An Approach for the Visualization of Crafts and Machine Usage in Virtual Environments

Evropi Stefanidi, Nikolaos Partarakis, Xenophon Zabulis
Institute of Computer Science, Foundation for Research and Technology – Hellas (FORTH)
Heraklion, Greece
email: {evropi, partarak, zabulis}@ics.forth.gr

George Papagiannakis
Institute of Computer Science, Foundation for Research and Technology – Hellas (FORTH) &
Department of Computer Science, University of Crete
Heraklion, Greece
email: papagian@ics.forth.gr

***Abstract*—Despite the cultural, societal, economic and traditional significance and value of Heritage Crafts and Intangible Cultural Heritage, efforts towards their digital representation and presentation, and subsequently their preservation, are scattered. To that end, this paper proposes an approach for their visualization in Virtual Environments, within which the practitioner is represented by a Virtual Human, their actions through animations resulting from Motion Capture recordings, and objects through their 3D reconstructions. Our novel approach is based on a conceptual, twofold decomposition of craft processes into actions, and of the machines used into components. Thus, in the context of this paper, we have developed a pipeline that delivers a Virtual Environment, through which a wide range of users, from museum curators and exhibitors, to everyday users interested by a craft, can experience craft usage scenarios. Via our visualization pipeline, we claim that we deliver an efficient way of visualizing craft processes within Virtual Environments, thus increasing the usability and educational value of craft representation, and opening the way to a variety of new applications for craft presentation, education and thematic tourism. In the scope of this paper, we focus on the Heritage Craft of loom weaving; however, our approach is generic, for representing any craft, after its decomposition according to our technique.**

Keywords-Machine Usage Visualization; Heritage Crafts; Cultural Heritage; Motion Capture; Virtual Humans.

I. Introduction

Heritage Crafts (HCs) involve tangible craft artifacts, materials and tools, and encompass traditional craftsmanship as a form of Intangible Cultural Heritage (ICH). Intangible HC dimensions include dexterity, know-how, and skilled use of tools, as well as identity and traditions of the communities in which craftsmanship is, or was, practiced [1].

Regarding their digitization, the advances in the 3D digitization of the shape and appearance of physical objects (3D reconstruction) have enabled the digital representation of tangible CH elements. The selection of a digitization modality and approach is central for accurate digitization, and is facilitated by guidelines focused on the Cultural Heritage domain [2]. In order to digitize not only the tangible elements of craft, but also the actions of the practitioner, the representation of the craft needs to include intangible dimensions.

As a step towards digitizing and representing HCs, we propose a novel approach for their visualization in Virtual Environments (VEs), within which the practitioner is represented by a Virtual Human (VH), and objects through their 3D reconstructions. Practitioner actions are reproduced by animating the VH based on Motion Capture (MoCap) recordings. The appropriate simulation of VHs is an important aspect, since crafts are practiced by humans and machines are designed for use by them. At the center of the proposed approach is a conceptual, twofold decomposition of craft processes into actions, and of machines into components, which include their physical interface. This is essential in the systematic transfer of craft practice from the physical to the virtual domain, while retaining realism. In more detail, this decomposition must be meaningful to allow the semantic representation of craft processes.

Using this approach, we claim that we could model a multitude of craft instances and machines, by decomposing crafts to simple motion driven operations, and machines to fundamental machine components. Thus, our contribution lies in a novel method for the presentation, representation and preservation of HCs, from which a multitude of user groups can benefit: (i) craftsmen whose work will be preserved and represented, (ii) local communities in which the craft is practiced, (iii) museum curators and exhibitors for the presentation of various traditional crafts and (iv) people without a specialization regarding Heritage Crafts, who are however interested in a HC and wish to learn more about it (e.g., tourists, teachers, school groups).

