MAE 207 - Punch Bot 3000

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***Abstract*— In recent years, haptic devices have become increasingly popular in various applications, including gaming, virtual reality, and medical gaming. However, most haptic devices lack the realism and physicality required for certain applications such as sports gaming. This paper presents the design and development of a boxing haptic device (punch bot 3000) using granular jamming technology. The device consists of a glove-like structure filled with granular material that can change its stiffness and shape under external pressure. The device is equipped with sensors and actuators to the user during boxing simulation. The prototype of the device accurately simulates the impact force and recoil of a punch, as well as the resistance and vibration of a punching bag. The proposed boxing haptic device provides an effective way for users who would like to box at home for fun and also for researchers to study the mechanics of boxing.**

***Index Terms*— ranular Jamming, variable stiffness, Haptic interfaces, virtual environment, gaminranular Jamming, variable stiffness, Haptic interfaces, virtual environment, gaminG**

I. INTRODUCTION

Boxing is a challenging and potentially dangerous sport that requires controlled gaming to minimize injury risk. However, traditional gaming methods might not be required for users who would want to box for fun. Haptic devices have potential, but existing devices lack realism for contact sports like boxing. Granular jamming technology offers an approach to create dynamic haptic feedback. This paper proposes a boxing haptic device using granular jamming technology to simulate impact force, recoil, and resistance. The device uses a glove-like structure filled with granular material such as coffee beans and equipped with motors with encoders and a solenoid valve that regulates the vacuum to provide realistic haptic feedback. This novel approach to haptic feedback in gaming helps gamers improve their skills and provide a better understanding of the mechanics of boxing.

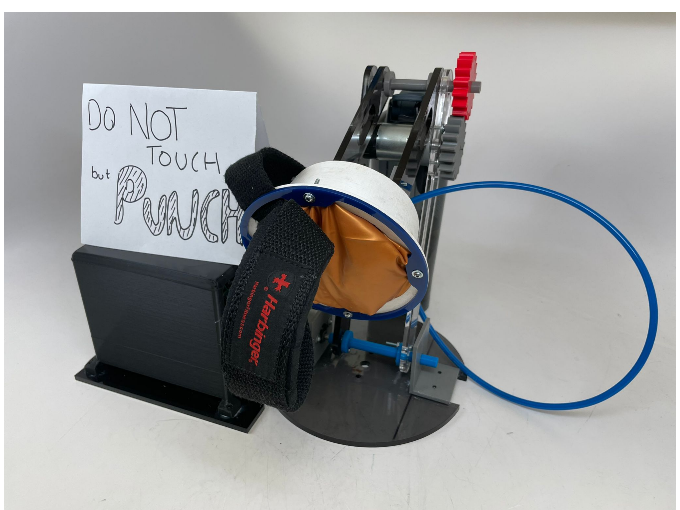

Fig. 1. Punch Bot Device

II. GRANULAR JAMMING FOR SPORTS GAMING

Haptic devices provide users with realistic tactile feedback and are used in a wide range of applications. However, most existing haptic devices for sports gaming lack the necessary realism and physicality, particularly in contact sports such as boxing. Granular jamming technology has shown promise in creating haptic devices with variable stiffness and shape. In this paper, we propose the use of granular jamming technology to develop a boxing haptic device that can simulate the impact force, recoil, and resistance of a punch when the the position of the fist comes in contact with a virtual punching bag. This novel approach to haptic feedback in sports gaming can provide a more realistic and effective way for athletes to improve their skills, as well as for researchers to study and understand the mechanics of boxing.

III. DESIGN

The overall design of the robot follows a classical concept of a two Revolute joint - 2 degree of freedom device. The model could be broken down into subcategories namely -
(i) End Effector
The end effector is designed to add additional haptic feedback in the means of stiffness. A Granular Jamming concert was used to achieve this response. This was designed by fabricating a bowl for a pouch to sit on. The pouch was made with the use of a balloon and using coffee beans as the granular component. The end of the end effector had a vacuum sealed slot through which a vacuum pipe was inserted. The vacuum was then regulated to a binary command of Off/On in order to simulate from a soft feeling to a hard one.

