Design and Implementation of a Robotic Device for Medical Percussion

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***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 a human with less variation between consecutive percussion actions.**

***Index Terms*—medical percussion, medical robot, MATLAB simulation, remote patient diagnosis**

I. Introduction

Manual percussion is a diagnostic procedure used in clinical examination whereby the chest, back and abdomen are tapped to determine the condition of underlying tissue through the acoustic response. Percussion is a preliminary assessment to inform other diagnostic methods such as ultrasonic sonography, computed tomography and magnetic resonance imaging (MRI) [1]. Whilst percussion is common in medical practice, it is not fully known what auditory attributes determine a diagnosis. This lack of knowledge and standardisation can lead to misdiagnosis [2], and disagreements between clinicians [3]. A deeper understanding of the acoustic response of percussion will provide new insights into the design of a robotic device to automate percussion examination. This has exciting future applications in that it might improve medical training, enable remote patient examinations or even increase the accuracy of percussion diagnoses.

The accepted percussion method is manual percussion. The left hand is fixed on the region to be assessed, with the middle finger isolated from the other fingers (Fig. 1 (a)). The middle finger of the right hand strikes the left and the examiner listens to the acoustic response [4]. Historically, devices have also been used to augment percussion methods. In the 18th century a percusor and pleximeter were documented (Fig. 1 (b)) and a stethoscope-attached handheld percussion device was patented in 2004 (Fig. 1 (c)).

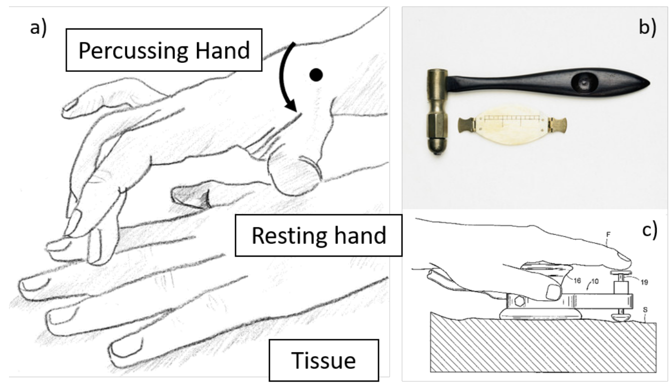

Fig. 1. Percussion methods and devices. (a) Manual Percussion [5]. (b) Percusor and Pleximeter [6]. (c) Stethoscope-attached percussion device [7]

Acoustic response in percussion examination is an established area of interest in the literature but has not been studied in the context of modern technologies. Interpreting the feedback from percussion is a multi-sensory fusion process, and through practice the performer adjusts the force profile and wrist stiffness to maximise the information gain, from the fusion of haptic and auditory feedback [5]. A robotic device capable of delivering repeatable motion could remove force inconsistencies inherent in human actions, allowing future researchers to focus on the relationship between the percussion action and acoustic response. This paper presents the design and implementation of a robotic percussion device that might be used to aid or automate percussion examination.

II. Methods

A. Mathematical Formulation

The percussion motion involves a flicking action where the motion originates from the elbow and force is transferred with the pivoting of the wrist; suggesting that the hand and forearm act as rigid links, and energy is supplied at the elbow joint and controlled by the wrist joint. The arm and hand movement of one percussion action can be broken down in the following steps:

1) The elbow joint provides initial torque to the forearm and hands with the wrist joint being compliant.

2) When the hand is at a certain distance above the body, the forearm motion stops and the hand continues to rotate around the wrist joint.
3) The finger tip impacts the surface and rebounds.
4) The examiner listens to the acoustic response and feels the haptic response with the resting hand.

The percussion arm is modelled as lightweight rods connected with revolute joints as shown in Fig. 2. Two extension springs were placed at the elbow joint for actuating the system, and at the wrist joint for compliance control.

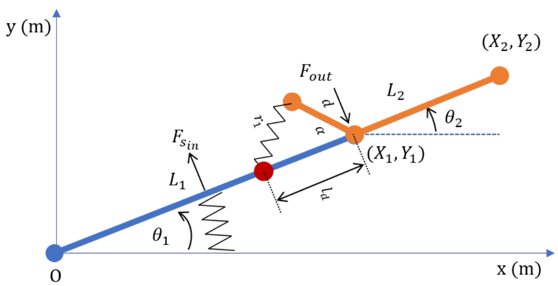

Fig. 2. Percussion arm model. Blue: Forearm, Orange: Hand, L_1: forearm length, L_2: hand length, (X_1, Y_1): wrist joint, (X_2, Y_2): finger tip, θ_1: elbow angle, θ_2: wrist angle, $F_{s_{in}}$: elbow spring input force, F_{out}: output force.

