HandSCAPE: A Vectorizing Tape Measure for On-Site Measuring Applications

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ABSTRACT
We introduce HandSCAPE, an orientation-aware digital tape measure, as an input device for digitizing field measurements, and visualizing the volume of the resulting vectors with computer graphics. Using embedded orientation-sensing hardware, HandSCAPE captures relevant vectors on each linear measurements and transmits this data wirelessly to a remote computer in real-time. To guide us in design, we have closely studied the intended users, their tasks, and the physical workplaces to extract the needs from real worlds. In this paper, we first describe the potential utility of HandSCAPE for three on-site application areas: archeological surveys, interior design, and storage space allocation. We then describe the overall system which includes orientation sensing, vector calculation, and primitive modeling. With exploratory usage results, we conclude our paper for interface design issues and future developments.

Keywords
input device, field measurement tool, on-site applications, orientation-aware, physical interaction, tangible interface

INTRODUCTION
The act of measuring is a human task that dates back thousands of years, and evolved from a need to describe physical structures for the purpose of construction or surveying. The act of measuring is often associated with body gestures, such as the way we stretch our arms when describing the length of an object (e.g. "I caught a fish this big"). This body aspect of measurement also gave rise to the first primitive units of measurement, such as the *cubit*, which was defined the distance between the elbow and the tip of one's fingers.

Measurement Tools
Over the years, measurement tools have evolved from using our arms and feet, to more quantitative tools such as rulers and tape measures. Throughout these evolutions of technology tools were augmented with new capabilities for surveys and constructions for greater accuracy and ease of use. More recently, the advent of electronics and computing has given rise to a great number of new tools and systems for digitizing and measuring 3D objects.

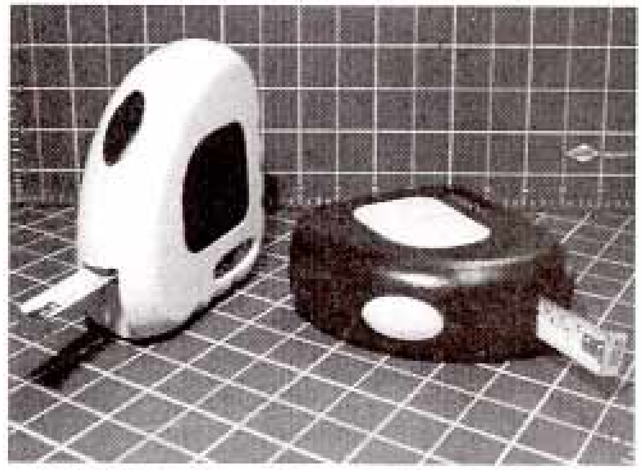

Figure 1. The HandSCAPE tool (12 x 12 x 4.5 cm)

Examples of these are commercially available 3D digitizing and modeling products include *Polhemus 3Ball™*[11], *Monkey2™* [10], *Digibot3™* [4], etc. Despite the accuracy and versatile usage of the device, many of these new tools are not practical or appropriate (and often too expensive) for common and portable measurement tasks; we have employed in such as use warehouses, construction sites, shipping yards, sporting events, and archeological field surveys.

More relevant measuring and testing input device is *SHAPE TAPE™* [12] which tracks the shape of tape while the tape is twisting and bending. It has 6DOF position and orientation of the two. Although the devices and systems provide accuracy and speed to digitize physical 3D, these are designed for a desktop application.

In terms of computer modeling of 3D environment, there are few programs that perform rapid modeling of primitive 3D scene [16] and allow sketching of freeform objects [8], against the complicated CAD like 3D modeling applications. Their emphasis is on ease of low-level correction and simplicity of interface for sketching. These are well developed in combining the ideal sketched by hands and computer-based modeling programs to improve the efficiency of sketching approximate models.

