STUDY ON APPLICATION OF MOTION CAPTURE TO DESIGN METHODOLOGY FOR GENERATING NEW GEOMETRY

Coupling Computer and Human Performance Using Motion Capture Technology for New Architectural Form and Space

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Abstract. This research aims to develop fundamental design methodologies for human space and product design by motion capture of human activity. It is intended to generate new geometry using a motion capture system as design input device and then to develop it to design interior space and products such as furniture from data extracted from human motion. In order to produce a ubiquitous and comfortable environment, performance modeling focusing on the relationships between space and physical motion is needed. Making an object of complex shape is thought to be a new application of motion capture technology. This research proves that the numeric data of body actions can be transferred and developed to object shapes.

Keywords. Motion Capture: Inclusive Design; Ergonomics; Design Process; New Geometry.

1. Introduction

The purpose of this research is to develop fundamental design methodologies using motion capture technology that will help generate new architectural forms and spaces that are not possible using conventional design methodologies and processes. Characteristics and feasibilities of the forms and spaces extracted from human performance and reconstituted by the proposed methodology are to be examined.

1.1. MOTION CAPTURE FOR DESIGN

Motion capture is a technique of digitally recording movement in 3D by detecting optical markers worn by an actor/performer. It is currently used mostly in animation tools for gaming programs and movies, and in sport sciences, manufacturing, and medical disciplines. It is rarely used, however, in the field of architecture and product design as an object data input device, and here the use of motion capture has been limited to rationalizing and optimizing space for human actions such as car driving. Most of the research using motion capture is in the visual disciplines and related disciplines. As early as the 1980s, the MIT Architecture Machine Group experimented with optical tracking of the human body for the design of space and the study of ergonomics (Sturman, 1994). The potential of motion capture and tracking has been demonstrated as follows:
- in the design of automobiles (Stephens, 2006) and for the *Kaizen* or improvement of automobile production (Kuriyama, 2006, and see Figure 1 below),

- for the development of virtual environments and simulation of human action in the virtual environments (Caputo, 2007),
- for designing assistive devices for physically challenged and aging populations (Kumar, 1997),
- for capturing, analyzing, and archiving traditional dance performance (Yamura, 2002), and
- for development of highly customized products and simulation of their manufacturing process (Tseng, 1998).

Figure 1. Evaluation and improvement of automobile production line.

As seen in the above, there is a lot of research involved in extracting and analyzing human action in the fields of robotics, virtual reality, and health care, and in line with recent development of computer technology many of the applications are now actually in use. Motion capture is rarely used as a design device, however. While it is used to analyze human action to develop kitchen design (TOTO), it mainly focuses on areas of action and rationalizing action, and it is hard to say that it is related to the design of the kitchen directly. There is one case that uses motion capture as a direct design input device, called Sketch Furniture by the Swedish design group FRONT (http://www.frontdesign.se/). They experiment with motion capture to design virtual furniture (such as tables and chairs in the air), and with rapid prototyping to embody virtual furniture. Unlike the ordinary process by which furniture is materialized through design studies using 2D drawings and models, in their process trajectories that their hands draw are directly transferred to the shape of furniture, which has a one-of-a-kind nature produced out of their interaction with the space. But this is one of the rare cases of trying to generate forms directly using motion capture for design.

1.2. RESEARCH BACKGROUND

From this overview of the applications of motion capture technology to design, it is possible to say that it is rarely used in the field of architecture and product design to lead to the objective design of products. Research and projects on motion capture are usually about simulating how human action can be efficient or how operability can be improved under somewhat restricted conditions or how existing processes can be streamlined, such as by the use of rotoscoping animation (Sturman, 1994). In the architectural discipline, it also focuses on how to remove unnecessary action and sources of danger rather than directly capturing human action and generating geometry out of the captured data.

The present research aims to develop fundamental design methodologies for architectural and product design involving motion capture technology. In addition, in the current process from design to production, some parts of the user’s needs for the product may be missed or modified during the course of the process, particularly when the designer translates the user’s design requirements (Figure 2). If motion capture can directly translate the user’s needs that are based on her/his conditions and mobility into physical forms, it may be possible to minimize the chances of missing information. It is also intended to examine the difference between the shapes generated by intentional and arbitrary actions.