In the context of this paper, we focus on the craft of loom weaving, and describe the application of our pipeline and decomposition methodology on this craft. Nevertheless, our approach could be used for the representation of a variety of crafts, after their segmentation according to our technique. The rest of this paper is organized as follows. Section II presents a discussion of related work. Section III describes how we designed the transition of loom weaving from the physical to virtual world. Section IV addresses the details of the design and implementation of our approach, while Section V presents our conclusions and future work. The acknowledgement and references close the article.

II. Related Work

To the best of our knowledge, there is no similar work regarding the digital representation of Heritage Crafts – or

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crafts in general - via the utilization of Virtual Humans, MoCap and 3D reconstruction; nor did we find other work that proposes the conceptual decomposition of crafts and machines used. Our approach is an extension of the work we conducted in [3], which presented a pipeline for the demonstration of tool usage for handicrafts and hand-held tools, to the world of HCs. In this paper, we take our research a step further, by focusing on HCs, and including all the steps that are needed, including interaction with craftsmen, in order to deliver a successful result for accurate representation of a HC. Therefore, in this section we present the related work we found regarding: (i) Virtual Humans and their use and importance in 3D applications, and (ii) tools for tool usage demonstration.

With respect to VHs, they constitute an important aspect of 3D applications, since humans can familiarize themselves with human-like characters. They mainly play the role of narrators [4] and virtual audiences [5]. In the context of VEs, they have already been used for explaining physical and procedural human tasks [6], simulating dangerous situations [7], group and crowd behavior [8], and assisting users during navigation, by pointing relevant locations and positions and providing users with additional information [9]. They can also play the role of a tutor, acting as an embodied teacher, enabling an individualized instruction for a massive number of learners. In our approach, they are used to represent HC practitioners, by demonstrating craft processes.

Regarding tool usage demonstration, M.A.G.E.S ™ [10] is a platform facilitating just that, by introducing an SDK for VR surgical training. It also includes a plugin for manipulation of tools in VR environments, which allows developers to transform any 3D model of a tool (pliers, hammer, scalpel, drills, etc.) into a fully functional and interactive asset, ready to use in VR applications. After the tool generation, users can interact with it in the VE and use it to complete specific tasks following recorded directions. Another tool is ExProtoVAR [11], which allows non-technical users to generate interactive experiences in AR.

With respect to the related work, we propose a novel approach that utilizes the concepts of Virtual Humans and demonstration of tools in VEs, but in the context of presenting and representing Heritage Crafts, so as to aid in their representation and preservation. To that end, we utilize 3D reconstruction to digitize the machines and tools used for each craft, and MoCap recordings for the actions of the craftsmen. Moreover, we induce the motion of the tools and machines from the human motion, by applying mathematical formulas for the simulation of the tool motion, and for the correct attachment of the tools to the corresponding body parts which should use them. Our contribution also entails the segmentation of the craft process into its essential parts, and the decomposition of the machines used into basic parts which we call Fundamental Machine Components.

III. Designing the Transition of Loom Weaving from the Physical to the Virtual World

The proposed design process for the representation of machines entails the conceptual decomposition of craft processes into actions and machine components. To facilitate presentation, the use case of loom weaving is considered.

It is essential that craftspersons are centrally involved in the conceptual decomposition, to provide functional insight and emic understanding of the represented process. In this case study, we collaborated with the practitioner community of the Association of Friends of Haus der Seidenkultur (HdS), Krefeld, Germany [12] (Figure 1), within the context of the Mingei EU H2020 Innovation action [13]. HdS provided descriptions and testimonies and allowed us to record functional demonstrations (MoCap, Video) of the practitioners, so as to perform careful observation and analysis of the craft. At the same time, collaborative sessions enabled craft understanding and provided insight from the perspective of the practitioner, towards a meaningful decomposition. Context definitions for our use case were then created, which are provided below, and are visible in Figure 2.

Figure 1. Co-design session at HdS.

Figure 2. Loom components.