The Basic HandSCAPE Concept
The motivating concept for HandSCAPE was to create a simple handheld tool which would allow workers in the field to digitize their measurements and gain the productivity and efficiency from modern-day computer technology. We considered several possible approaches,

such as computer vision, ultrasonics, or lasers, but the requirements of portability and robustness led us to investigate what could be done with the existing tool commonly known as the tape measure. It is portable, simple to use, and low-cost. For this reason, the traditional measuring tape continues to be the tool of choice for common everyday measuring tasks. We set out to augment a traditional tape measure with digital functionality, so that we could employ peoples' existing skills and familiarity in physical environments with this classic tool. The key innovation of HandSCAPE is that it seamlessly combines a 3D input device with a rapid 3D modeling visualization of non-desktop measuring application.

Orientation Awareness

Since a handheld tape measure simply measures a linear distance, and it is not apparent how such a device could be utilized to capture the necessary spatial information. However, if orientation sensors are added, angular information can be measured as well. Then, knowing the distance and direction enables such a device to measure *vectors*. By measuring a series of vectors, the spatial dimensions of a physical object can be recorded and reconstructed in digital domain automatically. Similarly, by choosing a fixed reference point for the entire space, then the relative position and orientation of each of the objects can be recorded by simply measuring the distance from one object to the next. This approach formed the basis of the HandSCAPE concept and proceeded the technology.

REAL WORLD NEEDS

In this paper, we present HandSCAPE as an example of a wireless technology to enhance the efficiency of on-site measuring tasks. We have closely studied the intended users, their tasks, and the physical workplaces to extract the needs from real world measuring tasks on-site. In the following sections, we first describe the potential utility of our device for each application. We then describe the overall system, which includes vector calculation, relative positioning, and generating 3D models. Finally we conclude our paper with reporting results from an exploratory usage and discussing intuitive observations. Furthermore we consider the future plan in further development of HandSCAPE.

Our research concentrates on field applications where getting information from the physical world becomes more complicated. The following three application areas will comparatively examine the aim of this research as a solution to particular measuring problems. Each application demonstrates issues in both hardware and software that arise in using HandSCAPE.

1. Optimal Packing in Storage and Transportation

Efficient use of space for packing, storing, and transporting goods is vital in the industrial sector [5]. As demand on space and distribution operation increases, investing in material handling and storage equipment to improve efficiency, profit margins, and reduce distribution and storage cost becomes crucial. High costs result from a lack of coordination between transport and storage systems, and between a storage system and its enclosure. The task of space optimization in terms of volume in bulk storage packing is usually a multi-step process involving measurements and calculations done by hand. HandSCAPE has transformed this process into a one step interaction with clear visualization. With HandSCAPE the measuring has also been directly coupled with space optimization, thus allowing the users to perform the physical task efficiently.

Figure 2. Trucking at a loading dock

Scenario: Trucking with Packing Simulation

Imagine two truck drivers who need to transport hundreds of differently sized boxes in a truck container (Fig. 2). Assuming i) it is not necessary to unload any of these boxes until arriving at the destination, ii) the weight of box is determined by the volume, iii) repeated access to a box is limited due to the truck driver's tight pick-up schedule. How, then, can they pack as many boxes as possible as fast as possible?

Given a known volume of available storage, the user employs HandSCAPE to measure the dimension of each box. Whenever a box is measured, the host computer determines the best-fit position of the current box to minimize the use of the space. After measuring all the boxes (Fig. 3), the optimal packing configuration is visualized on the screen (Fig. 4) and the actual physical packing can be performed according to this result.

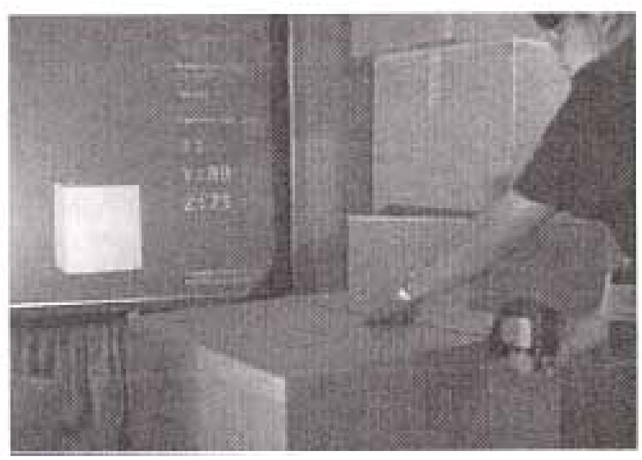

Figure 3. Using HandSCAPE for on-site packing optimization configuration displayed on screen.

