CONDUCTING FORM

THE USE OF GESTURAL HAND MOVEMENT AS A PART OF THE DIGITAL DESIGN TOOL-SET.

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This paper describes a practice based research project undertaken at the Autonomatic Digital Research Cluster at University College Falmouth.
The project explores how new design interfaces can be developed by investigating the possibility of using gestural hand movements in combinations with digital design and development tools.
This concept is inspired by some of the core elements from traditional creative practices. These elements include the direct intuitive interaction the maker have with form during the creating process and the use of the hand as the primary creative tool.
The paper centres on the investigation of two different types of equipment. The Microscribe® G2L – a digitizing arm, and the ShapeHandPlus™ motion capture data glove.
The investigations established several possible applications which resulted in range of finished products.
The findings of both investigations are compared and critically reviewed by the author.

INTRODUCTION

When Malcolm McCullough in 1996 published his seminal book, ‘Abstracting Craft’ on the development of information technology as a creative medium, his opening chapter was titled: ‘Hands’ - here he makes the case that the human hand is vastly under utilized in the emerging digital toolset.
Even though digital technology has developed dramatically since the publication of McCullough’s book very little seem to have happened in terms of how most creative professionals interact with these tools.
This research’s objective is to investigate the creative possibilities of integrating the I ntuitive use of hands with the vast creative potential of digital tools. An aim within this objective is to develop feasible applications for this concept in professional creative practices.
An aim of the research is also to explore how the evidence of ‘human hand’ from the creation process can be clearly reflected in the finished pieces. By this it meant the minor imperfections that is such a humanizing part of the handcrafted object. In contrast digital media offers ever increasing creative possibilities with the captivating prospect of absolute perfection but these new possibilities can often lead to creations based on very formal geometry.
This research seeks to explore the possibilities of using new technology as a conduit to capture the free flowing forms generated from gestural hand movement to create physical products which aesthetically clearly reflect the evidence of the a creation process involving the human hand.

In response to these aims and objectives, this project investigates the use of two low cost systems: The Microscribe® G2L - a digitizing scribe normally used for reverse engineering (Immersion 2007) and the ShapeHandPlus™ motion capture equipment (Measurand 2007). Both systems were investigated for the use of describing shape and form freely in space, movements which were recorded as linear paths or a series of coordinated points. The recorded data was utilized for a range of design processes some of which were developed specifically for this project.
The paper describes a range of production techniques for designing and making objects in a variety of materials, pieces which are critically reviewed by the researcher in relation to: the feasibility of the design and development method, the evidence of gesture in the final form, and the aesthetic quality of the outcomes.

Drawing on the successful outcomes of this project, the paper concludes by reviewing the results, the future potential of the concept and suggesting possibilities for extending the research.

INVESTIGATIONS WITH THE SHAPEHANDPLUS™ MOTION CAPTURE SYSTEM.

THE CONCEPT OF MOTION CAPTURE (MOCAP) AND THE TECHNOLOGY USED IN THE SHAPEHANDPLUS™ SYSTEM.

The best definition of what is commonly know as Motion Capture (Mocap) is still the one supplied by Scott Dyer, Jeff Martin, and John Zulauf, in a comprehensive white paper on the subject in 1995: [Motion Capture] "involves measuring an object's position and orientation in physical space, then recording that information in a computer-usable form. Objects of interest include human and non-human bodies, facial expressions, camera or light positions, and other elements in a scene."

