DESIGN AND IMPLEMENTATION OF A ROBOTIC DEVICE FOR MEDICAL PERCUSSION

Imperial College London

EPSRC
Pioneering research and skills

Dyson School of Design Engineering

Yongxuan Tan[1], Bennet Cobley[1], Oliver Thompson[1], Pilar Zhang Qiu[1]
[1]Dyson School of Design Engineering, Imperial College London

ABSTRACT

Medical percussion is a diagnostic procedure whereby the chest, back and abdomen are tapped to determine the condition of underlying tissue through the characteristics of the acoustic response. Although percussion is common in medical practice, there is a limited understanding of its dynamics. Experienced doctors may adjust the percussion force and impulse by varying the stiffness of the elbow and wrist joints, but the relationship between adjustments and acoustic response is unexplored. This work presents a novel robotic percussion device that aims to replicate the human percussion action using a two degrees of freedom linkage mechanism with adjustable joint stiffness. The force profile of a medical student performing percussion was recorded and a mathematical model of the mechanism was simulated in MATLAB to find suitable parameters to fabricate a hardware prototype. The device was tested on a silicone phantom tissue model. The measured force profile was similar to the human force profile but with less variation between consecutive percussion actions.

MATHEMATICAL FORMULATION

The percussion arm is modelled as lightweight rods connected with revolute joints as shown in Fig. 1. Two extension springs were placed at the elbow joint for actuating the system and at the wrist joint for compliance control.