Software: Optimal Packing Algorithm

The goal of our packing application is to determine the most efficient way of packing all the user's boxes. We surveyed approximation algorithms for some well-known and very natural combinatorial optimization problems, such as minimum set covering, minimum vertex covering, maximum set packing, and maximum independent set problems. The algorithm we derived for the application is an offline algorithm that achieves this goal by performing two steps. First, it sorts the boxes by volume, from largest to smallest. It then uses a greedy algorithm and packs the boxes in sorted order, using dynamic programming to determine the best position for each box. The result is an optimal solution for packing all the boxes.

- ***Volume Sorting***

The first step in the algorithm is to sort the boxes by volume from largest to smallest. Since the boxes are then packed in sorted order, this causes large boxes to be packed first. This conserves space because larger boxes tend to have a larger top surface area than smaller boxes so packing them first allows more stacking to occur because the smaller boxes can be packed on top of them. Additionally, we assume that the larger boxes are heavier than the smaller boxes, so packing the larger boxes first will prevent a heavier box from being packed on top of a lighter one. The second step in the algorithm is where the packing is actually performed. A greedy algorithm is used, so each box is packed in the currently optimal place. Since each box could potentially be in many places, we use dynamic programming to determine.

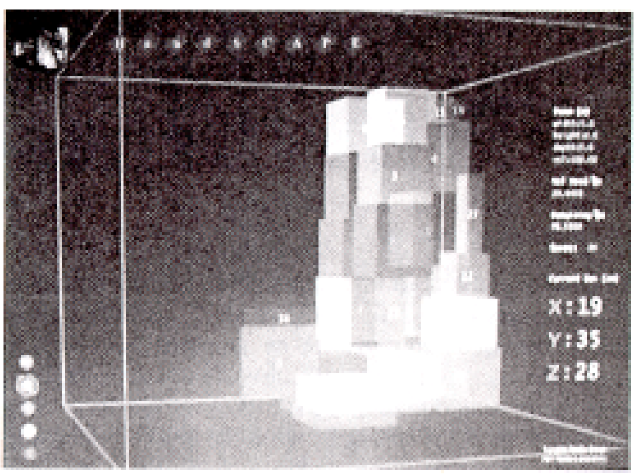

Figure 4. Optimal packing configuration simulation

- ***Determining the Best-Fit Position***

The given space is first broken up into *height* number of floors, where *height* is the height of the space. The algorithm then tries to place the box on each floor by starting from the back right corner and moving outwards, checking at each position whether or not there is space to place the whole box. Once a space is found, the placement is recorded and the algorithm attempts to place the box on the next floor. It does this for each floor and at the end, all possible placements for the box are compared, and the one that minimizes the amount of space used is the placement that used for the box. This is done for each box, in sorted order. The result is that each box is placed in an optimal position and the user can then efficiently pack his or her boxes according to the consequent configuration.

2. Collecting Measurements On-Site Excavations

The domain of archaeological field excavation promotes the comprehensive and interdisciplinary study of the human past. The goal is to preserve the great quantity of irreplaceable information associated with archeological excavations. For archeologists, there is the added responsibility of taking primary field data — the innumerable photographs, maps, drawings, and notebooks that make up the archeological excavation record [3]. Therefore, accurate recordings of the field datum of the specimens are crucial at the on-site excavations.

Figure 5. Three units in the process of excavation (above). Measuring the level and angle in a dig (right) [3]. Photo Courtesy of 1999 © Cotsen Institute of Archaeology at UCLA.

By taking all data on the site, a more dynamic and complex consideration of archeological data results, and much of the primary data is returned to the archeological community for further study. The goal of field measuring also becomes increasingly important in a large deposit because having to take the same repetitive set of measurements on hundreds of specimens each day quickly becomes so tedious that even the most conscientious workers may become careless. In order to reduce innumerous measurement errors, positioning measurements in the field needs a good measuring system to facilitate the accurate determination of the position of any object.