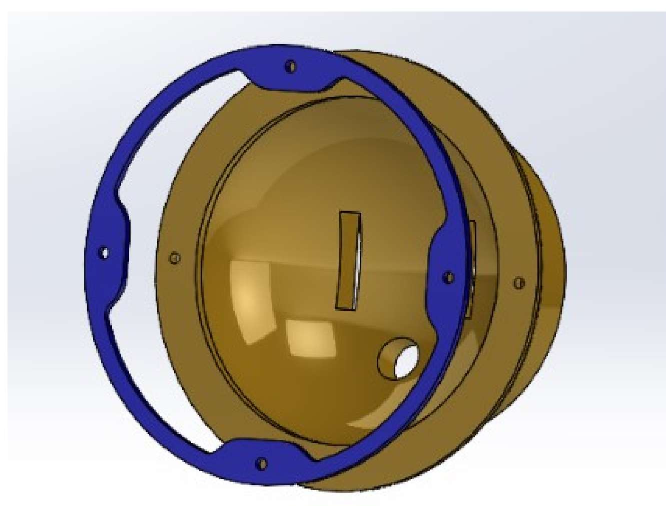

Fig. 2. CAD of the end effector bowl with a bracket to house the granular jamming pouch

(ii) RR Robot Arm
The Robot arm followed a simple 2 links with 2 revolute joint design. The link sizes were calculated with user testing and set to the lengths that would allow full range of motion. Each link

was fitted with a Geared Motor with an encoder acting as the joint. Readings from the encoder were then used to simulate force feedback. The first link was controlled using direct drive and the second link was controlled with the means of a 1:1 gear ratio rotation box which enabled weight balance flaws and smooth functioning of the joint.

(iii) Microcontroller
The hardware and electronic components including the end effector, robot arm and the vacuum regulator were controlled using an Arduino Mega microcontroller. Each motor was also wired to an individual motor driver in order to control rotations and torques. The vacuum generator was regulated using a solenoid valve that was wired to the Arduino board.

(iv) Electronic Containment
The whole device was connected to a base structure with a 3D printed housing which placed the electronic boards and the wires to tackle wire management and to make the model look visually appealing.

IV. Methods

A. Manufacturing and Assembling of the Device

The white bowl of the punch bot, the gears, the holder between the joint and the white bowl, and the shaft are 3D printed. The black base, joints and a cover at the white bowl are laser cut. During the assembling process, two gears are connected to the two joints to make them move consistently and bearing pulleys are used to stabilize the joints. A balloon is connected to the white bowl through the holes on the white bowl and the opening of the balloon is connected to the vacuum pump.

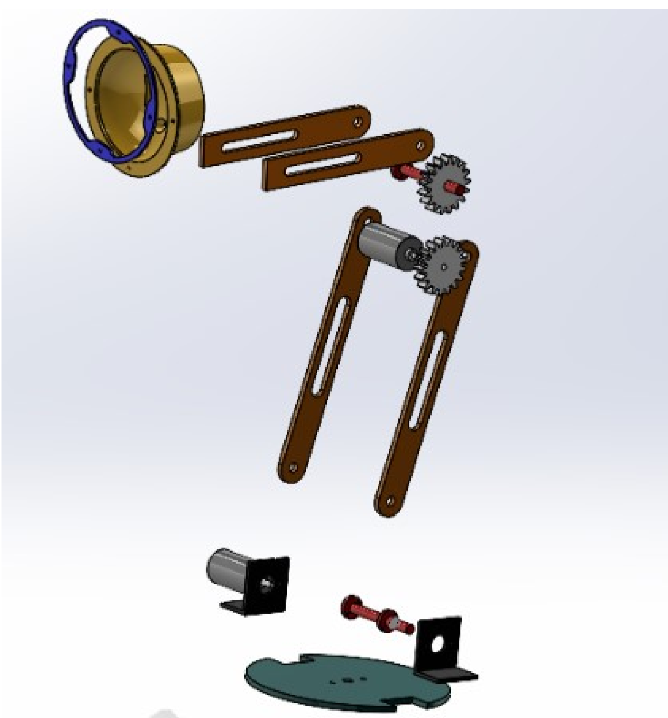

Fig. 3. Exploded CAD assembly of device

B. Tracking of the User's fist

The RR robot arm used in this punching device provides two degrees of freedom. To track the movement of each connection, two motors with encoders are used to provide the movement angles. Since the geometry of the robot arm is relatively simple, with both the lengths and the angle movements of the joints known, the end position of the device can be calculated using the following formulas.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} L_1 \times cos(\theta_1) + L_2 \times cos(\theta_1 + \theta_2) \\ L_1 \times sin(\theta_1) + L_2 \times sin(\theta_1 + \theta_2) \end{bmatrix} \tag{1}$$

where
$\theta = \frac{counts \times 180}{CPR \times GR}$
$\theta_1 = \frac{counts_1 \times 180}{64 \times 19}$
$\theta_2 = \frac{counts_2 \times 180}{64 \times 10}$
$L_1 = 0.254[m]$
$L_1 = 0.2032[m]$
Counts - Encoder counts
Counts1 - counters from motor at the base
Counts2 - counts from the motor near the end

C. Jamming

The effector of the punch bot consists of a balloon filled with coffee beans to simulate granular jamming to provide control of its stiffness. The jamming is further connected to a solenoid valve to regulate the vacuum which would simulate hardness when the fist position comes in contact with the punching bag. When the fist moves away from the punching bag, the balloon inflates back which would fit the users' hand in it. After the users put their hands into the device, the balloon will be jammed to keep its shape and provide stiffness to the user.