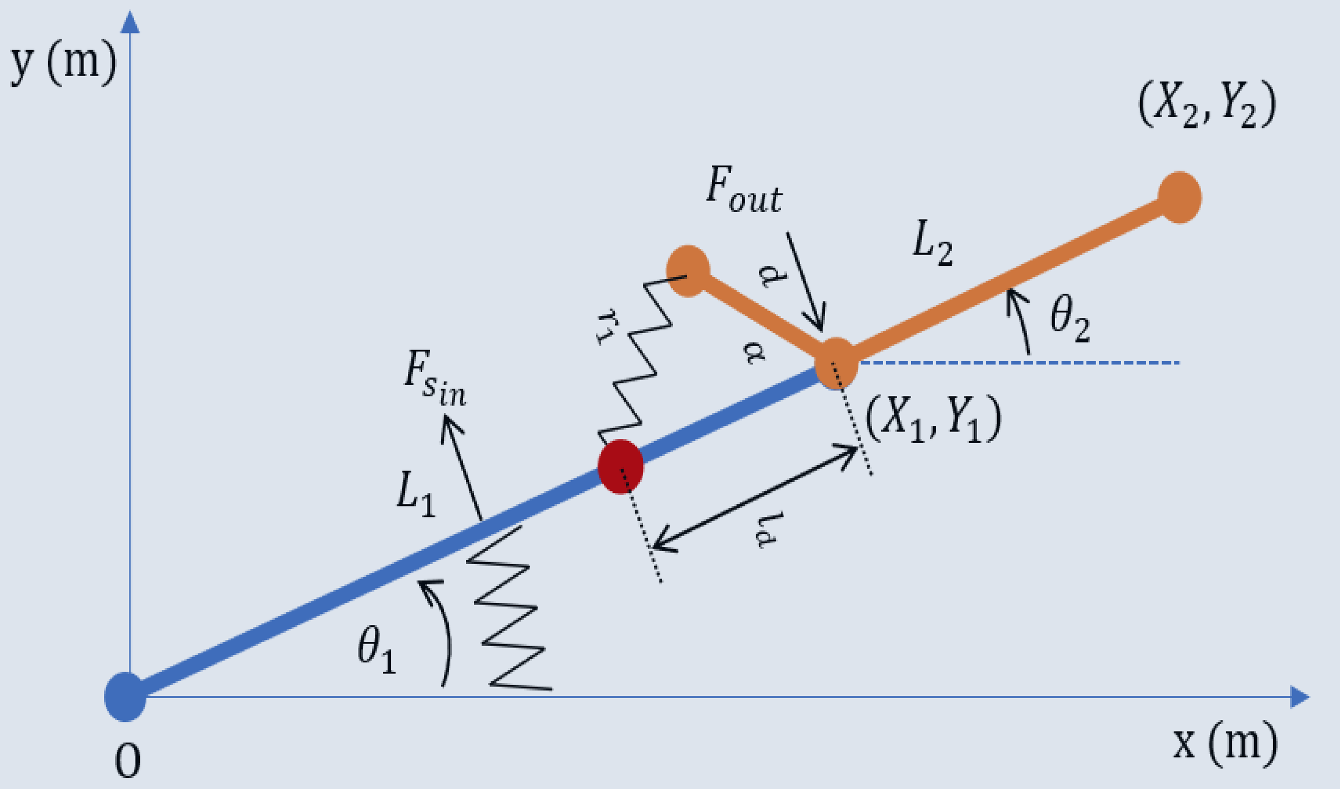

Fig. 1. Percussion arm model. Blue: forearm, Orange: hand, L_1: forearm length, L_2: hand length, (X_1,Y_1): wrist joint, (X_2,Y_2): finger tip, θ_1: elbow angle, θ_2: wrist angle, $F_{s_{in}}$: elbow spring input force, F_{out}: output force.

PARAMETER MATCHING

A medical student was asked to perform percussion on an Ecoflex 00-10 silicone phantom (150 mm by 100 mm). The percussion force ranged between 9 N and 11 N and the impulse between 0.7 and 0.8 Ns (recorded with a Tedea Huntleigh 1040 (20 Kg) load cell and NI USB-6341 interface).

The device was additive-manufactured. Its physical properties, including lengths, mass and centre of mass were used as input parameters to the MATLAB model which outputs spring stiffness for the elbow and wrist joints. The force applied by the end-effector can be further adjusted by adding additional mass. The human percussion force range is used as reference to select springs for the robot linkages, as shown in Fig. 3.

Fig. 4 shows the force exerted by the tissue using this design. The force and impulse applied by the robotic model were found to be 8.5 N and 0.5 Ns respectively, determined to be appropriate in magnitude compared to the human measurements but with a smaller deviation between taps.