Existing Field Measurements

To achieve the least error, archaeologists traditionally used a primary point for the vertical coordinate as a surface to the ground and lay out a grid system on which lines are no more than a meter apart. The excavators are locating an artifact with respect to two walls of the unit using the two tape measures laying in the pit. They are also using a third tape measure and a level string to measure depth. The level string is being stretched diagonally across the pit from the "candy cane" - a red and white metal pin near the bottom corner of the dig is set at a certain depth and does not move during the course of the excavation. (Fig. 5, above: Morse Point, Santa Cruz Island, Ca.). There is also a technique to measure the angle and position of the placement with a rigid level. It also consists of a carriage for the level bubble, and a pivot bracket to adjust the angle of the bar (Fig. 5, right). Despite various efforts and other on-site measuring techniques, it is difficult to reduce chances of error. Besides accuracy, the principal factors in choosing a measuring technique should be speed and possibility of error [3]. These objectives are way for a new measuring technology.

New Approach

Regarding the accuracy and speed of measuring excavation measurement in a field deposit, the awareness of orientation and position of artifacts is a key in getting surface data informatively. As an orientation-aware measuring device, HandSCAPE provides a way for the user to get an accurate relative location of the excavated fossil as well as a visualization of the artifacts found as the archaeologists dig further and further down. This information is determined using the vectors produced by HandSCAPE measurements.

• ***Positioning accurate location of artifacts***

HandSCAPE first begins by drawing out a rectangular area that is to be excavated. Once an artifact is found, HandSCAPE then sketches a rectangle that encircles the artifact. The corners of the original rectangular area can then be used as an anchor point in positioning the new artifact. This is simply done by using HandSCAPE to measure the distance between one corner of the outer rectangle and one corner of the outlining rectangle.

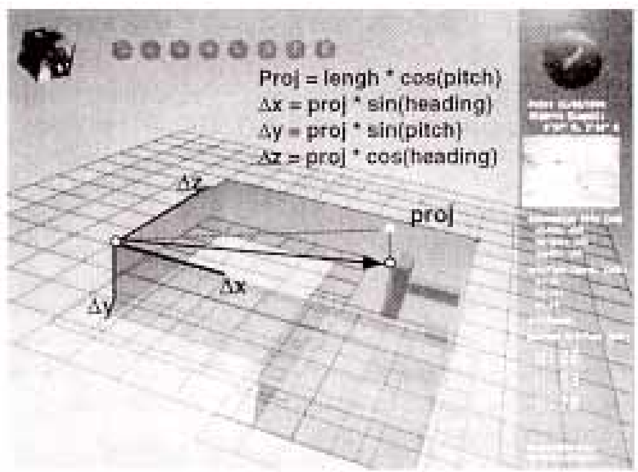

Figure 6. Accurate positioning of the location of an artifact in an archaeological excavation, on-screen visualization.

Taking the linear *length*, along with the *pitch* and *heading* calculations (discussed in implementation section) the user can determine the relative position of the artifact in a dig. Once the relative position of the artifact has been determined, two simple measurements in the x and z direction creates the small rectangular area outlining the artifact. One last measurement of the height of the object completes the representative cube of the artifact.

The remote computer displays the cube on computer screen (Fig. 6) in which the artifact is located within an outer three-dimensional box representing the area that has been excavated. As the excavator digs deeper, the outer box will become larger and any additional artifacts that are found will also be represented as a small box within the space. The overall result, therefore, is a 3D visualization of the area excavated containing accurate representations in terms of size and position of any artifacts that were found in that area. In addition to storing measurement data on a computer, HandSCAPE is also able to incorporate geographical and historical reference data while archaeologists perform the excavations. It enhances and verifies innovative archeological research with dynamic and interactive on-site data interpretation.

3. Modeling Architectural Interior Surfaces

Traditionally people have represented architectural interior surfaces on paper by measuring and drawing approximate sketches of the measurement. When the user needs to create a 3D model of the space for purposes of construction and furniture allocation, the usual approach involves typing all the measurements into a computer-modeling program to visualize the space. With this methodology, these two tasks (measuring and modeling) are always performed separately.