The concept was originally developed for the military and human medical research. During the 1980 and 1990 the technology started to be employed in the animation and film industry (Furness. 2004). Even though Motion Capture is today used in a wide range of applications, there has been little research into the use of the technology as a creative tool or conduit to use human movement to create physical 3D shapes.
There are many different methods of digital Motion Capture. The most commons ones are optical systems which rely on the use of a number of cameras to record the motion by locating the spatial coordinates by “overlapping” the recordings and thereby triangulating the positions. These systems often involve the use of “markers” which are placed on the user. The markers can take the form of active markers such as LEDs or passive markers such as small reflective spheres which rely on a pulsating projected light source to record their location in space. The family of Mocap systems via the concept of markers also includes systems relying on magnetic position location.
All of these systems have their own strengths and weaknesses, but despite many years of research Mocap remains a complicated affair, with none of the optical methods as problem free solutions. The problems include several issues, such as ‘occlusion’ (Furness 2004), which is the optical obstruction by the body or limbs of the wearer. The continual identification of which marker is which, is also a potential problem area. Another major issue is that of cost, both in terms of acquiring the systems but equally the man-hours it takes to operate them (Liverman 2004).
In addition to the marker technology there are ‘mechanical’ Mocap systems which require the user to wear physical recording devices for each joint, these are the so-called exoskeleton systems such as the Gypsy Mocap system (Metamotion 2007).
The equipment investigated in this research relies on a principle related to the exoskeleton, however instead of a mechanically moving recoding device this system, developed by the Canadian company Measurand, relies on fibre optics to record the movement of the human joints (Measurand 2007). Fibre optic tapes are strapped to the wearer and connected to recoding software on a computer. The underlying principle of the system is that the bending and twisting of the fibre optic tapes can be recoded or relayed via computer graphics in real-time. When applied to a body the level of twist and bends of the tapes can be related to human kinematics through a series of algorithms.
Some of the advantages of these fibre optic based systems are the low cost, relative robustness and the real time recording feedback.
The Shapehand™ and Shapehandplus™ is part of a range of various products based on this principle, which Measurand have supplied for a number of years.

The Shapehand™ records only the movement of the hand and individual digits, where ShapeHandPlus™ also records the movement of the arm, the hand and the fingers from the shoulder joint down. Both systems can be use as a part of a full Mocap body outfit, in pairs, or as individual pieces of equipment recording just the movement of the fingers, hand or arm respectively.

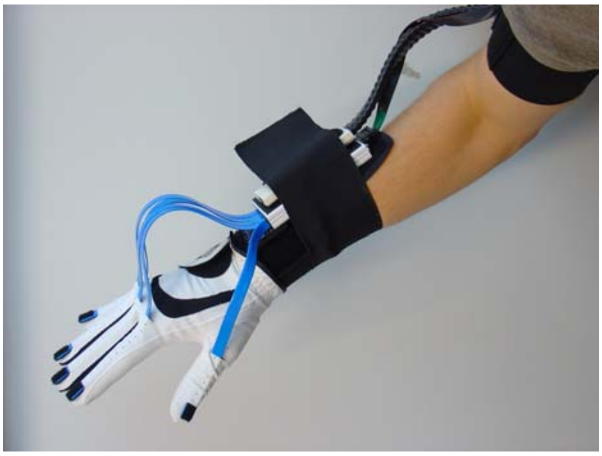

Figure 1. The ShapeHandPlus™ data glove

USING THE SHAPEHANDPLUS™ SYSTEM.

The fibre optic tapes of the ShapeHandPlus system attach loosely to the body of the wearer by Velcro straps. The tapes for the hand and fingers are attached to the end and the back of the fingers via Velcro pads attached to a generic (golfing) glove supplied with the system. The system in it's basic form connects with Measurand's own recording software (ShapeRecorder) via cables to the host computer's serial or USB port, a wireless option is also available at extra cost.

The tapes are calibrated with predetermined arm and hand positions based on the cardinal body poses. There is a comprehensive range of hand and arm positions supplied through the bundled software, but individual customised poses can also relatively easily be made up within the software to fit the individual users needs.

The data from the equipment is relayed 'real-time' as a graphical representation on screen via the supplied software which is very useful as the recording can be viewed and monitored continuously by the user.

The system is supplied with a comprehensive users guide and after a period of getting used to the system it was found relatively straightforward to set up, not quite 'plug and play' but far from the complexity reported from other systems. Apart from the occasional software glitch it was found that the system is relatively easy to operate via the supplied software.

As the focus of this research is to establish the potential use of this equipment as a general creative tool, the ease of use and the potential for a user to operate the systems single-handed is very important. This is certainly possible with this equipment, however the process of strapping the tapes to hand and arm is greatly aided if a helper is present.

RECORDING MOTIONS

Through the supplied software, recording arm and hand movement can be done in number of file formats: Cartesian coordinates, C3D marker data or 'Biovision Hierarchical Data' (BVH) skeletal data. Measurand recommends that to prevent the potential loss of data, recording should be done in the Measurand's own RAW file format and subsequently played back to be converted to other file format for export to the required application. This research project found this process of subsequent reformatting of file types time consuming and cumbersome, whereas recoding straight into the BVH file did not seem to pose any problems and no loss of data was ever experienced.