Fig. 4. Jamming of the end effector as it reaches the virtual bag

D. Haptic Feedback

Since our punch bot is a 2R robot(2 revolute joints), we use formula1 to calculate the position of the end effector along the x & y axis.

We further use equation (1) to calculate the jacobian as follows

$$J = \begin{bmatrix} -L_1 \times sin(\theta_1) - L_2 \times sin(\theta_1 + \theta_2) & -L_2 \times sin(\theta_1 + \theta_2) \\ L_1 \times cos(\theta_1) + L_2 \times cos(\theta_1 + \theta_2) & L_2 \times cos(\theta_1 + \theta_2) \end{bmatrix} \tag{2}$$

where θ_1, θ_2, L_1, L_2 are the same as above. Then,

$$Torque = J^{-1} \times forces$$

can be used to calculate torque. As mentioned above, this device tracks the movement of the users' fist. Once the fist moves past the threshold of the x and y position set in the device, the user will feel Haptic devices provide users with realistic tactile feedback and are used in a wide range of applications. However, most existing

haptic devices for sports gaming lack the necessary realism and physicality, particularly in contact sports such as boxing. Granular jamming technology has shown promise in creating haptic devices with variable stiffness and shape. In this paper, we propose the use of granular jamming technology to develop a boxing haptic device that can simulate the impact force, recoil, and resistance of a punch. This novel approach to haptic feedback in sports gaming can provide a more realistic and effective way for athletes to improve their skills, as well as for researchers to study and understand the mechanics of boxing. Similar to hitting a wall, the base motor will generate a reverse force to produce a virtual wall when the user reaches a certain point. The amount of torque is calculated with the jacobian matrix (equation (2)) which describes the forward kinematics of the two joint robot arms.
The punching bag is rendered at a distance of 0.03m from the initial position along the Y- axis only. It was not rendered along the X-axis because, rendering along X-axis as well would make it like like a cube i.e., horizontally as opposed to making the punching bag vertically which defeats the purpose of the goal.

E. Visualization

A processing program is used to visualize the movement of the user. There is a fist showing on the screen corresponding to the users' position. The fist on the screen will move in both x and y direction based on the movement of the user. There is also a box showing on the screen to show the user the virtual wall. When the fist is in touch with the box, it can no longer move towards it. This aims to increase the haptic feedback felt by the user with the help of visual impact. As seen in figure 5, the user would be able to notice the position of the glove as they move their hand.

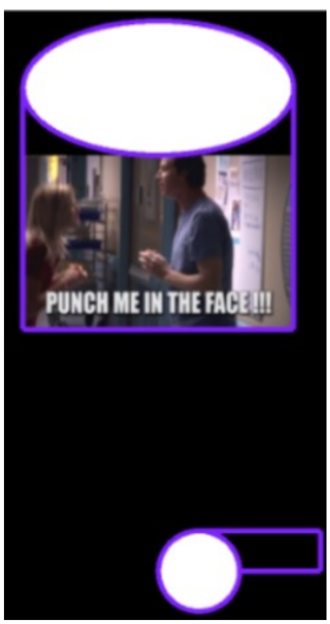

Fig. 5. Virtual rendering software - Processing used to visualize punch simulation

V. Results

The goal of this project was to learn about combined actuation to increase the user haptic feedback. A user study was conducted to test the effectiveness of the granular jamming and the virtual wall rendered. In the study, each student was asked to put their hands in the balloon and feel the stiffness both with and without granular jamming. Then they were asked to move the device forward to feel the stiffness at different points on the workspace of the punch bot. This study collected the responses from 6 students in the class.