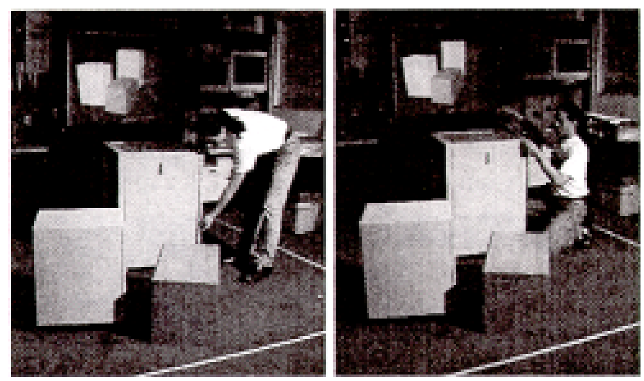

Figure 7. Measuring physical objects and generating the corresponding 3D models

To overcome the need to abstract physical space into units of measurement and subsequently translate those measurements to units usable by graphics, HandSCAPE allows the user to focus on the task of measurement alone when generating digital models. Moreover, it is very complicated to model relations between the objects and spaces without measuring orientation. Note the fact that orientation measure is even more complicated if modeling requires accurate visualization of a physical space that contains several objects.

Scenario: Primitive Modeling of Interior Spaces

An interior designer steps into a room containing several pieces of furniture that he or she wishes to model. The primary interaction involves taking measurements of these objects and the distances between them. Once the user measures an object, its representative three-dimensional model with corresponding vectors immediately appears on the host computer in real-time. The coordinate defines the endpoint of the vector that originates from the base of the tape measure and passes through this point in the three dimensional space. Now the user measures the vector, *(x, y, z) (r, θ, φ)* between the first and second objects. The user can measure multiple physical objects in the space. It is also possible to make a procedure such that the user can capture the measurement vectors in any arbitrary order as natural as we used to perform.

IMPLEMENTATIONS

HandSCAPE is a single unit consisting of a measuring tape along with custom sensing electronics located on a printed circuit board. It communicates through a RF signal to perform graphics rendering with *TGS Open Inventor™* and using customized Visual C++ programs.

Figure 8. System Components

To increase the mobility of the system, we especially implemented the whole system on a 400Mhz laptop (Fig. 8). The digital model generated by the measuring input is displayed on the computer screen and made available for manipulation by a keyboard and a mouse.

• ***Data Processing***
Technically, the digital tape measure tracks the length of the measuring tape by means of a linear optical encoder. The handheld electronics module also includes a two-axis micro-machined accelerometer made by Analog Devices. The accelerometer acts as a tilt sensor that indicates the displacement of the HandSCAPE device from the horizontal plane. To measure the final degree of freedom, rotation about the vertical axis (heading), we have used a three-axis magnetometer responsive to the Earth's magnetic field in its three sensing axes. The Microchip PIC™ controller, PIC16C715 compiles the sensor data described above and transmits it through a RF interface to a host computer.

• ***Wireless Communication***
To increase the mobility of HandSCAPE for on-site applications, wireless Radio Frequency communication is employed. The RF unit is composed of two bi-directional parts, an on-board RF transmitter/receiver and an external RF receiver/transmitter base unit which communicates with the host computer via a RS-232 serial interface. A cyclic redundancy check has been incorporated to ensure accurate data transmission between HandSCAPE and the base unit. The RF unit utilizes the ultra-compact, low-cost LC-series transmitter and receiver, communicating at 315, 418, 433MHz from Linx Technologies. The range of this communication is 30 feet to 50 feet, based on the magnetic interference on the site. Using RF technology also allows HandSCAPE to handle multiple users with just one base unit since the data from each handheld unit can be tagged and processed accordingly by the host computer.