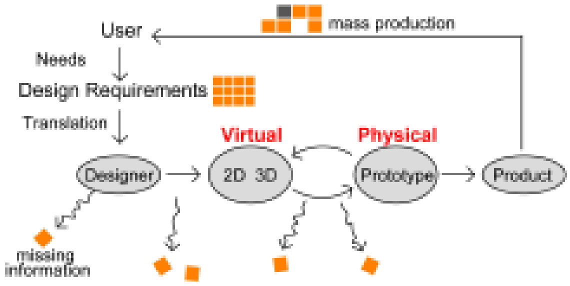


Figure 2. Current process: some information may be missed or modified.

1.3. RESEARCH MODE

In order to embody architectural form and space out of fundamental performance using motion capture technology, the research examines how to generate new geometries out of human performance. To achieve the final objective of designing and constructing ubiquitous and comfortable space, the geometries will be evaluated from two different aspects, physical and virtual views. First, captured data are transferred to computer graphics (CG) software to reconstitute them into virtual prototype (VP), and the prototype is evaluated visually and technically using the analysis function of the software. Then it is materialized using rapid physical prototyping (RPP; a 3D printer is used in this research) and further evaluation is carried out using this actual/physical and tactile model from aesthetic and functional viewpoints (Figure 3).

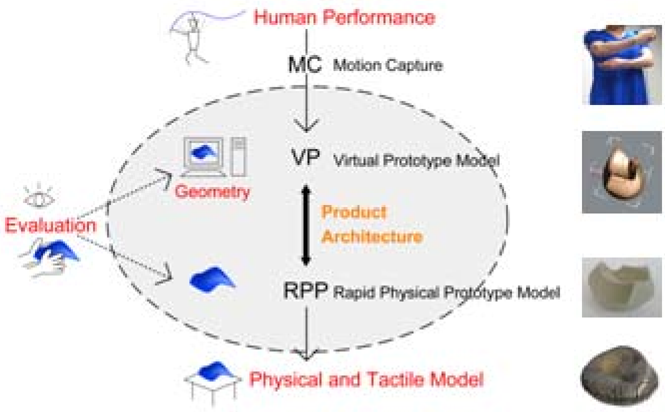


Figure 3. Shape-generating process and evaluation.

As for the design process, because the development of the process that incorporates VP and RPP is a key to establishing a methodology to generate a new geometry, their effective combination is to be examined. In the next step, two types of geometries are generated by human action to examine how the process can be altered. One of the experiments is how to embody alternative design of a corridor. Most buildings employ orthographic design, though various architectural designs of complex shape have been experimentally developed. With this logic, corridors are designed functionally straight and we are forced to walk along this straight lane. If we should successfully construct corridors out of the human action of walking, how is the shape of the corridors altered?

1.4. EXPERIMENTAL ENVIRONMENT, TECHNOLOGY AND DEVICES

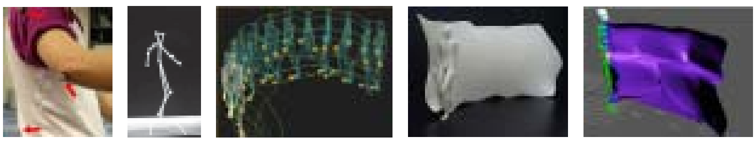
In this research, the actual experiment uses facilities of the in-house Information Research center's motion capture room at Toyohashi University of Technology. Machines and tools for the motion capture:

- Vicon data station; Vicon workstation software
- Analysis software (BodyBuilder)
- Optical cameras (12 sets) (Figure 4c)
- Calibration apparatus
- Reflection markers (15mm in diameter)
- Capture space
- Testee performer