Starting and stopping the recording was found to present a real issue. The 'start and stop' of most pieces of machinery and equipment are conventionally operated by the hand or the fingers, like the example of a power tool switch. However this is clearly not a very suitable solution for this concept as all of the fingers are potentially employed as the actual creative tool. On the basic ShapeHandPlus system, starting and stopping the recording is done though a keyboard command on the host computer. In use this was found to cause some difficulties. This is especially the case if the system is to be operated by a single person, as it can be hard for the user to maintain concentration and 'flow' of the 'performance' while having to return to the host computer's keyboard to initiate and terminate each recording. Measurand can supply a foot-operated switch to help with this issue but this requires the user to coordinate with another limb.

'Excess motion' at the beginning and the end of the recording can also relatively easily be removed later in various programs, but it can be very hard to determine the intended 'start and stop' at the time of creation in a subsequent editing process. Perhaps the best solution to this problem is to develop a system which can be operated by voice commands.

As previously mentioned the ShapeHandPlus in its basic form records only the motion of the arm, hand and fingers from the shoulder down, and only in relation to the point of the shoulder. The system on its own does not have any means of registering it's overall location in space. In practical use this means that any movement of the body, the torso or the shoulder in isolation or as part of a movement is not recorded. Therefore movements which to the user appear to be large and dramatic can in the recording be much more modest if the body and/or the shoulder has also been moved in space during the recording.

In practical terms this means that the system for this concept is best utilised with the user attempting to keep the shoulder joint as static as possible, possibly aided by leaning or sitting against immovable object. However the issue can also resolved by extending the system to include motion of the shoulder in relation to the rest of the body, or using the equipment as a part of an optical or magnetically based Mocap system which firmly establishes the overall spatial coordinates for the system.

ACCURACY

At first glance the system appears to have a reasonable performance in terms of accuracy. By using the system's live feedback feature the relayed motion appears to correspond adequately to the actual movement preformed. For film and animation purposes this level of precision is probably perfectly usable, with the dramatic expressions of various gestures and movements easily recognisable.
However when attempting to use the system for this project's intended aim (as a conduit for recording hand movement to design physical shapes) - it becomes clear that the system's accuracy is less that satisfactory. Closer investigation of the graphical representations of recordings in the form of linear paths (in the IGES file format) revealed that the perceived shape describe by the user bore little resemblance to recorded paths.
The lack of accuracy in the system probably has several causes. The way that the system is fitted to the user by Velcro straps may contribute significantly to the problem, the fittings have to be loose enough ensure the user the freedom to move, whilst firm enough for the equipment to stay in place. In practice this balance is very hard to achieve, and inevitably the equipment slides off it's original position. This can be rectified by recalibrating, but it is not always clear to the user when, or if, this is necessary. The fibre optic tapes are not elastic which means that in order for the tapes to accommodate the various movements of the body, they have to compress by bending into loose 'loops', and this bending may not be consistent.
However the main course of the problem probably lies in the nature of the system relying on the curvature of the fibre optics. The Mocap application of this principle is still relatively new and one would expect the technology to improve over the coming years, although in terms of accuracy this method will probably never rival that of camera based Mocap systems.
The accuracy of the ShapeHandPlus™ system could be analysed closely by recording controlled movements via one or more conventional video cameras and synchronise these recordings with recordings from identical 'virtual' view points in motion capture software and compare the data of two sources. However the focus of this research is to investigate the potential of the general concept, a very detailed technical investigation of one specific piece of equipment therefore falls outside the remit of this particular research project.