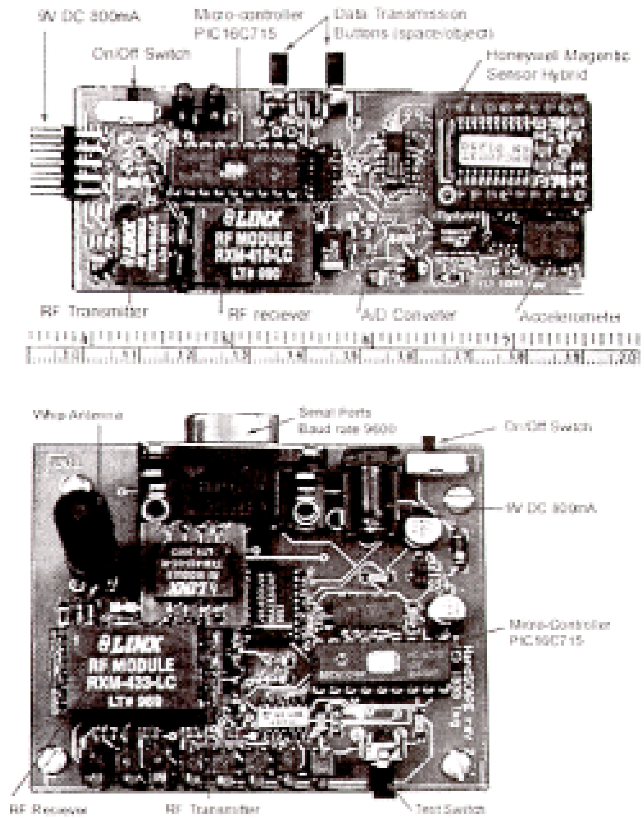

Figure 9. Handheld Board (9 x 4 x 1.5 cm, top) and Base Unit (6 x 8 x 2 cm, bottom)

Vector Calculations

Although the vector is a quantitative description of the physical dimension, the task of estimation frequently does not require this numerical abstraction. In actual measuring tasks therefore, we measure linear distances with a series of vectors to recognize the volume of objects and spaces. Thus, orientation awareness is a significant contribution to the demand of measuring tasks. This embedded function enhances the capability of the hand-held tool effectively.

• ***Coordinate System***
Azimuth information can be extracted from its readings much in the same way as a digital compass. We chose to represent 3D orientation in spherical coordinates, as it was the most natural choice given the sensor data. Note that *r*, the radius, is obtained from the length of the tape, *θ* is produced by

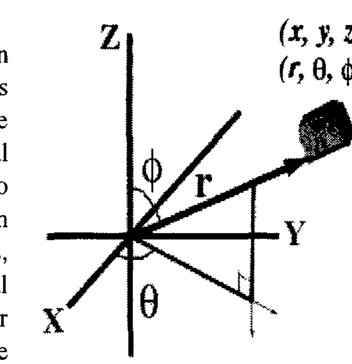

Figure 9. Coordinate System

the magnetometer data, and ϕ is derived from the accelerometer data.

• *Pitch and Heading*

The orientation of HandSCAPE is determined from the *pitch* and *heading* calculations, which are made from the compass and accelerometer readings. The *pitch* calculation is how much HandSCAPE is being tilted from the horizontal. The *heading* calculation corresponds to what angle, with respect to magnetic north, HandSCAPE is being held. The compass and accelerometer readings are all normalized to 512. The *pitch* calculation is the inverse *sin* of the normalized x reading from the accelerometer:

```
pitch = sin^-1(ax_norm)
```

The *roll* calculation is needed to determine the heading. It is simply the inverse sin of the normalized y reading from the accelerometer:

```
roll = sin^-1(ay_norm)
```

To determine *heading*, the normalized horizontal compass x and y are first calculated, using the following

```
cx_norm_horz = cx_norm * cos(pitch) +
        cy_norm * sin(roll) * sin(pitch);
cz_norm * cos(roll) * sin(pitch);
cy_norm_horz = cy_norm * cos(roll) +
        cz_norm * sin(roll);
```

where cx_norm is the normalized x reading from the compass, cy_norm is the normalized y reading. and cz_norm is the normalized z reading. In all cases, the readings are normalized to 512. The *heading* is then determined from the following [Table 1].

