VClav 2.0 – System for Playing 3D Virtual Copy of a Historical Clavichord

Krzysztof Gardo and Ewa Lukasik

Institute of Computing Science, Poznan University of Technology,
60-965 Poznan, Poland
Krzysztof.Gardo@put.poznan.pl, Ewa.Lukasik@cs.put.poznan.pl

Abstract. VClav 2.0 system presented in the paper enables user to interact with a digital 3D reconstruction of the historical clavichord in a manner similar to lifelike using Virtual Reality gloves to “play” music. The real clavichord was constructed by the famous maker in 18th century, Johann Adolph Hass from Hamburg, and is at the exposition in the Museum of Musical Instruments in Poznan, Poland (department of the National Museum). This is a system powered by the NeoAxis game engine and equipped with 5DT Data Glove 14 and Polhemus Patriot tracker. It is an exemplary solution for museums to actively present musical instruments.

Keywords: cultural heritage**,** Virtual Reality, 3D modeling, clavichord, gesture driven HCI.

1 Introduction

Musical instruments represent very specific art objects in museum collections. Apart from being attractive as historical items of visual art, they are sources of sound. Their full appreciation is possible while listening to their music played live. Also an observation how the sound is produced is interesting for visitors. Musical instruments are interactive, but their interactivity may be hardly ever experienced in museums or because of their protection, or because their old mechanisms are entirely or partly damaged and the sound cannot be demonstrated. Most musical instruments at the exhibitions are mute. Replacing real objects by virtual ones – located in the natural scenery – constitutes an interesting solution opposing museum labels “do not touch”. Advances in Virtual and Mixed Reality technologies give rise to new ventures devoted to the digitization and access to museum objects [8].

Mixed Reality (MR) is a term concerning visualization technique based on both real and virtual objects. It superimposes graphics, audio and other sense enhancements over a real-world environment in real-time. In general Mixed Reality requires three-dimensional interaction in which users’ tasks are performed directly in a 3D spatial context [1]. It is possible to achieve using 2D input devices, but more desirable is using 3D technology. Typical 3D devices are 3D mouse, data gloves, pointer or gesture devices and other multiple DOF sensors or trackers available in the market or in the research labs. Unfortunately they come with a heavy price tag [3].

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Using Mixed Reality for presenting musical instruments is a challenge. Visual animated representations should be combined with sound and should enable real time interaction, so that the user has the impression of playing an authentic instrument. The research papers in the domain of digital reproduction of musical instruments concern rather the reproduction of their elements, as e.g. the two plates (top and back) of the soundboard of a historical violin [7] or an organization of virtual musical instruments exposition [6].

VClav 2.0 system presented in the paper is devoted to the precise visual reconstruction of the historical clavichord in the Virtual Reality with Virtual Reality data gloves to "play" music. The real clavichord was constructed by the famous 18th century maker, J.A. Hass, from Hamburg. The instrument was accidentally found, in a very bad condition, with many parts destroyed, and brought to the Museum of Musical Instruments in Poznan, Poland, for restoration. In order to make the audience acquainted with all interesting design solutions and decorative facets of the instrument and to show, how to play it, it was decided to perform a virtual reconstruction with new HCI interfaces.

A clavichord is a European stringed keyboard instrument known from the late Medieval to Classical eras [2]. It is still used in performances and recordings of renaissance and baroque music. It produces sound by striking brass or iron strings with small metal blades called tangents. Vibrations are transmitted through the bridge(s) to the soundboard. The action is simple, with the keys being levers with a small brass tangent at the far end.

The paper is structured as follows: Section 2 recapitulates the works on the 3D model of Hass clavichord undertaken within VClav and VClav 2.0 projects, Section 3 presents Virtual Reality hardware and software used in VClav 2.0, Section 4 desribes the system for playing a 3D virtual copy of Hass clavichord and Section 5 concludes the paper.