Yarn is a continuous length of interlocked fibers, produced by spinning fibers into long strands. *Warp and Weft* are the horizontal and vertical threads of a fabric. *Weaving* is the process of yarn transformation to fabric; vertical warp threads (warps) are held in tension on a loom, while weft is perpendicularly interlaced, fastened in-between elevated (upper) and lowered (lower) warps. A *loom* is a piece of machinery that facilitates weaving. The configuration of upper and lower warps (or the weave of the fabric), determines the structure of the woven fabric. *Shed* is the space due to the temporary separation of upper and lower warps. A *treadle* is a loom lever that mechanizes shed creation. A *shuttle* is a device used to interlace weft through upper and lower warps. Finally, a *beater* is a tool used to fasten the weft to the warp.

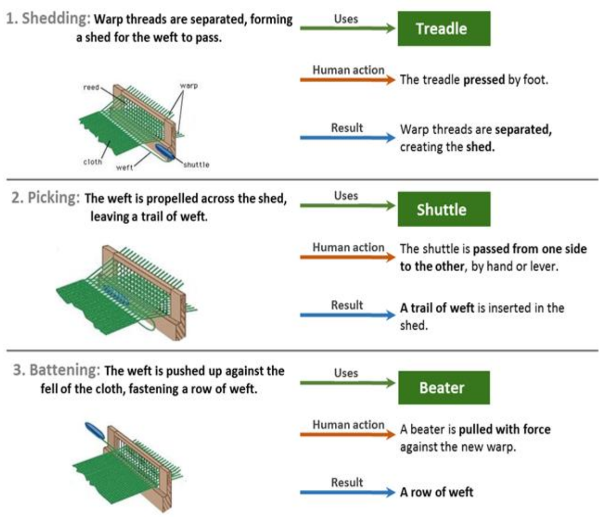


Figure 3. Storyboard of the three stages of weaving and the machine parts involved.

Central to the process is the *loom* machine, which retains warps at tension, to facilitate the thread-by-thread interlacement of weft through them. There are several types of looms. In the conventional loom, weft is introduced using a shuttle. Each thread of weft is fastened by a beat of the beater [14].

Regarding our approach, the weaving process was decomposed into 3 actions, repeated for each thread of weft [14]: (i) *Shedding*: warp threads are separated to form a shed, (ii) *Picking*: weft is passed across the shed using the shuttle, and (iii) *Beating*: weft is pushed against the fabric using the beater. The decomposed loom interface components are the shuttle, treadle and beater, depicted on the left side of Figure 2. Initially, textual descriptions were created collaboratively for each action, which also identified the machine interface components and human body parts used to operate them.

We thus developed an analytical way to visually and textually represent a process comprised of actions performed on objects and machine interface components. In this collaborative process, the need for a representation that is intuitive to the practitioner and analytical enough for a semantic representation of the process was identified. To that end, storyboards were selected as a methodological approach to address this need. The weaving process was encoded as a sequence of actions and reviewed by the community of practitioners, finally producing the storyboard visible in Figure 3.

This decomposition of the weaving process contains the interplay between human motion and components of the physical interface of the machine. To meaningfully represent the machine interface, we decompose it in elementary components, called Fundamental Machine Components (FMCs). These FMCs are rigged 3D models enhanced with functionality that simulates their motion, as described in Table I.

IV. Design and Implementation of our Approach

The proposed approach is generic towards the transfer of knowledge on machine usage to Virtual Environments. To that end, we segment the recordings of practitioners during machine usage into actions and categorize them by introducing them as items in a *Motion Vocabulary* (MV). At the same time, we decompose elements of the physical interface of Machines into FMCs. Thus, we call a *Motion Vocabulary Item* (MVI) an entity that represents an action, or part of an action, and contains a motion recording and possibly a reference to an FMC.

The steps of the pipeline for the proposed approach are the following:

- Involvement of craftspersons in the conceptual decomposition, to provide functional insight and emic understanding of the process to be represented.
- Decomposition of machine interface components.
- Acquisition of machine 3D model.
- MoCap of operators using the machine.
- Implementation of a VH.
- Segmentation of MoCap recording into a MV.
- Retargeting of recorded motion to the VH operating a 3D model of the machine. While human motion is recorded in MoCap files, we do not have MoCaps for the FMCs, because it is simpler and more cost-efficient to induce the machine motion by combining the mechanics of the FMC and the human motion from the MoCap. Moreover, in this way, we avoid the intervention and instrumentation of machines, which could alter their usage.
- Visualization of modeled process.