B. Parameter Matching and Results

A medical student was asked to perform percussion on an Ecoflex 00-10 silicone phantom (150 mm by 100 mm), chosen to simulate abdominal tissue [8]. The force profile was recorded with a Tedea Huntleigh 1040 (20 Kg) load cell and NI USB-6341 interface. The percussion force ranged between 8 N and 10 N, the impulse between 0.7 and 0.8 Ns.

A CAD (computer aided design) model was made using Fusion 360 (Fig. 3) and the physical properties of the model were used as input parameters to the MATLAB model. The geometry of the forearm was modified to make the device more compact and PLA plastic was assigned as the material for the linkages. The lengths, mass and center of mass of the linkages were used as inputs to the MATLAB model, and the model outputs suggested 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. 4.

The designs were additive-manufactured using a Prusa MK3S. The cam is driven by a Tower Pro MG996R continuous servo motor, controlled by an Arduino Uno. Fig. 5 shows the force exerted by the tissue using this design, recorded using the same equipment that measured the human force, detailed previously. 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 with smaller deviation between taps. The frequency of the tapping actions can be changed by controlling the motor speed, the effect of percussion frequency and force in relation to the acoustic feedback will be investigated in future studies.

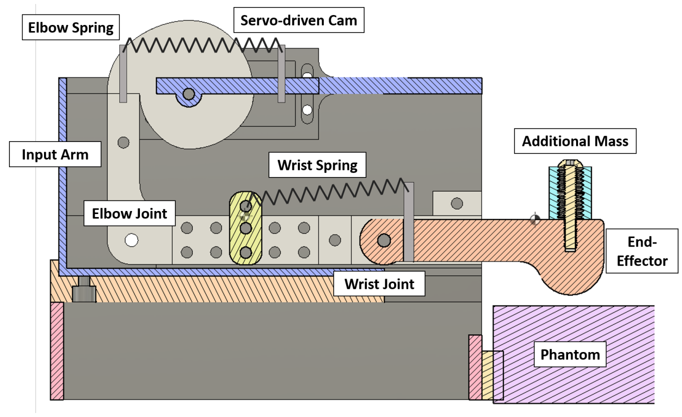

Fig. 3. CAD model of robotic percussion device. Additional mass can be added to the end-effector to adjust the impact force.

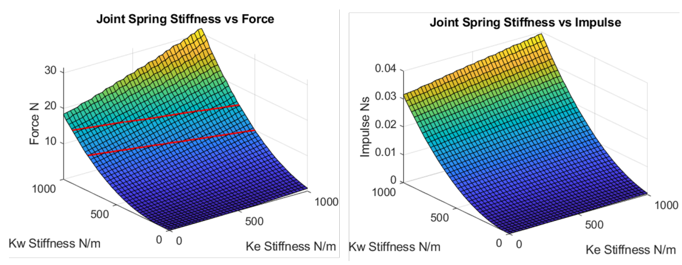

Fig. 4. Assume tissue deformation of 5 mm at impact. Ke: elbow spring stiffness. Kw: wrist spring stiffness. Left: elbow spring stiffness has a greater contribution to force. The region bounded by the two red lines matches the human force range. Right: wrist spring stiffness has a greater contribution 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.

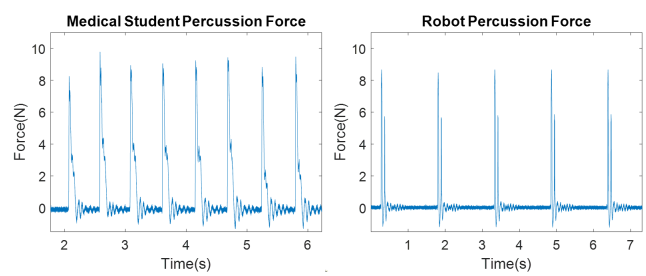

Fig. 5. Force readings of the human and robot performing percussion on the phantom. Human average force: 8.2 - 9.8 N, average impulse: 0.7 - 0.8 Ns. Robot average force: 8.5 N, average impulse: 0.5 Ns. The tapping frequency of the robot was 0.68 Hz (1.5s for each tap).

III. Conclusion 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.

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