cx_norm_horz	cy_norm_horz	Heading
0	< 0	π/2
0	> 0	3π/2
< 0	Anything	π - tan^-1 (cy_norm_horz/ cx_norm_horz)
	< 0	- tan^-1 (cy_norm_horz/ cx_norm_horz)
> 0	≥ 0	2π - tan^-1 (cy_norm_horz/ cx_norm_horz)

Table 1. Determination of heading from normalized horizontal x and y compass calculations

Once *pitch* and *heading* have been calculated, the current orientation of HandSCAPE can be determined. *Pitch* is how much HandSCAPE is tilted. If it is at $\pi/2$ or $-\pi/2$, it is being held vertically and a *y* measurement is being read. *Heading* corresponds to how much HandSCAPE is turned. During initialization, the room heading is calculated. This is the heading that corresponds to a perfect *x* measurement. If the difference between the room heading and the calculated *heading* is greater than $\pi/4$, then a *z* measurement is being made. Otherwise, the reading is of a *x* measurement. Thus, with the *pitch* and *heading* calculations, HandSCAPE can determine its orientation and therefore determine which dimension of the box is being measured.

Relative Positioning 3D Objects

• *Generating 3D models*

The room modeling application involves measuring the contents of a room as boxes in their correct orientations and relative positions. The orientation of a box can easily be determined from the heading of the *x* measurement. The angle a box is turned is the difference between the heading of the room and the heading of the *x* measurement.

```
rotateAngle = heading - room_heading;
```

The placement of a box depends on its relative positions to the box that was measured before it. Each distance measurement is taken from the back right corner of the previous box to the front left corner of the next box. We can again use the *pitch* and *heading* calculations (discussed in Implementation section) to determine the relative position of the new box.

```
x_translation= length x cos(heading -
        room_heading);
y_translation= lengh x sin(pitch);
z_translation= lengh x sin(heading
        room_heading);
```

x_translation and z_translation are the distances between the two corners in the x and z direction respectively. y_translation is how much higher (or lower) the corner of the new box is from the corner of the old. From these three calculations, we can determine the position of the new box with respect to the box measured before it.

Modeling a room begins by first determining the room heading, for later orientation calculations. The first box is then measured, then the distance between the first and second, then the second, etc. By going through the room and measuring all the boxes and the distances between them, we can rapidly model the room. Later on, the user can move to the computer and manipulate the objects in digital space. For example, he/she can rotate the model in order to gain a greater understanding of the spatial relationships through views from different angle. The user can also simulate object allocation and space configuration.

• *Object mode vs. Space mode*

HandSCAPE generates a series of vectors, which can be used to produce a digital representation of the physical object. The vectors generate the correctly oriented models in accurate relative positions to each other. A frame of reference is established for each new object in relation to objects that have already been measured. As long as each set of measurements originates from a certain reference point in both physical and virtual space, and this relationship is consistently observed, the objects will be modeled correctly relative to each other. Each vector is tagged as an *object* or *space* measurement by the micro-controller, selectable by a button on the device. In *object* mode, the vectors are taken to be *the dimensions* of a parallelepiped, which represents the object being measured. In *space* mode, the vector is taken to indicate *the spatial* *relationship* between objects, and serves as the reference point for the next object to be measured. Whenever a new measurement is transmitted to the computer, HandSCAPE emits an audible tone through the onboard buzzer and light signals so that the user recognizes the data transmission.

EXPLORATORY USAGE RESULTS

We exhibited HandSCAPE in the Emerging Technology Pavilion at SIGGRAPH'99, demonstrating the optimal packing application (Fig.3). We let hundreds of users from diverse research backgrounds use HandSCAPE. It was very easy to inform them about how the device works, because they were familiar with using measuring tapes in everyday life, and the size and shape of HandSCAPE is that of a standard tape measure. Secondly, most users were surprised at the tight coupling of visual cues with transmission of data. The interaction was very natural and users were convinced of the efficiency in speed and accuracy of what they were measuring.