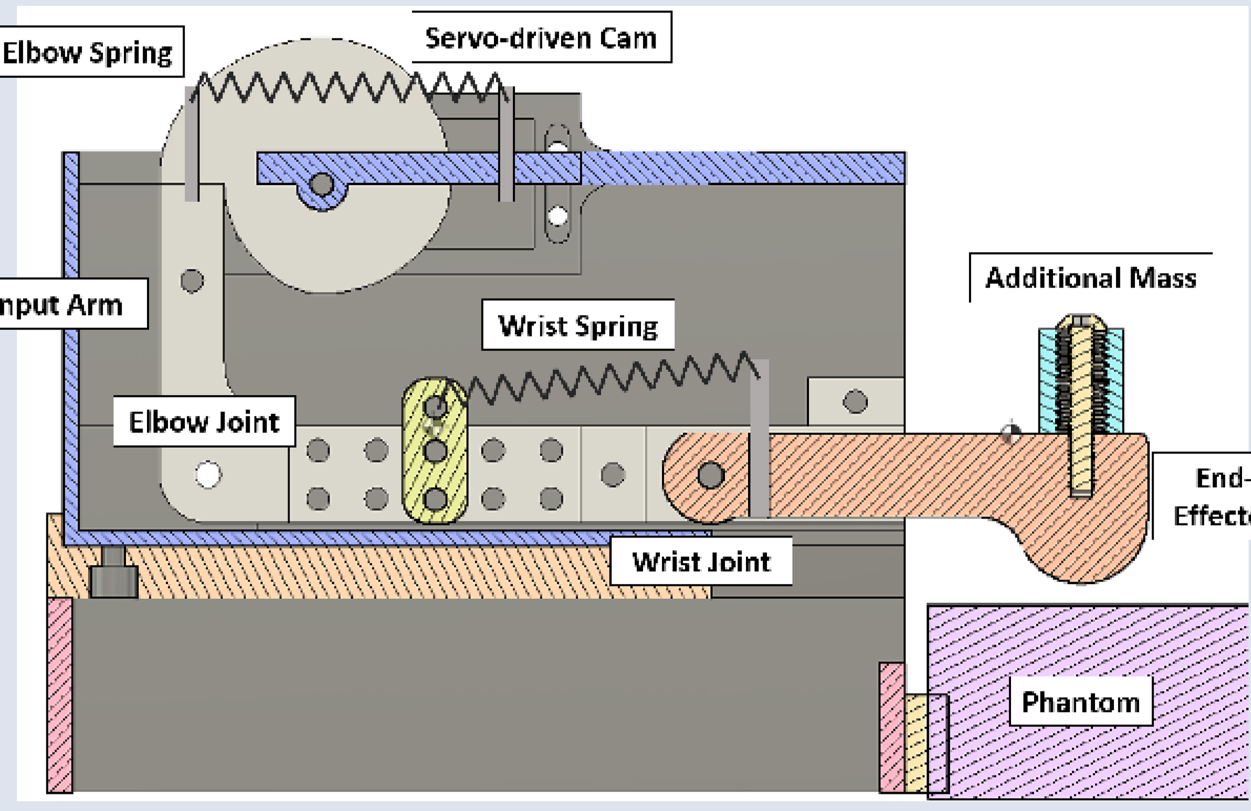

Fig. 2. CAD model of robotic percussion device.

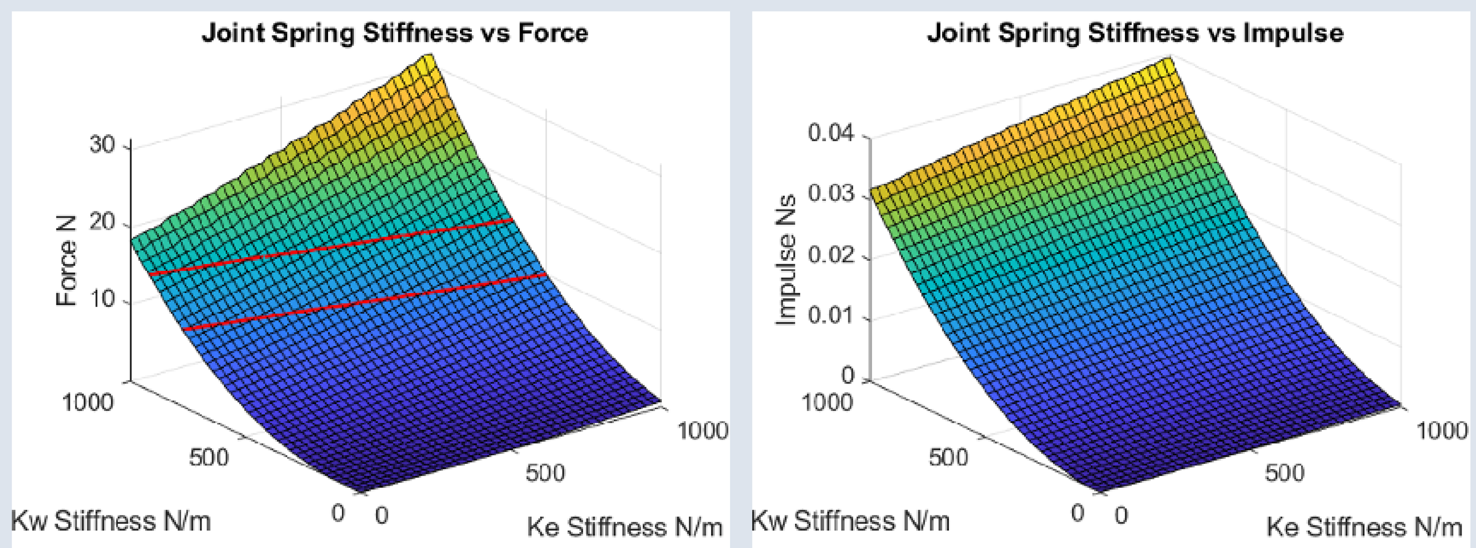

Fig. 3. Plots of joint spring stiffness against force and impulse. Ke: elbow spring stiffness. Kw: wrist spring stiffness. Left: elbow spring stiffness has a greater contribution to force. The region bounded by the two red lines matches the human force range. Right: wrist spring stiffness has a greater contribution to impulse, but is less than that of the human trial, this may be caused by the inaccurate estimation of the coefficient of restitution of the silicone phantom.