2 From VClav to VClav 2.0

The main objectives of the VClav 2.0 project were to create the faithful 3D model of the J.A. Hass clavichord with sound generating mechanism in operation and to introduce a realistic interaction between a user and an on-screen virtual instrument. The project is an extended version of VClav system (described in [5]), written in Java, where the 3D model of the clavichord was embedded. A great effort has been put to the photorealistic 3D modeling of the clavichord and to activate its movable parts. The process of virtual reconstruction of the instrument was thoroughly planned and followed part by part in the manner similar to the real one. The 3D model of the clavichord was based on the blueprint scheme, photographic documentation and on the actual instrument inspection. It was built part-by-part by the University team and covered with faithful textures, including valuable paintings on the soundboard. The 3D digital model was embedded in a standalone Java application written from scratch by the team. It enables a user to manipulate instrument's parts and uncover its certain layers. The interaction with the digital model is possible using a 3D mouse - a space navigator, together with a traditional mouse. Although the functionality of VClav was simplified, several of its stages, mainly modeling in Autodesk 3ds Max constituted the base for VClav 2.0 tasks.

The whole reconstruction process included the following steps:

- analysis of the construction of the instrument and planning the digital reconstruction steps,
- modeling the exact copy of the parts of the instrument in 3D software environment,
- digitally reproducing historical textures,
- reconstructing missing parts and digitally "repairing" destroyed parts,
- choosing the VR tools necessary to provide the assumed functionality and interface,
- creating the digital environment to manipulate and to play the digital clavichord,
- creating or adapting the physics engine, i.e. computer software that provides an approximate simulation of certain physical systems, such as rigid and soft object dynamics in real-time and equipping objects with basic physical features.

VClav 2.0 significantly extends the functionality of the first version. All operations are executed in a realistic manner – a player, wearing a data glove, has his/her hand virtually reproduced on the screen and plays the virtual instrument, as a real one.

The extended functionality and real-time operation demanded using an advanced software tools that would simulate the performance, actions and physical phenomena while operating various parts of the virtual instrument. An existing systems have been considered, including physics and game engines [4].

A physics engine is computer software that provides an approximate simulation of certain simple physical systems, such as rigid body dynamics (including collision detection), soft body dynamics, and fluid dynamics, of use in the domains of computer graphics, video games and film. Their main uses are in video games (typically as middleware), in which case the simulations are in real-time.

A physics engine often constitutes a core part of a more advanced system – a game engine. A game engine is a software system designed for the creation and development of video games. The core functionality typically provided by a game engine includes a rendering engine ("renderer") for 2D or 3D graphics, a physics engine, i.e. a module simulating physical phenomena or collision detection (and collision response), a control module receiving signals from input devices (a keyboard, a mouse, a joystick, etc.) and a sound controlling module. The above-mentioned features of the game engine may be applied using the Application Programming Interface provided by the engine, however some of them are so advanced that they make available a complete set of tools for producing games via the software development kit (SDK) including all the indispensable libraries for scripting, animation, artificial intelligence, networking, streaming, memory management, threading, localization support, and a scene graph. Some engines are equipped with converters that allow the programmer to rewrite data from external programs to make them compatible with the modules of the engine.

The following requirements have been imposed on the game engine to be used within the VClav 2.0 project:

- programming language and IDE: C #, MS Visual Studio 2008,
- independence from the graphics driver: OpenGL and DirectX 9,
- built-in physics and sound system.

Searching for the engine was carried out using DevMaster.Net website, which contains a database of game engines with advanced search engine [10]. After a thorough analysis of the available game development software, the NeoAxis engine in its non-commercial version (described in the Section 3) was chosen in the form of the middleware software. The engine was responsible for displaying three-dimensional graphics, playing sounds, and simulating the software environment for the realization of physics laws provided by a physics simulation engine NVIDIA PhysX.

3D models of the clavichord parts, the scenes, and the virtual hand were exported as models compatible with the NeoAxis engine where motion was added to various parts of the clavichord and a hand.

VClav 2.0 system operates in two modes:

- a 3D clavichord model manipulation and
- playing the instrument.

The manipulation mode allows the user to control moving parts of the instrument (e.g. opening and closing the covers) and using his/her own hand represented as the model on the screen. In the game mode a player wearing the glove can "hit" the keys of the clavichord by the virtual hand fingers, activate the key levers with tangents and generate the sound. The WAVE samples of a real clavichord [9] sound are used to play music.