In practical use the lack of accuracy is the main obstacle for a successful application of the ShapeHand equipment for this concept. The system does seem to register even very small movements but the exact distance, angle or trajectory appear to be much more arbitrary. This situation can be helped by compensating the movement using the live feedback on the host computer. This it is one of the system's most valuable features, not only does this facilitate monitoring of the motion continuously during the recording, it also enable the user to check the calibration of the system at any giving time. Furthermore it gives the user the opportunity to practice moves before committing to a recording.
Other ways of compensating for the equipments lack of accuracy is to record motion at alternative angle, though trials it was established that recording movement of the hand, arm and fingers diagonally across the users chest provided better result than motions moving from 'side to side' or straight back and forth.
Despite all attempts of getting good data during the recordings it appeared to be impossible to achieve files which did not need subsequent editing to make them usable the intended purpose. This editing process does present some real difficulties in relation to this research's stated aim of establishing methods of creating pieces, which aesthetically clearly reflect the evidence of the design process involving the human hand. Any editing must be kept to a minimum in order not to loose any of the 'dynamics' and small 'imperfections', which gives a genuine evidence of the maker's hand.

APPLICATIONS FOR THE PROCESS - CERAMICS

The initial idea for an application for this process was a to use the process to create a series of ceramic shapes. The link with the malleable nature of plastic clay and the predominate use of the hand as the creative tool, this application seem to be an obvious connection with the concept of this research project. A series of movements were recorded describing imagined vessels. As previously mentioned the files were recorded directly as BVH files in the ShapeRecorder software. In order to translate the movement into linear paths the files were imported into the Softimage XSI program were an animated skeletal representation of the motion allowed the trajectory of the hand and fingers to be converted into three dimensional lines in the from of IGES files.

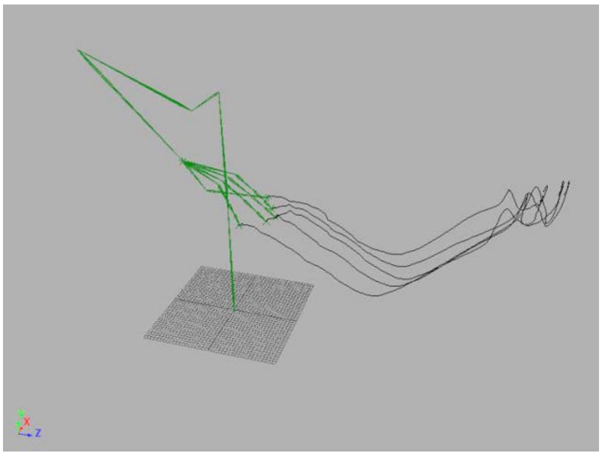

Figure 2. Animated skeletal representation of motion in Softimage XSI

These files were then imported into the Rhino 3D software to be used as construction splines for surfaces or ‘solid’ forms. The construction of these forms poses an interesting question; how to best represent the arbitrary space between the fingers, as this area is clearly not part of the recorded movement. The Rhino software allows for an infinite variety of curvatures that will connect the splines into a surface, but these curvatures can have a dramatic effect on the aesthetics of the object. The most commonly used solution for this project was not to apply any curvature at all but leave the connecting space as straight sections. This was judged to be the most ‘aesthetically honest’ way of dealing with this issue. Choosing this option also means that the paths are clearly visually represented. Following the construction of surfaces or 3D solids in the Rhino program the files can be developed into physical shapes by a number of digital production methods such as Rapid Prototyping (RP) or Computer Numerically Controlled (CNC) milling.
For this project CNC milling was chosen as the preferred development method. The reason for opting for this technique was the possibility of working with larger shapes (the commonly available RP build envelope is still limited in size, usually around 300mm to 400mm cubed, and building larger objects via this method is prohibitively expensive). CNC milling also provides a superior surface quality to RP and gives the options of developing the shapes directly in a wide range of materials.

For this investigation a number of shapes, were milled in blue foam using a Bridgeport VMC 1000 3 axis-milling machine (Hardinge 2007). The milled foam shapes were then sealed with varnish and plaster moulds suitable for slip casting were then developed from them, after which the ceramic pieces could finally be made and fired.

Figure 3. Ceramic (porcelain) form of a hand movement recorded via the SahpeHandPlus system.

Even though the project succeeded in establishing a complete creation method from Mocap shape recording to finished ceramic item it was found the ceramic medium may not be the most suitable material for this concept. The process of making suitable plaster moulds from the milled shapes is complex and time consuming due to the inevitable irregular shape of the forms. Many of the forms are also poorly suited for the process of dying and firing, leading to high losses in the later stages of the production. Further research may establish more successful ways of applying this concept to the ceramic medium.