2. Experiment 1

2.1 FORM GENERATED BY WALKING ACTION

As the first step in generating form out of the human body and action, the action of walking is captured and tracked as a basis of geometry. Simple walking movement is captured and its trajectories are transformed to surface geometry. Walking is one of the most basic human actions and is thought to be suitable for the first step of this research. Before capturing actual human action, a simulation is carried out as a preliminary experiment using CG software in the same settings as is done with actual motion capture. It is intended to generate geometry not by the conventional concrete units but by the dimensions of the individual human body and her/his performance, and then to apply the methodology to creating architectural space. The process is composed as follows (Figures 5a-5e):
1) Optical markers are put on joints (indicated by red arrows in Figure 5a).
2) The subject walks around inside the detectable area, with the action captured along a timeline.
3) Captured data of action are imported to the "BodyBuilder" analysis software and the data are examined and adjusted (Figure 5b).
4) The data are again transferred to the "3ds max" CG software to connect trajectories of walking action and generate a surface for constructing a virtual prototype (Figure 5c).
5) Out of the same data, a rapid physical prototype is produced to check visual and aesthetic quality (Figure 5d).
6) The surface is also animated along the timeline to simulate how a new geometry might construct space (Figure 5e).



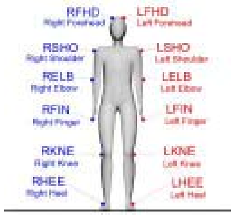
5a 5b 5c 5d 5e

Figure 5a-5e. Process of generating geometry.

2.2. RESULT OF SIMULATION

Figure 6a shows a surface that is generated by the CG software simulation out of the trajectories made from S-curved walking by a testee/performer who wore markers on the right side of her body. Optical markers were placed on the right heel, right knee, right finger, right elbow, right shoulder, and right forehead as shown in Figure 6b.

6a



6b

Figure 6a and 6b. Surface generated by the action of S-curved walking.

2.3. FINDINGS

As Figures 7 and 8 show, the surface generated by simulation of motion capture of the human action of walking resulted in complex and somewhat disfigured geometry. It proves that even walking, one of the fundamental human actions, can formulate complex shapes out of various motions including rolling of body, swinging of arms, and stepping of feet. Humans, therefore, draw 3D geometry in space accidentally and unconsciously, which indicates the possibility of using motion capture technology as a design tool. Due to differences such as height, weight, and ways of walking, the geometry may differ from person to person. Nonetheless, while it is complex in shape, as long as the width of swinging arms and cycle of stepping are constant some laws of how the surface is constructed can be found. If one did not know that the surface was generated by human walking action, it might seem like something that had been created intentionally.

Figure 7. Detail of walker's surface. *Figure 8. Physical and tactile RPP model of surface by 3D printer.*

3. Experiment 2

3.1. FORM GENERATED BY INTENTIONAL ACTION

In the previous section, experimental simulation proved that from human action such as walking, motion capture can generate complex geometry that is different from geometry made by the conventional method, and may be applicable to architectural design. It is, however, necessary to construct not an arbitrary form but a concrete form in case it is necessary to use the form to design products for specific needs. To meet this goal, experiment was carried out using an actual motion capture system, for which a testee/performer wore optical markers on four points of her right arm (shoulder, elbow, wrist, and finger) as seen in Figure 9a and drew an intentional form in the air. Her motion was captured every 0.01 second (Figure 9b). Each trajectory of the marker has coordinates along the timeline (Figure 9c), and the coordinate information was transferred to CG software to construct a surface (Figures 9d and 9e).

