Haptic Piano Key based on a Real-Time Multibody Action Model: Mechatronic Design and Force Feedback Validation

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Piano action model

The *touch* of a grand piano mainly results from a dynamic mechanism – called *action*, Fig. 1 – which propels the hammer up to the string, given the key motion. The multibody model [1] of Fig. 2 has been developed, containing the action main parts and involving five rotational degrees of freedom. The model also takes the specific constitutive force laws of the materials (felts, springs, ...) into account, along with the intermittent contacts between the bodies.

Global experimental validation [1] through high-speed camera shows in Fig. 1 that the hammer motion is well caught by the model, apart from the back-check capture.

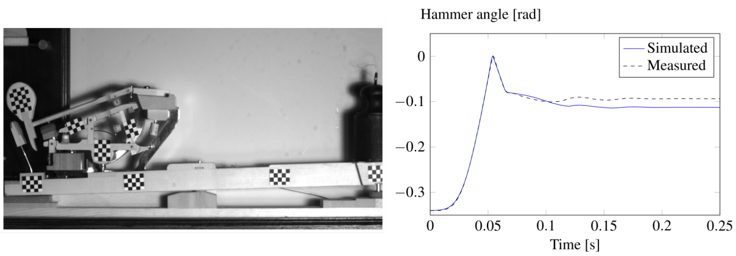

Figure 1: Piano action [1]. Left : Global high-speed camera model validation. Right : comparison between experiments and simulation results.

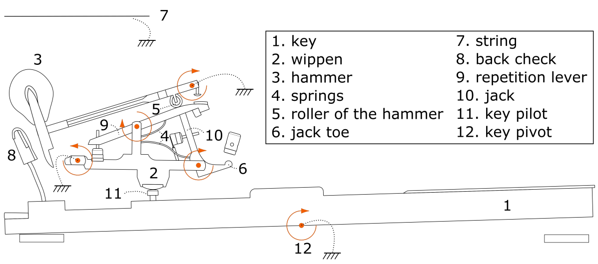

Figure 2: Multibody model elements and its five degrees of freedom in circle arrows.

In line with our previous work [2], we propose to use this multibody model, which is based on the Robotran software [3], to enhance the haptic rendering of digital pianos keyboards. This contribution focusses on the hardware-in-the-loop integration of the model and on its force feedback validation.

Haptic feedback mechatronic design

For the pianists, force feedback principle aims at reproducing the same *touch* sensation, i.e. F_{haptic} in Fig. 3. An active device reproduces the force F_{act} on the key pilot, based on the reference force F_{mod} computed by the multibody model. Two position sensors capture the key *kinematics* to drive the model simulation.

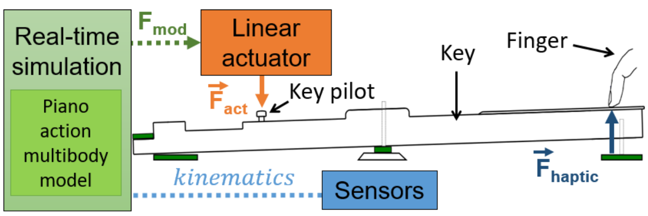

Figure 3: Piano action multibody model force feedback principle.

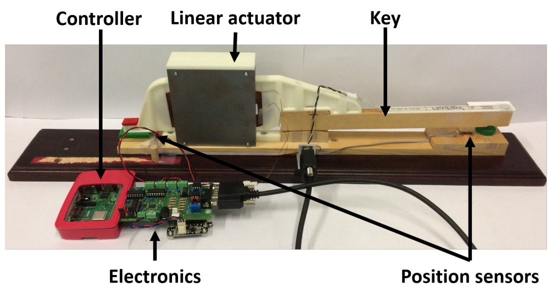

Figure 4: Mechatronic design of one key haptic feedback device [2].

The prototype of Fig. 4 consists of a linear actuator rigidly attached to a piano key. An embedded controller computes the model in real-time (i.e. in less than 1 ms), while the electronic boards drive the actuator accordingly.

Although current C/C++ implementation on a UNIX system gives satisfactory results [2], research currently underway investigates the Robot Operating System (ROS) as a more flexible software tool to enhance the modularity as well as the real-time capabilities.

Force feedback validation

Measurements of the F_{haptic} on an acoustic Yamaha grand piano with an external actuator acting on the key gives an overview of the force feedback to render. The set-up used is shown in Fig. 5. Adamou proposed in 2019 [4] a similar approach by sensing the static and dynamic responses of instrument keyboards thanks to a homemade measurement device.

The actuator of Fig. 5 imposes a motion and measures a current which is proportional to the force. The superimposed measurements of Fig. 6 have been done for nine different notes on the Yamaha keyboard, plus on the Renner demonstrator of Fig. 1. The key was pressed at a constant speed of 0.03 m/s. While the general behavior is globally identical, it shows small differences between the notes. However, escapement phenomenon – which is an essentiel sensory feedback – is clearly visible between -7 and -10 mm, but shifted in position.

Figure 5: Experimental measurements.

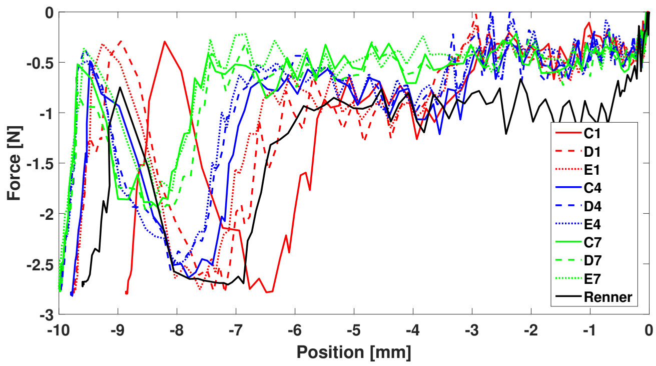

Figure 6: Forces F_{haptic} versus key position for 10 different keys of a grand piano.

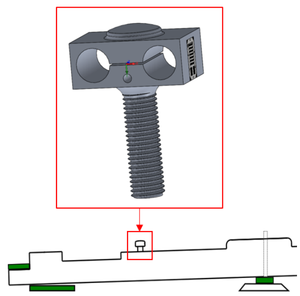

Figure 7: Strain gauge design.

The model output force F_{mod} should render the force at the key pilot that would cause a force equivalent to these F_{haptic} of Fig. 6. To ensure that, a custom force sensor is currently under development that is based on a strain gauge approach. The designed test body of Fig. 7 will be inserted instead of the key pilot number 11 in Fig. 2 to capture the strain so that the sensor can measure the force applied by the wippen to the key pilot, which is exactly the force F_{act} that the actuator has to apply in the haptic device. Finally, the modeling and the experimental forces will be confronted to adjust the model parameters accordingly so that the prototype of Fig. 4 will render the *touch* of a grand piano in a satisfactory manner.

Acknowledgments Authors would like to thank Alex Bertholet of UCLouvain for his help and support in the strain gauge design process. Sébastien Timmermans is FRIA Grant Holder of the Fonds de la Recherche Scientifique-FNRS, Belgium.

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