Model the Soft Finger Piano Keystroke with a Mass-spring-damper

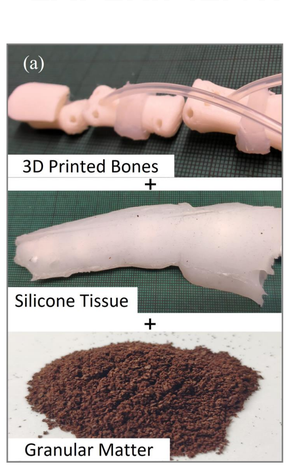
Reduced-order Modelling for Piano Keystroke with a Soft Particle Jamming Finger

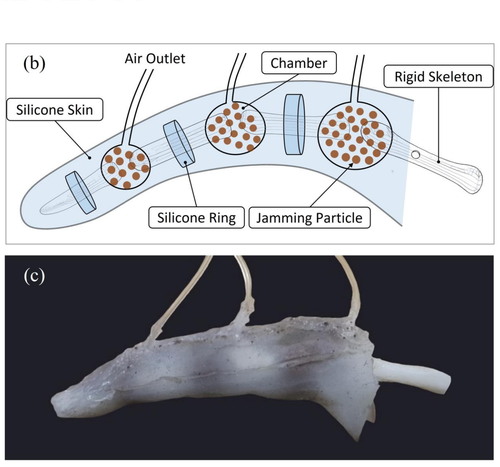
Huijiang Wang , Yuyi Zhang, Luca Scimeca, Cheryn Ng and Fumiya Iida

INTRODUCTION

- A feedforward control model is needed for robots to perform precise piano key pressings.
- The non-linearity of soft finger makes it challenging to model the keystroke action.

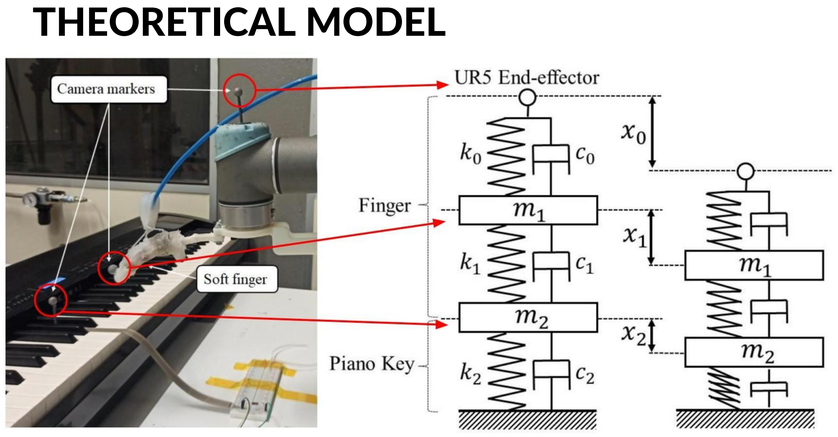
EXPERIMENTAL SETUP





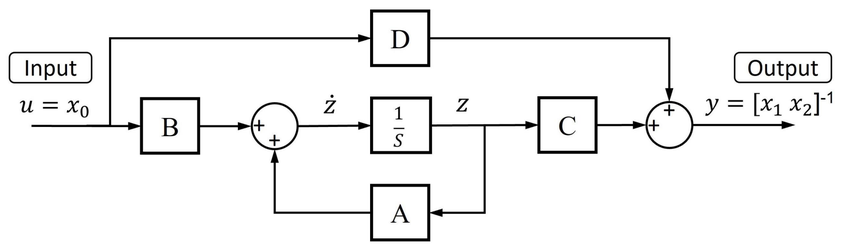
- Particle jamming soft finger, stiffness controlled by vacuum pressure.
- 3D infrared motion capture system recording the marker displacements.

THEORETICAL MODEL



- 2 DoF mass-spring-damper model
- Estimate stiffness and damping coefficient using system identification
- Analyse the dynamics using state-space model

$$\begin{cases} m_1\ddot{x_1} = k_0(x_0 - x_1) - k_1(x_1 - x_2) + c_0(\dot{x_0} - \dot{x_1}) - c_1(\dot{x_1} - \dot{x_2}) \\ m_2\ddot{x_2} = k_1(x_1 - x_2) - k_2x_2 + c_1(\dot{x_1} - \dot{x_2}) - c_2\dot{x_2} \end{cases}$$