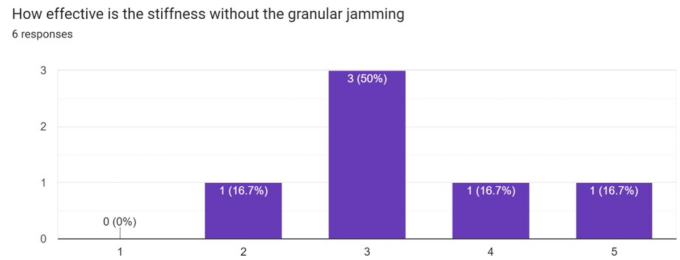

Fig. 6. Effectiveness Without Jamming

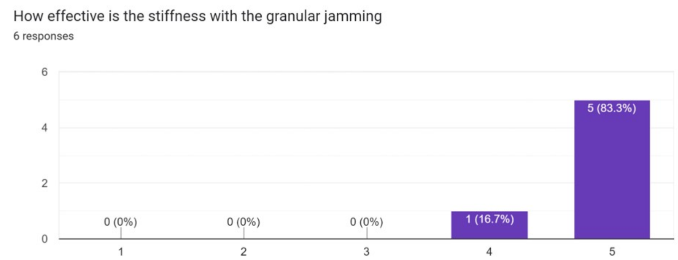

Fig. 7. Effectiveness With Jamming

The result is that more than half of the people only feel medium stiffness or less without the jamming. With the jamming, most people feel the stiffness is effective.

VI. Potential applications

This punch bot can potentially be used for bowling and basketball as well. The balloon at the end can be jammed with different stiffness to simulate the basketball and the bowling ball. The two degrees of freedom allows it to act with the users as they are playing basketball and bowling. Once the virtual environments such as mass-spring-damper for basketball and bowling are generated, this punch bot can provide people with emulational feedback as they are playing basketball and bowling as well.

VII. Discussion

There are two kinds of haptic feedback, vibrotactile and force feedback. Based on these two feedback, there are kinesthetic and tactile devices. Generally, kinesthetic haptic devices transmit force from ground to hand and tactile haptic devices create vibrations to hand. For this project, the jamming provides vibration feedback and the motor produces the force feedback. When both kinds of feedback are available, the user will feel strong haptic feedback. This does an experimental research on the different parameters that affect haptic feedback. Some of those parameters are stiffness, damping, amplitude, decay rate and frequency. Each parameter varies the type of feedback felt. It is noticeable through the project that a combination of multiple parameters does have a significant change in feeling. Other ways this could be simulated would be introduction of frequency and amplitude with the means of a vibration factor. Further testing would also determine importance levels of each parameter in different actuator configurations.

VIII. Error

The main case of error experienced in the device was due to motor slip. Motor slip was caused due to hardware issues which led to inconsistencies in position of the virtual boxing bag surface with each test. However a user study was conducted to calculate the consistency of feedback accounting for the irregularities.
The graph in figure 8 shows a linear curve while comparing the irregularities and the feedback which shows that the feedback felt was consistent irrespective of virtual wall location. A factor

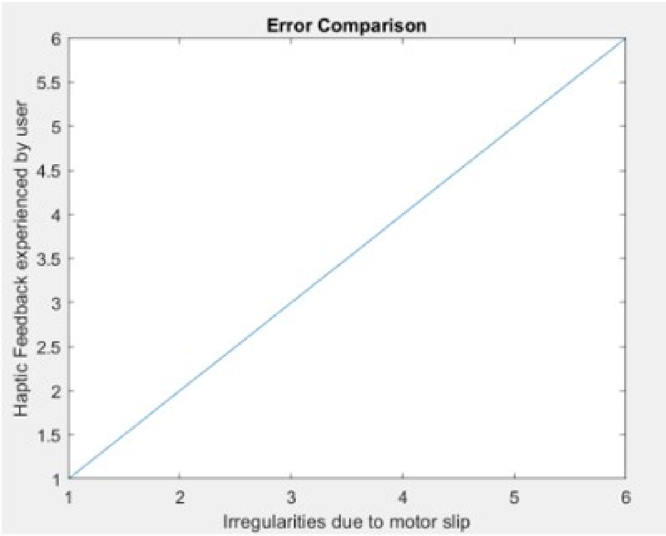

Fig. 8. error comparison graph representing linear feedback feel

that played a role to bring this consistency was the jamming. The motor slip had not affected the activation of jamming and hence the stiffness was consistent while reaching the wall with the punch. However motor slip did affect the visual environment as the program was taking the rotation of the motor to calculate the virtual position of the hand.

IX. CONCLUSIONS

This is just a prototype device, with just one virtual environment rendered in it and only contains simple visualization. This prototype however was able to test the effectiveness of feedback control when there are a combination of parameter activated. In this case it was force feedback and the stiffness component provided by the jamming mechanism. In the future, further research can improve the design of the system to solve the slipping of the motor, render more virtual environments such as mass-spring-damper to suit it for more sports, and improve the display of it with Chai3D to get a better visualization. Other parameters such as frequency and amplitude could also be added to enhance the feedback in the means of vibration felt at the end effector.

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