The following sections present the implementation of the proposed approach for the case study of loom weaving.

A. MoCap

The motion of practitioners was recorded in MoCap animation files, using a NANSENSE R2 [15] motion capture suit, during MoCap sessions.

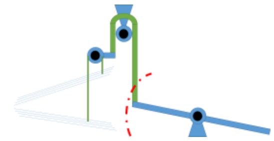
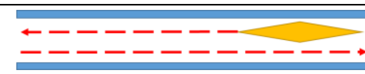
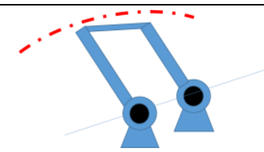
B. Loom Model Acquisition

Often the machine is extremely difficult to reconstruct, due to its placement in the constrained environments of workshops and museums. As this was the case with the looms we had at hand, we used a basic loom model found at [16] to demonstrate our approach. Of course, any 3D model of the machine could be used.

C. Virtual Humans

The VHs that reproduce the recorded actions are 3D Avatars. In this case study, the VH was created in *Poser Pro 11*, and then imported to our development platform (*Unity3D*).

TABLE I. DECOMPOSITION OF LOOM WEAVING INTO STEPS

Steps	Action	Result	Design of the FMC[a]
Shedding	**Treadle** is pressed by **foot**.	**Warp threads** are separated, by the press of the **treadle**.	
Picking	The shuttle is passed from one side to the other by **hand**.	A **row of weft** is created by a pass of the **shuttle**.	
Battening	The **beater** is **dragged** with force on the new warp.	Weft row completed using the **beater**.	

a. In the figures, dashed lines plot the feasible induced motion trajectories.

D. Motion Vocabulary

The next step entails the decomposition of the process of loom weaving into actions. Thus, we edited the MoCap animation files, to correlate the motion segments (MVIs) to the conceptually decomposed actions. These segments are considered building blocks of the weaving MV, which is the basis of sequences, or "sentences", encoding weaving processes.

E. Loom Machine Abstraction

We then proceeded with defining the elements of the physical interface of the loom as FMCs. Each one is comprised of (i) a 3D model of a machine part, and (ii) motion rules that represent the feasible, induced motion of the FMC during its operation.

F. Association of Virtual Humans and FMCs

Machine interface components, represented as FMCs, are associated with the VH body part(s) that are used for their operation (e.g., treadle with foot, shuttle with hand, beater with both hands). We first establish a pairing between the FMC and a point on the Avatar. Subsequently, the preferred grip posture is defined. For this purpose, we employ the following entities:

- Avatar *A*, with skeleton *S*, is comprised of joints and skin *T*. Skin *T* is a, possibly textured, deformable 3D surface, represented by a mesh of triangles. When *A* is animated, *T* deforms according to the motion of *S*.
- Two grip points, g_L, g_R on *T* encode the grip center for the left and right hand respectively. These points are selected with respect to the FMC, as objects may not always be held in the same way.
- Each hand has a reference frame based on orthogonal unit vectors. These are u_x^L, u_y^L, u_z^L, for the left and u_x^R, u_y^R, u_z^R for the right. The center of the frame is selected at an anatomically meaningful location.
- An FMC has a reference frame based on u_x^M, u_y^M, u_z^M, which are orthogonal unit vectors for the FMC. Each FMC is centered at its centroid.
- The FMC has a preferred usage position (e.g., grip, foot position). This position may not be unique.
- A posture *p* is comprised of (i) a configuration of the joints of *A*, (ii) a preferred location and (iii) orientation of *A*'s body members, for FMC usage.
- An animation is a transition from a posture to another, represented by a sequence of states of the *A*'s joints.

