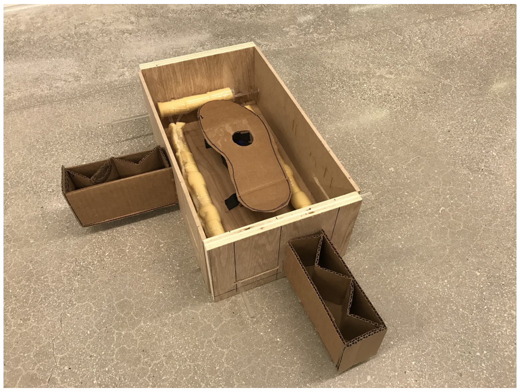

Fig. 3. First Sketch Model

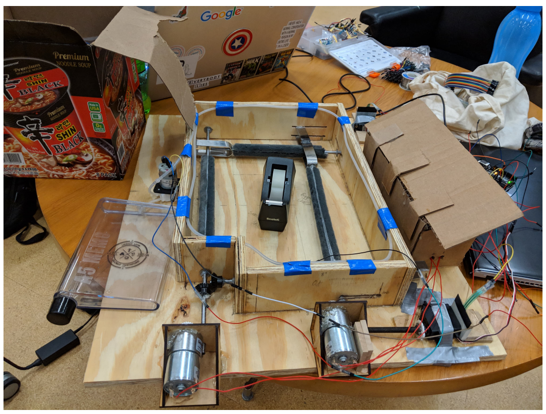

Fig. 4. Second Sketch Model

is responsible to stop the auto-fitting mechanism was damaged through soldering because the heat melted to conducting strip. In addition, the pump was too weak to disperse enough cleaning agent on the bristles. The bristles were not able to brush the shoe as well because the bristles were too short to reach the surface of the shoe. The takeaways from this sketch model were to limit the axis of freedom, replace with a more powerful pump, and to get bristles with longer bristle length. We have also decided to stay away from using wood in our alpha prototype to reduce friction and lower the tolerance.

For the alpha prototype, we came up with the idea about using idle bearings and rails to ensure a smooth transition from point to point. Modification was also made on the U joints, which was used to avoid interference with the other bristle shafts. Due to the melting temperature of aluminum was too low, we press fitted shafts into the U joints and bearings into the shaft in order to secure them in designated location. To activate the operation of the device, there were a few options to go about. We could have a push button that will activate once the user step on the platform, through a Bluetooth remote, or by using voice command of Alexa. The method of voice command through Alexa was pursued because it was innovative, and I have the technical knowledge to accomplish it. The method can be achieved by integrating a WiFi module that can communicate with Alexas server, then a signal will be sent to a relay to start the circuit once a command was placed.

ANALYSIS

The first parameter that we would like to find out was the dimension of the bristle length so that it can cover a wide range of shoe sizes. To obtain this parameter, we need to first define our upper boundary and lower boundary of shoe size that we wanted to cover. We came to an agreement to let our upper boundary to be mens US size 15, while our lower boundary was womens US size 5. The maximum and minimum of coverage dimensions were determined by the length and widest foot width of the upper boundary and lower boundary shoe size. The maximum length and width were found to be 12.125in long and 4in wide, while the minimum dimensions were 8.5625in long and 2.8125in wide.

The next thing that we wanted to find out was the torque required to turn the bristle shaft while the bristle was brushing off the sides of the shoe. Assume the normal force exerting on the shoe was 0.7lbf, with given bristle and shaft diameter, 1.5in and 0.5in respectively, and static friction coefficient between rubber and plastic of 0.8. The friction force was calculated to be 0.6 lbf using equation 1. The torque applied was found to be 0.45 lbf-in using equation 2. As the rated torque on our 12V DC motor was 1.47lbf-in, the friction force can be easily overcome.

$$F_{friction} = N\mu_s \tag{1}$$

$$T = F_{friction}(\frac{D_{bristle})}{2} \tag{2}$$

In order to support a maximum of human weight of 350lbf, we would like to find out if acrylic can withstand that amount of load without breaking it. The area of the foot platform was found to be $15in^2$.The distributed pressure was found to be 23.33lbf/in^2, which is 0.161 MPa. The tensile strength of acrylic was found to be 65MPa, hence acrylic would be able to hold up the load that we need. The last uncertainty that we validated was the volume of water dispersing out from the tube. We determined that the volume flow rate that we require was 50mL per second. With the flow rate rating on our current pump, which is 4L/min or 67ml/s, it is capable of achieving our ideal flow rate.

EXPERIMENTAL RESULT

During the final test day, the device did not manage to function as expected. It was all started at the DC motor housing for the auto fitting mechanism. Due to poor project management, that component was not able to be design according to the initial plan. A rail should have been built to limit the axis of freedom and a housing with correct dimension was not able to be designed and fabricated. The second reason that lead to the failure was that the force sensor was not able to provide a consistent data which prevented the function of calling the foot auto-fitting mechanism to stop when it hits the surface of the sneaker to happen. The third reason of failure was due to improper adhesive method for the gears to stay intact with the shaft. In overall, all electronic components were functional and the Alexas voice command activation was working.

Discussion

The shoe cleaning device is a device that automates the action of cleaning and provides a few convenient features such as foot auto-fitting mechanism and Alexa voice command enabled function. Out of the five functional requirements that we proposed in the beginning, only one was achieved which was having a fully automated shoe cleaning operation. Comments from instructor, peers and group member were collected in order to make improvements on the current shoe cleaning device in the future. To resolve the foot auto fitting mechanism, the bolt and nut which acted like a lead screw should be replaced with a ball screw which can provide a smooth and consistent linear transition. Having an encoder built in, we can easily utilize the data to improve the precision on location of the bristle shafts. Furthermore, to allow the gears to stay intact with the shafts, the metal rods can be machined so that the gears can be press fitted into the shaft. Finally, the current acrylic structure can be replaced with stainless steel so that it can hold a user with a heavier load.

Conclusion

The alpha prototype was not functional in the final testing and it only achieved one out of five functional requirements that was proposed in the beginning. Mechanical components failure was the main reason that prevented the functionality success of the device. Ball screws and stainless steel can be integrated into the current alpha prototype for future improvements. To achieve all functional requirements, the current alpha prototype needs to improve to be more sturdier, have fully functional shoe cleaning operation and using an effective cleaning agent.