FURNITURE

Following the investigation with the ceramic medium a further investigation using the same concept as a furniture design tool was undertaken.
In this case motions describing a series of stools seats were recorded. Using the previously described technique the files were converted, and surfaces were created and developed via CNC milling using polyurethane resin board as the material. The form used for the seats was a long relatively flat linear motion. Editing of the recording was kept to a minimum, limited mainly to that of scaling. The long proportion of the shape meant that shape could be made into three separate seat sections which placed together produced the whole continuous shape.

Figure 4. Seat design developed during the investigation of the ShapeHandPlus.

Throughout the seat there is clear visual evidence of individual movements of the fingers during the recording, with even the smallest trembling of the digits clearly reflected. The aesthetics could perhaps best be compared to that of a hand thrown pot with the hands and fingers of the makers clearly evident in throwing lines left on the finished piece. Dispite the distinctive aesthetics, the function of the seats were not compromised, they remain perfectly useable and comfortable, albeit with and an interesting tactile effect.

Figure 5. Evidence of the maker: Detail of the seat created duing the ShapeHand investigation and detail of hand thrown porcelain cups

After milling the seats were sealed with varnished and attached to metal legs, which were made by conventional manufacturing methods.

Using the concept for this application proved very successful, mainly due to the direct manufacture of the seats, which stood in contrast to the complex mould making and subsequent lengthy production method as was the case with the ceramic pieces. Using the concept in collaboration with conventional manufacturing methods also showed great promise rather than describing the whole piece purely via Mocap.

GRAPHIC DESIGN

While the two first investigations with the ShapeHand dealt with the use of the concept to design three-dimensional pieces, an alternative approach applying the equipment for creating two-dimensional graphic design was also undertaken. In this investigation a series of tea towel patterns were developed by recording the motion of drying up a teacup with a towel. These movements were converted from three-dimensional files into two-dimensional vector paths. The paths were then printed digitally on cotton and made into a series of tea towels. The concept here was to use the intended action of the object (the tea towel) directly as a graphical representation on the object itself. This use of the technology also showed great potential and could be utilised in a wide range of related two-dimensional graphics applications.

Figure 6. Tea towels with patterns created via motion capture

INVESTIGATION WITH THE MICROSCRIBE® G2L

Along side the exploration with the ShapeHand equipment a related investigation was undertaken using a Microscribe® G2L digitising arm. Superficially the two pieces of equipment seem to be very different, but with this research’s focus on the concept of using gestural hand movement as a part of the three-dimensional digital design toolset, the two pieces of equipment turned out to compliment each other well.

Figure 7. The Microscribe G2L

The intended application for the Microscribe is not designing or capturing motion but digitising, measuring and inspecting already exiting objects (Immersion 2007).

A previous research project, which among other results produced a range of trophies for the United Kingdom Science Park Association (UKSPA), established that the Microscribe has a lot of potential as a three-dimensional drawing tool. In this project the scribe was used to record free flowing three-dimensional sketches by moving the arm of the Microscribe around in 'mid air'. The movements were recorded direct via the Form Z 3D modelling software and the shapes were produced via Fused Deposition Modelling (FDM) Rapid Prototyping (Jorgensen 2005).

Figure 8. Trophies for UK Science Park Association, created with the Microscribe

To expand on this research it was decided to investigate with the Microscribe to develop the range of applications for this concept.

Although the Microscribe is not a specific design tool there are a number of related products on the market, which are. SensAble Technologies produces a range of haptic arms which have a similar principle to the Microscribe but are dedicated design tools. The ability of these arms as design tools in combination with the FreeForm® software are thoroughly described by Sener et al, (2003). However the haptic element was not considered to be an important issue in this research project. Furthermore these haptic systems are generally considerably more expensive and only work with a limited number of dedicated software packages (SensAble 2007). The Microscribe works directly within a wide range of 3D modelling programs and has the added advantage of versatility, as it can be used for it's intended purpose of digitising, as well as an intuitive design tool or even as a combination of the two.

Many of the shortcomings found in the ShapeHand equipment were complimented by the abilities of the Microscribe. One of the most crucial qualities of the scribe was the high level of accuracy. The Microscribe has the ability of capturing 3D data down to an accuracy of 0.4 mm. While working with the scribe the user can therefore be generally confident that the data captured during a designing session is of his/her movement rather that arbitrary equipment response.

