UPRIGHT PIANO ACTION: EXPERIMENTAL CHARACTERIZATION AND MULTIBODY MODELING

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Summary In this work, a multibody model of an upright piano action is presented, that has been experimentally validated via high speed camera. The model takes all the bodies into account as well as specific felt force laws and body geometries to deal with intermittent contacts. In addition, experimental tunings of model parameters have been undertaken. Simulations of the model allow, among others, to estimate the maximal playing frequency and a minimal input force on the key to produce a sound. More specifically, the bridle strap and butt spring usefulness are discussed, showing the interest of the multibody modeling approach for studying piano actions.

INTRODUCTION

In pianos, the sound is produced by the impact between the hammer and the strings. A mechanism – called piano action – propels the hammer according to the key motion which is controlled by the pianist. Upright pianos contain an action which differs from that of the grand piano. Both complex, these two actions can be modelled through multibody methods to analyse their behaviour over different impulses and to help understanding their functioning.

The multibody model is based on a demonstrator action, see Fig. 1. The latter has been used for both physical parameters estimation and experimental validation. An equivalent CAD replica of that action has been carried out.

PREVIOUS MODELS

Whereas many publications developed models of the grand piano action, very few focus on the upright piano ones. A first noticeable attempt by Oledzki presents a dynamic model containing only two masses and a nonlinear spring based on experimental observations [1]. After that, several publications of Ramin Masoudi, John McPhee and Stephen Birkett led to the most complete vertical action dynamic model so far. Using the graph theory, they modelled the physical interactions between the five main bodies of the action [2]. Their simulations already allowed to explore the model behaviour under different impulses. Five new features (bridle strap and butt spring, flexibility of some parts, new felt contact model, etc.) were introduced in [3] to enhance the model fidelity and an experimental validation is presented in [4].

In line with the upper modeling works, we propose to build an action multibody model, thanks to the symbolic Robotran multibody software [5], while going deeper in the parameters identification through well-targeted experimentations.

UPRIGHT MULTIBODY MODEL

Based on the action of Fig. 1, the model consists of five mobile bodies, several stops and springs shown in Fig. 2, all moving in a vertical plane. The model considers only rigid bodies, no backlash in the joints and simplified contact geometries: the corresponding bodies shapes are approximated by circular arcs or line segments to find the contact patch location and to compute the reaction forces resulting from felts laws characteristics. Fig. 3 illustrates the case of the hammer-jack contact geometry.

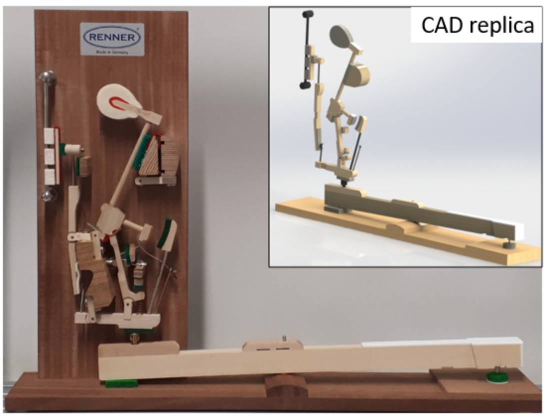

Figure 1: Upright piano action demonstrator and its equivalent CAD replica.

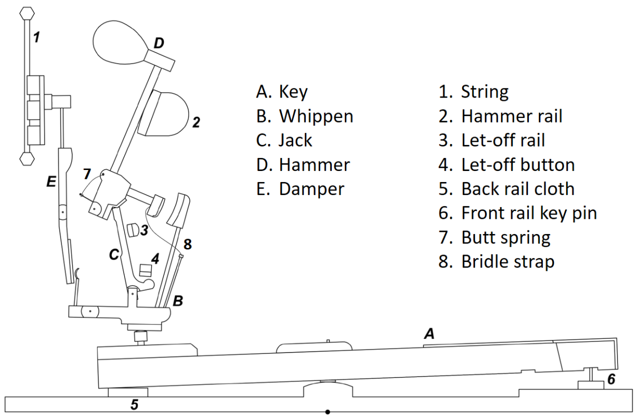

Figure 2: Multibody model main components: mobile bodies (resp. other elements) are indicated by letters (resp. numbers).