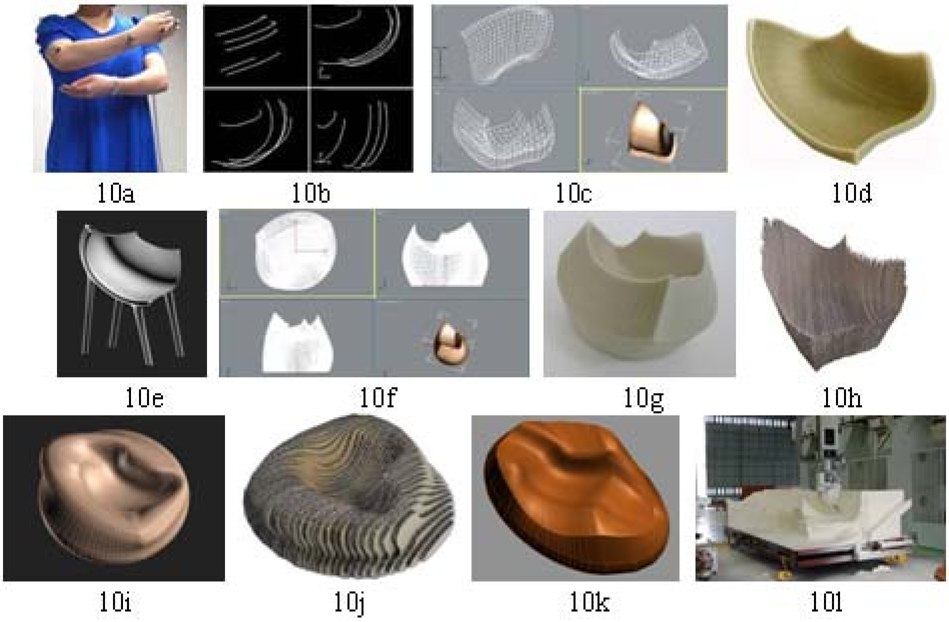
9a 9b 9c 9d 9e

Figure 9a-9e. Generating form with intentional action.

With this process it is possible to extract trajectories that humans draw in the air and construct a surface directly out of them, which can liberate the design process from conventional drafting implements and mouse connected to the computer for some parts. It allows prototyping the desired form fairly faithfully, and the effectiveness of the motion capture system as design input tool is verified.

3.2. DESIGNING A CHAIR

Based on the above preliminary experiment, an empirical experiment of designing a shape for an easy chair is underway. The motion that is captured and extracted is that a mother is dandling her baby in her arms. From this motion a surface is generated to become a bearing surface of the chair with which a chair is designed. The process is described in the figures 10a-10l.



Figures 10a-10h. Generating form for an easy chair from the motion of a mother holding a baby.

1) Extracting a dandling motion by acquiring xyz coordinates from markers placed on the arms (Figure 10a).
2) From the xyz coordinates, trajectories are generated using 3D-CAD software (10b).
3) Out of the trajectories, a surface is generated as a basic object for the bearing surface of the chair (10c).
4) The surface is transferred to RPP model using 3D printer to examine the shape (10d). This physical mockup is used to verify the shape from both aesthetical and functional point of views (10e and 10f) and altered according to the evaluation.

5) A cradle-like chair is designed encompassing the surface and the shape is verified using RPP mockup (10g).

6) Full scale model was made using cardboards for test and evaluation (10h).
7) Based on the evaluation of the above full scale model, the design is modified (10i) and evaluated by the laser-cut model (10j).
8) Then again the design is altered (10k) and the data of the model is sent to the collaborator shipbuilder for 5-axis-CNC-machine milling (10l) to embody this shape.

4. Conclusion–new theory of form generation

This research-in-progress proves that form can be generated by capturing and tracking trajectories of human action. In the existing architectural design process a designer plays a leading role to design shapes through their interpretation of the design requirements of the actual users in which it should be difficult to capture the real needs of them and materialize the needs. In addition, during the course of representing the idea of the form in drawing format and then going on to the production phase, the original idea cannot always be embodied as intended. Contrarily, in the process that adopts motion capture, shapes that may be difficult to design by conventional methods may become possible without losing critical information. In addition, because unlike conventional process even people who have no design background can represent their design ideas easily, it may lead to manufacturing customized products according to their body shapes and health conditions, which will contribute to designing not only ordinary products such as furniture but also assistive devices for physically challenged and aging people (Figure 11 for the alternative design process that incorporates motion capture). Although this research is in its early-mid stage, once this methodology is established it is expected to become one of the useful methodologies for generating new form and space.

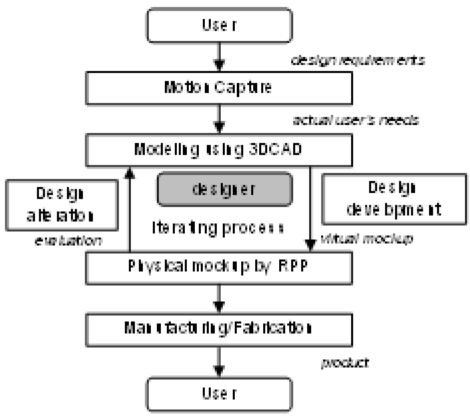


Figure 11. Alternative design process.

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