The fact that the Microscribe also works directly within many of the most common design software such as Form Z and Rhino 3D is a huge advantage (Immersion 2007). Rhino was the software predominately used in this research project. The scribe connects directly into the program without the need for any additional software installation. Within rhino there are a number of software tools specific to the Microscribe. However, the equipment can also operate as a general pointing device with almost all other tools in the program - like a conventional computer mouse but far more accurate and with the added third dimension of the Z-axis.

Clearly when using the Microscribe the user's freedom of movement is slightly more restricted, compared with the ShapeHand outfit. The scribe's arm is not able to rotate 360˚ in all joints therefore certain moves may need to be practiced and pre-planned so the Microscribe's arm can be positioned to accommodate such shapes, although in practical use this is rare and does not pose big difficulties if this does happen. Completely free movement is also to a minor degree curtailed by the fact that user is grasping a stylus attached to a mechanical arm. Again in use this is less of an issue as the arm is counterbalanced and has very smooth operations in all moving joints.

In terms of the equipment's use as a creative tool, the most obvious difference between the two pieces of equipment is the single point data input you get from the Microscribe. This clearly excludes the opportunity of interacting dynamically with the fingers, however a single point input can have an advantage in term of aesthetic clarity as the following description will illustrate.

APPLICATION – GLASS

As a part of the investigation of the Microscribe a new concept of glass bowl design was specifically developed. Just like the ShapeHand investigation the process starts with the recording of hand movements. This was done by holding the tip of Microscribe and describing series of splines or loops whilst the motion was being recoded using the Rhino software. The splines were described in ‘mid air’ without the guidance of any stationary object to achieve a genuine expression of the movement of the human hand. The only active editing was the software’s ability to automatically close the lines into complete loops.
The creative intention during the recording was to describe the rim of a bowl or vessel. After recording the splines were extruded in the Z-axis to produce developable surfaces (Schodek et al 2005), which were then achieved using Rhino’s ‘unroll surface’ command. This resulted in a two-dimensional surface with an edge containing the variable Z-axis coordinates. While combining these coordinates with the X, Y dimensions (from the top view) of the splines, the three-dimensional splines could be represented by two two-dimensional projections. This meant that physical 3D models of the splines could be developed very easily by combining these two projections using a bendable sheet material.
This was done by using 0.5 mm thick stainless steel sheet, from which the developed surfaces with the edge containing the Z coordinate were cut using a CNC laser. As the top projection (X, Y axis) did not need to be bendable, it was advantages to use a more stiff material of 6mm MDF (medium density fibreboard), which was also cut to shape using a CNC laser cutter. By squeezing the stainless steel sheet into the laser cut loop in the MDF board (which acted as a collar), accurate physical models of the three-dimensional splines were achieved.

Figure 9. The process of developing the glass shapes.

The concept was to use these models as kiln moulds to shape glass vessels from flat sheets of glass. In order to do this the stainless sheet ring was further supported by casting refractory material around it, which meant that the flammable MDF collar could be removed before moulds were placed in the kiln. Circular disks of 6mm flat glass were then used to create shapes in a kiln forming process known as ‘ free fall slumping’ (Cummings 1997). In this process the glass will soften and gravity will make the glass take the shape of the stainless steel ring’s edge. In the centre where the glass is unsupported, heat and gravity will make the glass bend to a beautiful fluid dome which forms the ‘body’ of the bowl.

Figure 10. Glass bowl (un-trimmed edge) result from the Microscribe investigation with the recorded line/edge clearly visible.

After cooling the excess glass which overhangs the edge can be trimmed to the line created by the stainless steel ring, or alternatively left on for aesthetic effect.

The particular method of manufacturing the stainless steel moulds, which was developed specifically for this project, showed great potential for future use.
The results of the method are especially pleasing, with the edge of the glass vessels as the main focal point

reflecting the single line gestural input from the hand movement. This was especially the case were the overhanging surplus glass was trimmed away, leaving the optical qualities of the glass to create a dark edge of the bowl illustrating precisely the recorded line from the Microscribe. It is also very satisfactory that the dome of the bowls is a natural result of the making process, rather than an 'arbitrary' surface, as was the case with the ShapeHand investigation. Here straight sections had to be created via the Rhino software to connect the recorded splines into surfaces that could be developed via CNC milling.