3 Virtual Reality Hardware and Software

The project VClav 2.0 uses two Virtual Reality input devices: 5DT Data Glove Ultra 14 and Polhemus Patriot tracker. As a display 3D options have been considered, but finally a full HD 2D monitor was used as most available at the time of finalizing the project. Fig. 1 presents the development environment for VClav 2.0.

The target operating system of the project is Microsoft Windows XP/Vista/7 installed along with Microsoft. NET Framework 3.5 [11]. The project was written in C# and prepared in Microsoft Visual Studio 2008 integrated development environment. Its implementation was based on the NeoAxis Engine(Non-Commercial SDK 0.8.4.2 [14]) and libraries and controllers of the VR tools used in the system. For designing 3D elements Autodesk 3ds Max 2010 was used.

3.1 5DT Data Glove Ultra 14

5DT Data Glove 14 Ultra is a 14-sensor data glove, equipped in two sensors per finger, that measure finger flexure as well as the abduction between fingers [17]. There are USB and wireless version of gloves. Sensors output value is in the range 0-4095. The glove was tested by static and dynamic tests. Static tests were performed on motionless hand. The stability of sensors output was different for each of them, but acceptable for assumed fingers motions. Dynamic tests were executed for flexures of individual fingers and have also shown certain amount of variability (acceptable).

3.2 Polhemus Patriot Tracker

Polhemus Patriot tracker [16] utilizes AC tracking technology. The source and sensor contain electromagnetic coils enclosed in plastic shells. The source emits magnetic fields, which are detected by the sensor. The sensor's position and orientation are measured as it is moved. It provides dynamic, real-time measurements of position (X, Y and Z Cartesian coordinates). Update rate is 60Hz per sensor., latency - less than 18.5ms. The tracker was tested while moving along the three coordinates and showed the greatest error along Z-coordinate. However playing the keyboard instrument hardly involves movement along Z-coordinate, therefore the results were considered as acceptable.

3.3 The Display

The digital reconstruction of the clavichord was devoted for the exploitation in the Museum of Musical Instruments, so it had to offer a full HD image quality to present the details of construction and ornamentation. Although a 3D display has been considered as a presentation device [1], including a the Head Mounted Displays, it was finally decided to use traditional full HD two-dimensional 40" monitor, as best suited to the existing setting in the Museum and most available at the time of finalizing the project.

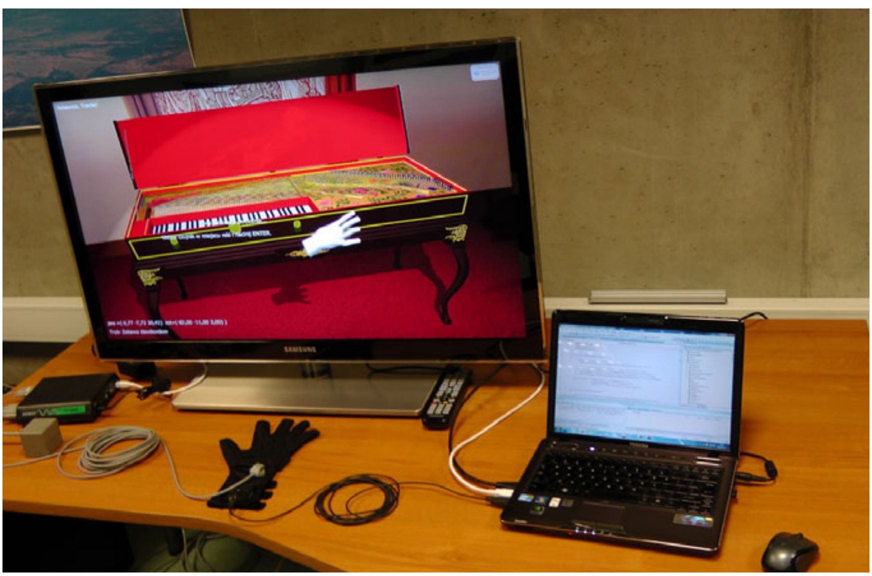

Fig. 1. VClav 2.0 development environment: Samsung LED 40' display, laptop Toshiba U500 Series, Patriot Polhemus Tracker and 5DT Data Glove 14 Ultra