A *preemptive posture* is the preferred for *A* posture at the first moment of the FMC usage. A preemptive animation is an animation that brings *A* to the preemptive posture.

For our case study, we define the following concepts:

- Loom *L* is represented by a mesh of triangles, encoded by its vertices, l_v, and its triangles, l_t.
- *TRE*, *BEA*, *SHU* are FMCs for the treadle, beater and shuttle, respectively.
- Points b_L and b_R on the *BEA*, denote the grip locations of the left and right hands.
- Animations p_L and p_R, for preemptive usage postures for the *BEA*, for the left and right hand.
- Preemptive usage animations f_L and f_R for the placement of the left and right feet on *TRE*.
- Point d_a on *TRE* at the center of the area that the foot is pressing on the treadle. Preemptive usage postures s_L, and s_R encode shuttle grip by the left and right hand.
- Point u_s on *SHU* (shuttle centroid).
- MV for Loom Weaving MV_{LW} contains MVI_{TRE}, MVI_{BEA} and MVI_{SHU} which are the treadle, beater and shuttle animations (encoding human motion but not machine motion):
  - MVI_{TRE}: treadle pushed down and released.
  - MVI_{SHU}: shuttle pushed from left to the right and vice versa.
  - MVI_{BEA}: beater pulled towards the operator for a beat, then pushed away.

- Animation function *AN(A/FMC,* Posture) which animates either the *A* or FMC according to a MVI.

A scene is the VE where the *A*, FMCs and objects are instantiated, and the FMCs, *L*, and *A* are brought to the reference frame of the scene. This is achieved by appropriate *rotation R* (encoded as a 3x3 rotation matrix), a translation *t* (encoded as a 3x1 matrix) and a scaling *s* transformation for each component, once and prior to their import in the VE. Each 3D point, let *q*, of the object's 3D model undergoes transformation $R* sq + t$, where * denotes matrix multiplication. The transformations are individual for each of the FMCs, loom and *A*, and are denoted as R_T, s_T, t_T for the treadle, R_S, s_S, t_S for the shuttle etc.

G. Induced Machine Motion

Induced machine motion was simulated as follows:

1) Principle of induced motion.

Let avatar *A* at the preemptive usage posture of an FMC. We consider the execution of a *MVI* by *A*, during a time interval. The motion of the FMC due to the MVI is called *Induced Motion* of the FMC. We propose a synchronization method of the FMC's motion with that of the VH for each MVI, based on the feasible induced motion trajectory of the FMC.

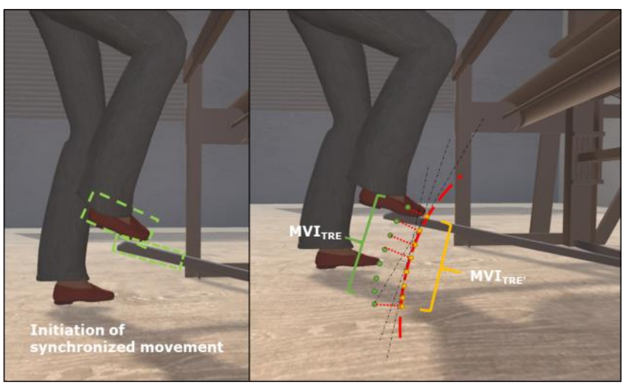


Figure 4. Visualization of the foot pressing the treadle.

2) Treadle Motion.

Treadle motion is performed by execution of MVI_{TRE} and denoted as $AN(A, MVI_{TRE})$. The treadle is moved when the bounding box of the *TRE* collides with the foot of the Avatar. The virtual motion is achieved through a function $TRE'=AN(TRE, MVI_{TRE}')$, where MVI_{TRE}' contains the projections of MVI_{TRE} to the motion trajectory of *TRE* (Figure 4).