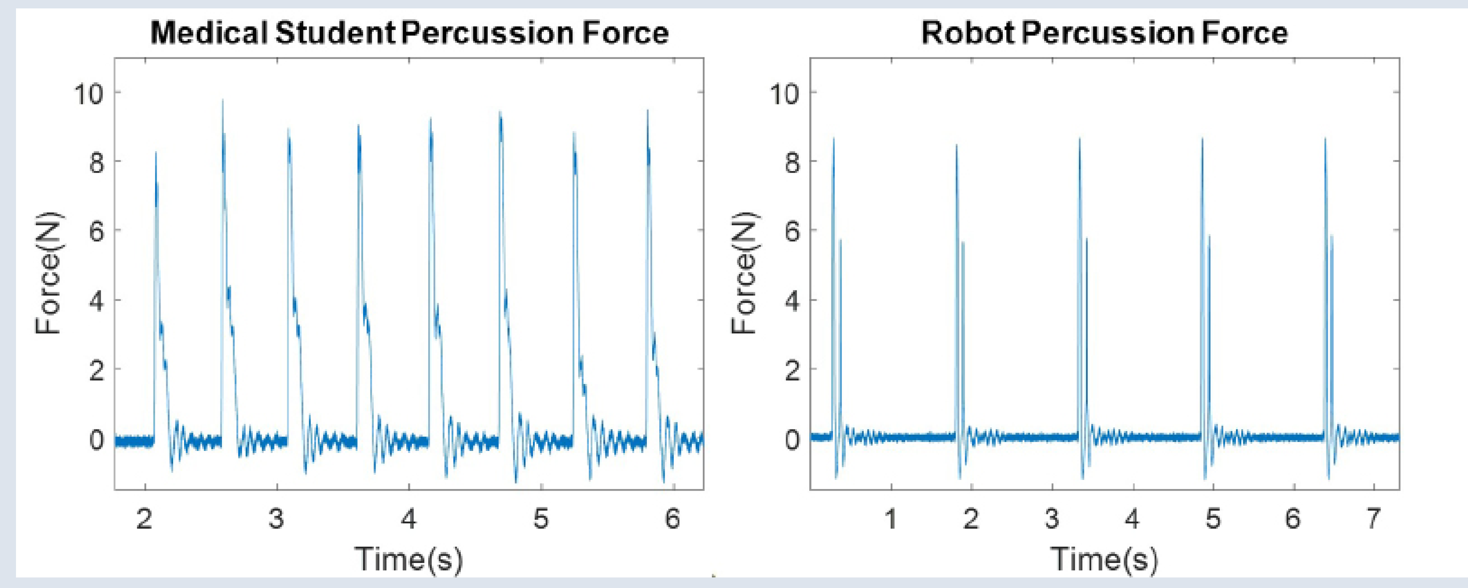

Fig. 4. Force readings of the human and robot performing percussion on the phantom. Human average force: 8.2 - 9.8 N, average impulse: 0.7 - 0.8 Ns . Robot average force: 8.5 N, average impulse: 0.5 Ns. The tapping frequency of the robot was 0.68 Hz (1.5s for each tap)

CONCLUSIONS AND FUTURE WORK

We presented a robotic device to replicate manual percussion. Following analytical insights from simulation of the manual percussion method, a novel actuation mechanism was designed. A compliant joint provided an accurate recreation of the percussion action. The robotic device showed comparable force and impulse profiles to the human participant, with better consistency between percussion actions. Future studies will explore variation in the acoustic response of tissue samples with differing pathologies.

LinkedIn IDs:
jacob-tan-ic
pilar-zhang-qiu
oli-thompson
bennetcobley

MATLAB and Python codes available at Github:
github.com/ot316/Percussion-RRP