3.4 NeoAxis Engine

NeoAxis Engine is a complete integrated development environment for creating interactive 3D graphics including 3D virtual worlds, AAA games, and realistic simulations [14]. The system comprises a real-time 3D engine and a suite of full featured tools. It uses OpenGL graphics and MS. Direct3D drivers to display graphics. It is integrated with PhysX technology and ODE Physics, which allow the designer to simulate physical phenomena for the displayed scenes. To play the sound DirectX Sound System or OpenAL can be used. Non commercial version with limited functionality has been used in the project. From a numerous tools of the engine, the following have been used:

- *Resource Editor* - a tool for viewing and editing partial resources used in the project, i.e.: 3D objects, states of system physics, sound or special effects.
- *Map Editor* - the integrated object placement toolkit for the easy building of game scenes.
- *NeoAxis Engine Exporter* - model exporters, supporting popular 3D packages, including Autodesk 3ds Max.

NeoAxis Engine Exporter is a tool to convert models from Autodesk 3ds Max to the form compatible with OGRE standard used within the NeoAxis Engine. This tool is able to create a mesh with the material and then apply it to the model. Exporter recognizes the backbone of the model together with the animation, which can be used in the project.

4 System for Playing a 3D Virtual Copy of a Historical Clavichord

The work related to the project implementation was carried out in several consecutive stages and in a particular order. The first stage consisted of modifying three-dimensional VClav models of clavichord, scenes, and virtual hand for the new environment of NeoAxis engine. Second and third stages were associated with the creation of physics model of the clavichord and the virtual hand. In the last stage of the project the application code has been written.

4.1 Modifying the 3ds Max Models to the NeoAxis Engine Format

Model of the Clavichord and a Scene. Every functional element of the virtual clavichord had to be the individual 3D object (drawer, key, lid). A great deal of modifications was performed to the VClav model elements, as some of them were composed of several parts, e.g. the key consisted of five separate shapes: white and black part, and three wooden components and a tangent. All of them had to be merged into one object.

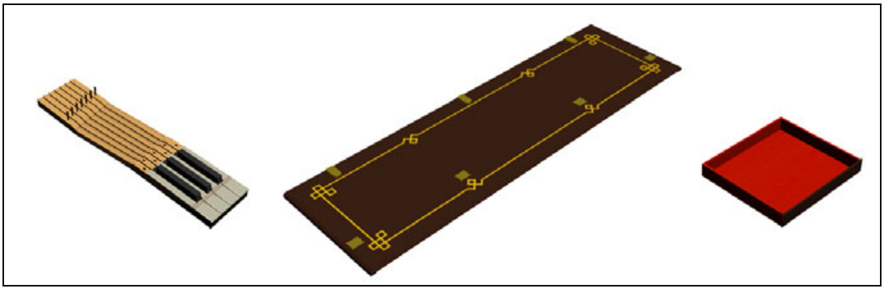

Fig. 2. Dynamic objects in VClav 2.0: keys, the lid, the drawer

Fig. 3. Static objects in VClav 2.0: the casing and the rack

Before exporting the objects to NeoAxis engine, they were also equipped with the additional features: texture format, animation switching on/off, switching on shadows, gravitation and collision between the objects. At this stage the names of objects were adapted to the new environment. Particularly important was assigning numbers to the keys, because depending on their number, a sound of a specific pitch is played. These elements are only presentation parts used by the engine. Apart from them every object has its shape, which is taken into account during detection of collision or simulation of the physical environment. Fig. 2 and Fig. 3 present examples of dynamic (movable) and static objects in VClav 2.0.

Model of the Virtual Hand. The 3D model of a hand comes from the free TurboSquid service [15]. Its modification consisted in its equipment with the skeleton system of fingers. In the 3ds Max it may be realized using the tool “Bones” (Create->System->Standard). It is necessary to point out the beginning and the end of the bone. Program merges bones situated close one to the other. Some difficulty was related to adjusting bones system to the shape of the hand, which in this case is in an unusual arrangement of fingers – while playing the keyboard. It had also to be rescaled to match the size of the clavichord.