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Parameters experimental characterization

Experimentations conducted on subparts of the model have allowed us to identify forces laws coefficients. For example, the friction of the hammer rotating joint has been characterized by identification between simulations and experiments, depicted in Fig. 4, using high speed camera tracking at 2000 fps. Whereas, with a 1-kg mass as input, the model reacts similarly as the demonstrator for the pre-impact phase [0;0.1] s, the imposed key motion causes the hammer to hit the string a bit too early, around 0.1 s in Fig. 5, but in a quite satisfactory manner, given the modeling parameters uncertainties.

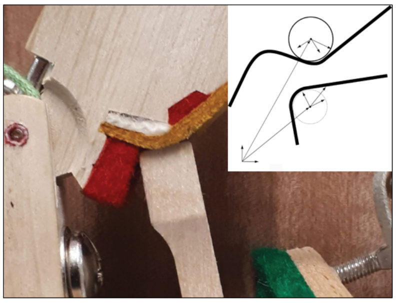

Figure 3: Modeling of the hammer-jack contact geometry.

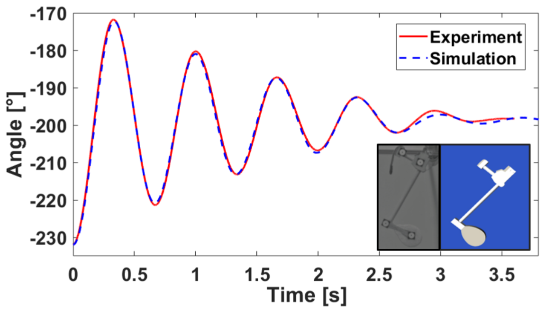

Figure 4: Hammer rotation time history: Sim. vs Exp.

Model advanced simulations

Exploration of the model response to an increasing frequency of key force inputs shows that the hammer is unable to hit the string from around 11 Hz. Therefore, 10 Hz can be considered as the maximal playability frequency of the model. Actuate experimentally the action with an external actuator provides a value between 11 and 12 Hz. The minimal force so that the hammer reaches the string and produce a sound is around 1.2 N, which correspond approximately to the experimentally measured values between 1.12 and 1.21 N. More importantly, the importance of the bridle strap and butt spring – see Fig. 2 – is illustrated in Fig. 6: they both help the hammer to travel back faster to its rest position so that key strokes can be repeated faster. This result is original since it refers to specific elements whose role is not clearly explained, even by piano tuners.

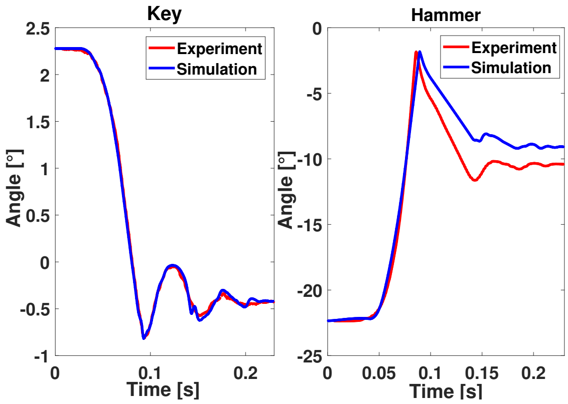

Figure 5: 1-kg input simulation.

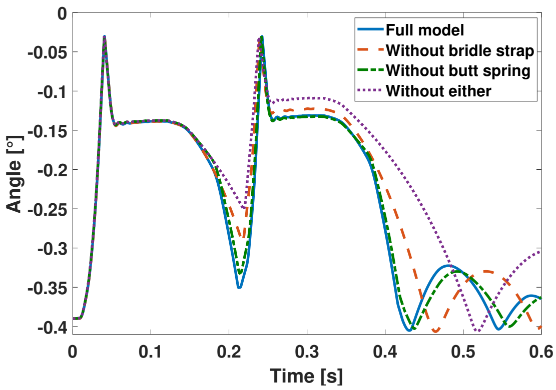

Figure 6: Hammer angular position for a double blow.

CONCLUSIONS

A multibody model of an upright piano has been carried out and has shown reasonable agreement with experimentations. Additional simulations have helped us to quantify and analyse the action performances, in particular for the bridle strap and butt spring whose role is important in fast dynamics. Improvement of the parameters identification would enhance the model fidelity for the next future, having in mind that it could be used in real-time to enhance the haptic feedback touch of numerical pianos, as we are currently developing for a grand piano action [6].

References

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