A variation of the process using a line of stainless steel rods to represent the recorded 'movement spline' instead of the stainless steel ring, was also developed as a part of this project. This principle comes close to the concept of reconfigurable tooling as describe by Halford (2005), but with a very different application.

DISCUSSION

The area of human computer interface is one that is certain to develop rapidly over the coming years. It is amazing how long the Window/Icon/Mouse/Pointer (WIMP) interface have managed to dominate the way most creative practitioners interact with IT based tools. Although the concept of WIMP will probably remain as an option within most systems, it is likely that the dominance of this way of interacting will change dramatically over the next few years. While a lot of alternative interfaces have been theorised about (Buxten, 2007), or used in very specialised fields, it is just now we see the signs of an emerging general change. An example of this could well be Apple Inc.'s (2007) announcement of the iPhone. The phone features one of the first gesture recognition interfaces on a mass consumer product. While most of the iPhone is controlled the same way touch screen computer kiosks have been operated for years, a number of commands on the new device can be controlled by gestures of more than just one finger. The iPhone's patented 'Multitouch' can involve two or more fingers. An example is the iPhone's image organisation and manipulation section where scaling and zooming are controlled by pinching or spreading with two fingers (Apple 2007). If this does not sound revolutionary in itself, it is worth taking a look at Jeff Han's presentation at the 'Technology, Entertainment and Design' (TED 2007) conference at Monterey, California last year. Here Han demonstrated a system which could be manipulated with combination of all ten digits. Han illustrated through a number of different applications how the interface of the creative IT based toolset of the future may not have much of an interface at all, rather than a completely intuitive gestural interaction. While both of these examples are based on a purely two-dimensional gestural interaction with a flat screen, it will now be very interesting to see how long it takes for the three-dimensional side to catch up. Like the development in the two-dimensional field (Buxten 2007), much of the technology is probably already available and has been for some years, but market forces may lay a damper on the development of such systems into commercially available kits. Many of the current crop of designers may still feel more comfortable with the keyboard and mouse input they have 'grown up with', all whilst the users of motion capture will be satisfied with the ever increasing quality and diminishing cost of the process. The result of this situation is that maybe very little commercial motivation for combining the needs of these two worlds to deliver an affordable system that crosses some of the boundaries that have traditionally divided these sectors. It is interesting to see how industries with equally high dependence on three-dimensional digital toolset, which is the case with design/engineering and animation, it is still a cumbersome task transferring files from one field to another. At the start of the research project involving the ShapeHand system, the files had to be converted though 5 different formats in order to be realised via CNC milling (the process was later shortened to 3 conversions). There should be no reason why the motion capturing software should not be able to record directly in a file format that could be processed directly in CAM, however there has probably not yet been a good commercial argument for doing this. Maybe it will take an entirely new generation of creative practitioner to create a new market for such systems.

One issue is the ever-increasing ability of the 'data input' technologies, another matter is the creative use of these. The full potential of the ever improving digital tools may only be reached by researching the wider development processes they can play a part in.

This is illustrated very well with the Microscribe investigation, which could be argued to have produced the most successful results due to the fact that a lot of effort went into developing a completely new making process specifically for this piece of equipment to play a part in.

This issue may also be raised in terms of the motion capture technology, which despite some mixed results from the equipment investigated in this project, still shows great potential as an interactive design tool. Despite the fact the use of such systems have been common in the animation and film sector for a number year, searches have shown very little evidence of other projects researching the use of the technology for this application. Apart from this programme the only other project which could be found to have a similar focus is the Swedish design group 'Front Design's project from 2006 (Front Design 2007).

For reaching the full potential of using Mocap as a design application the performance, usability and price of the current available equipment would probably need to improve somewhat. However with the current rate of development this is likely to happen within the next few years. In the same period it would be very beneficial to continue to research the possible creative applications of this improving technology. Motion capture will clearly not be suitable for all creative practices, but it could have a lot of potential in a wide range of applications, were it could play a very interesting role in developing a more intuitive design interfaces as well as providing the possibility of leaving an aesthetic imprint of the future creative practitioner's hand.

Figure 11. Glass bowls with trimmed edges, results from the Microscribe investigation.

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