4.2 Definition of Physical Mechanisms of the Clavichord and a Hand

In NeoAxis Engine there exists systematic and hierarchic structure of resources. The highest in the hierarchy of resources is a Map. First the designer has to create a map, which is the starting point to display a scene. The Map consists of units called Entities. The Entity can be shaped as a mesh and imposed on its Material. Other Entities are: light, camera, particle effects or sound. The important Entity is the type instance (Type). The Type combines a mesh covered with Material, Sound and Physics Model.

To be able to create a virtual environment in which physical dependencies between objects, similar to the real ones exist, the set of rules has to be defined. These rules form the Physics Model. The Physics Model is composed of Bodies, joints between the bodies (Joints), and the engines and motors (Motors). Each body defines a shape (Shape) and describes its physical properties such as static friction, dynamic friction, center of gravity, the material (based on the calculated mass). The shape of the body consists of several basic shapes (Shape). Basic shape may be one of the structures such as rectangular, capsule, sphere, and mesh (Mesh Triangle) - which in a non-commercial version of the engine have been blocked. It is an important limitation, as it was impossible to construct clavichord physics using the mesh of the instrument model. Instead the model of the instrument (casing, keys, cover, drawer and others) was constructed in the 3d studio Max using exclusively cuboids. Some additional objects contained information concerning rotation axis of keys and places, in which lid hinges were placed. The NeoAxis engine is not equipped in the tool that would enable the export of physics models from the 3ds Max, that is why a special script, MaxScript, describing cuboid data in the text file, was created. Then the "raw" data representing shapes were re-writen to the file with the notation concordant with the description of the model in the NeoAxis engine.

NeoAxis engine is equipped in a system simulating physics phenomena. Initially the hand and fingers models constituted a complex system of bones joints, and motion engines of ServoMotor type. However due to some unacceptably long reaction times the function of bending had to be created from scratch. The following operations were created: moving and rotating a hand and fingers as well as bending fingers. These operations demanded from the system co-sharing additional information describing the intermediate states of the elements of the object.

4.3 Implementation of the Mechanism Controlling the Glove and the Tracker

The control mechanism of input devices converts data coming from the tracker and from the glove in such a way as to allow visual mapping of the location, slope and a state of the user hand. Received data are subject to transformation according to the calibration data.

All glove sensor data are standardized in such a way that the value equal to 0 responds for the natural flexion of the finger. Maximum flexion of the finger responds to the sensor value equal to 100%.

4.4 VClav2.0 in Use

The main interface to the system is composed of the Data Glove and the Tracker. The keyboard is used for some basic commands. Moving a virtual hand is accomplished by moving the user's hand, on which the tracker sensor is placed. Bending virtual fingers is realized by bending the fingers of the user hand wearing 5DT Data Glove.

Navigating in the virtual world is via a virtual white hand in two modes:

– a 3D clavichord model manipulation,
– playing the instrument.

In the first mode the virtual hand opens the lids of the instrument. To enter into the playing mode the user has to press [SPACE] on the computer keyboard. The camera is moved over the keys and fingers may push the keys to play the instrument. (Fig. 4). Consecutive pressing [SPACE] will restore the view of the whole instrument.

Pressing the key by the finger of the virtual hand in playing mode causes its rear part to rise so the tangent hits the string. In real instrument the string is set into vibration and the sound is produced. In the virtual version the sound is played from samples when the rear part of the virtual key reaches the appropriate height.

Fig. 4. The scene view in a *play* mode

5 Conclusions

The goal of the project presented in this paper was to popularize the valuable 18th century clavichord of Johann Adolph Hass, that will never be playing in a reality due to its severe damage. In the search of the method to virtually present the clavichord, its construction and the way to generate sound, the idea was realized, to make the virtual 3D copy of the instrument and to equip the user with the virtual data glove to enable him/her to virtually play the instrument. VClav 2.0 system has been built powered by the NeoAxis game engine and equipped with 5DT Data Glove 14 and Polhemus Patriot tracker. Since the NeoAxis engine was applied in its non-commercial version, several functions were programmed from scratch. A series of user tests were accomplished including public active demonstrations. VClav 2.0 found appreciation of both – users and the staff of the Museum of Musical Instruments. However the data glove appeared not enough sensible and precise to make the user feel comfortable while touching keys. The results seem promising for further development of the project which will go towards more robust solution.

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