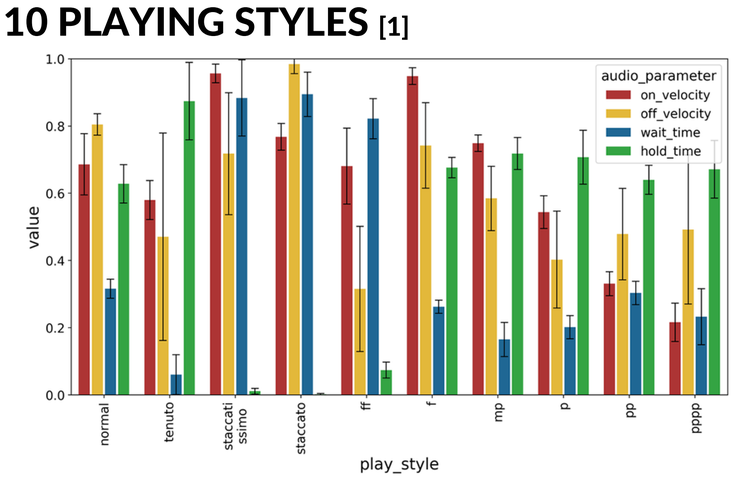


$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{k_0 + k_1}{m_1} & -\frac{c_0 + c_1}{m_1} & \frac{k_1}{m_1} & \frac{c_1}{m_1} \\ 0 & 0 & 0 & 1 \\ \frac{k_1}{m_2} & \frac{c_1}{m_2} & -\frac{k_1 + k_2}{m_2} & -\frac{c_1 + c_2}{m_2} \end{bmatrix} \quad B = \begin{bmatrix} \frac{c_0}{m_1} \\ \frac{k_0}{m_1} - \frac{c_0c_1 + c_0^2}{m_1^2} \\ 0 \\ \frac{c_0c_1}{m_1m_2} \end{bmatrix} \quad z(t) = \begin{bmatrix} x_1 \\ x_1 - \frac{c_0}{m_1}x_0 \\ x_2 \\ \dot{x_2} \end{bmatrix}$$

DISCUSSION

The behaviours of high-order, non-linear and soft-bodied interactions can be modelled as a linear time-invariant system. This method has potential to be developed into a general feedforward model for soft robot decision making on keystroke actions.

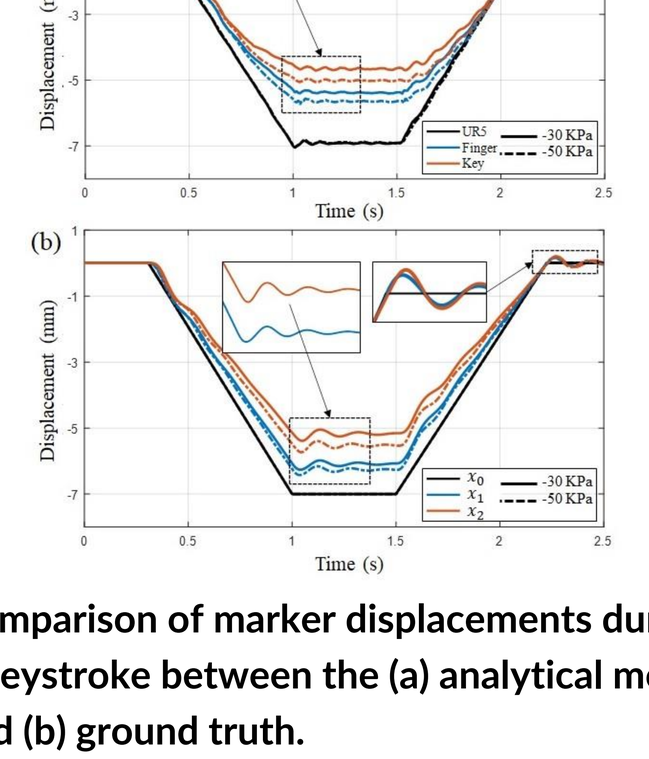
10 PLAYING STYLES [1]



DISPLACEMENT COMPARISON

Comparison of marker displacements during a keystroke between the (a) analytical model and (b) ground truth.

MIDI PRIDICTION



Comparison of the normalized MIDI velocity from (a) analytical model and (b) ground truth.

[1] Scimeca, L., Ng, C., & Iida, F. (2020). Gaussian process inference modelling of dynamic robot control for expressive piano playing. *Plos one*, *15*(8), e0237826.

Bio-Inspired Robotics Lab

UNIVERSITY OF CAMBRIDGE
Department of Engineering