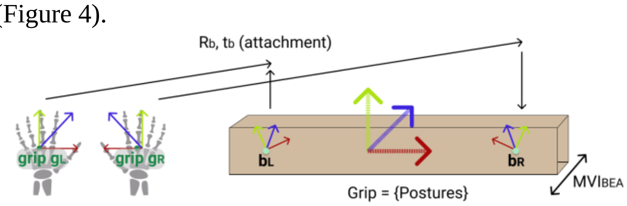


Figure 5. Attaching the hands on the beater.

3) Beater Motion.

The preferred posture of A's hands is reached by animating *A* using a preemptive animation, so that $A'=AN(A,p_L)$, $A'=AN(A,p_R)$. Hand motion is performed by MVI_{BEA}' through function $A'=AN(A, MVI_{BEA}')$ and loom motion through $L'=AN(L, MVI_{BEA}')$, where MVI_{BEA}' contains the projections of the grip points to the motion trajectory of *BEA* (Figure 5).

4) Shuttle Motion.

Shuttle motion MVI_{SHU} is simulated through function $A'=AN(A, MVI_{SHU})$, while the attachment of the shuttle to each of the hands of the Avatar is performed by $A'=AN(A', s_L)$ and $A'=AN(A', s_R)$ for the left and right hands respectively (shuttle is exchanged between the hands) (Figure 6). The motion of the shuttle is represented as $L'=AN(L, MVI_{SHU}')$, where MVI_{SHU}' is modeled as a constant linear motion, between the starting point of the *SHU* feasible induced motion trajectory and its ending point, and vice versa.

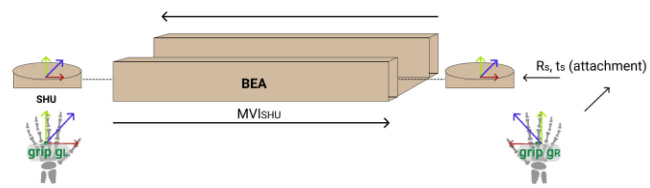


Figure 6. Attaching the hands on the shuttle.

Figure 7. Visualization of the result: the VH is operating the loom.

V. Conclusion

This work presented a novel approach for the representation of machine usage by Virtual Humans in Virtual Environments and described its implementation for the case of loom weaving. Resulting from our pipeline, the visualization of an Avatar using the loom are visible in Figures 7 and 8, with Figure 8 focusing on the treadle operation. The proposed approach allows for further configurations to facilitate the representation of other crafts including machine usage.

The application of our approach on the craft of loom weaving allowed us to have an initial validation of our pipeline, in the context of the described experiment; however, it is imperative, and part of our immediate future plans, to conduct an evaluation with craft experts, to have their verification. Subsequently, and after any necessary changes stemming from their feedback, we will evaluate our system with users from various target user groups, such as

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museum curators, exhibitors and non-craftspeople, such as tourists. Finally, we aim to further generalize our approach, by including new Fundamental Machine Components in our framework and studying new crafts and techniques.

The genericity of the approach stems from the reusability of the main components of the proposed pipeline. Motion Capture technologies can be used to record any human operation involving the usage of tools and/or machines. Furthermore, our approach of decomposing a machine in Fundamental Machine Components allows us to define different components used in different operations to achieve different results. The binding of such components with process-specific knowledge adds to the novelty and reusability of our approach.

Figure 8. Detail of the foot of the VH operating the treadle while loom weaving.

As a second use case where the proposed approach is being applied, efforts are already being put towards representing the hand-based craft of mastic cultivation, practiced in the island of Chios, Greece, utilizing the pipeline described in this paper. Namely, after having performed Motion Capture of the mastic cultivators' movements, we are now in the process of segmenting the actions in their elementary parts, as well as digitizing the tools used with their corresponding motions. The overarching goal is the capability to represent and present a plethora of crafts, thus contributing to Heritage Craft presentation, representation and valorization. At the same time, our proposed pipeline presents opportunities for use cases that go beyond the field of Cultural Heritage, as it could be used to model various handicraft actions, e.g., using garden tools or assembling furniture, by decomposing them into their fundamental actions and components, according to our methodology.

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