Feedback

By running the optimal space configuration software, users could clearly see that the current box they measured was packed in the best fit position just as it would be in normal real world optimal packing. We proved that HandSCAPE was working in both hardware and software for the application. Although we only presented the packing optimization application, users responded well to adopting the device to various other uses. They even mentioned themselves that HandSCAPE is a very practical device that could be applied immediately to certain real world needs. Some users asked us about the capability of HandSCAPE to measure not only straight lines, but also curves.

Comparative Experiment

We conducted a simple experiment to study two factors of interest, *speed* and *accuracy*. Each subject performed the experiment using two different tape measures --one being HandSCAPE and the other being a normal measuring tape. We asked 15 non-professional users to perform a 3D modeling task, (i.e. measuring a box and modeling it on the computer screen). Using the normal tape measure, users followed the standard approach of entering the measuring value into the modeling program to visualize the box. With HandSCAPE, on the other hand, users simply needed to measure the three dimensions of the box and its visualization immediately appeared on the screen. Results of this experiment are shown in Table 2. From the data we observed 77% of users were more accurate when they used HandSCAPE. Measuring with HandSCAPE was also an average of 2.1 times faster than measuring with a normal tape.

LIMITING FACTORS and FUTURE WORK

Despite the potential improvements, we have also observed errors caused by pushing the button two or three times repeatedly. These errors usually resulted in graphical errors. We also found that the accuracy of orientation is greatly affected by nearby magnetic fields. Definitely the archaeology and interior design applications need more accurate and precise orientation measurements. For these limiting factors, we have plans to add new features such as add and delete buttons to correct the transmission. To increase the accuracy of the orientation measurements, we plan to explore another technology to improve the current sensing hardware.

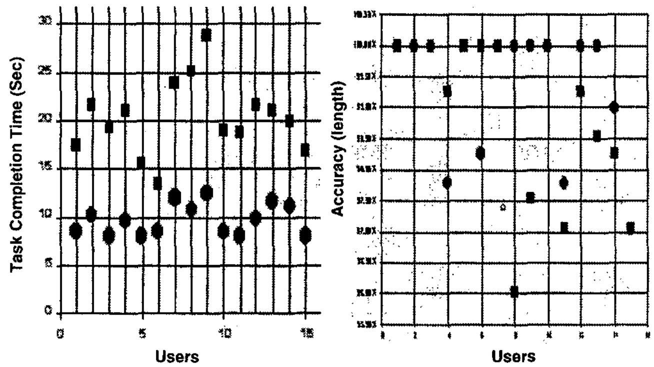

Table 2. User data showing subject accuracy and completion time without HandSCAPE (■) and with HandSCAPE (●).

We have also learned from each application how generally useful HandSCAPE is not only in hardware but also in software. For instance, archaeologists mentioned that we needed to give more control over the visualization on computer screen of the "pointclouds" – i.e. 3D positioning visualization of artifacts inside of the dig. Therefore we plans to adjust the software interface. Another challenge is to explore modeling curves and manipulating surfaces by integrating a high dimensional input device [1]. We will look carefully into the possibility since the aim of this research is for existing real world applications and user population. We will look more closely at the applications and reflect the needs in our future direction.

DISCUSSION

At the beginning of this paper we proposed a new interface design for addressing real world needs. By examining the comparative efficiency issues on each on-site application, we were able to verify our work in certain intuitive observation:

- ***Value of traditional interaction techniques:*** Without the need to learn and adjust to a new interface, making use of existing physical skills preserves the human senses and interactions that are commonly employed in everyday life [6], [9], [14]. In this case, feedback from physical tasks can have an immediate influence on the user's activities. Note that HandSCAPE knows what the user is measuring in real-time. This real-time feedback reinforces the means of understanding physical space in the digital domain, not just through measurements but also perceptual, tactile, and kinesthetic feedback in physical environments. In addition two-handed interactions in measuring use the natural way of using motion to recognize 3D spaces and object.

- ***Application-specific:*** As opposed to designing a general-purpose interface, there seems to be a clear advantage in designing interfaces that are very application-specific, [2],

[7], [13], [15]. Bridging the gap between existing measuring techniques and new features of digital modeling functions provide a comprehensive interaction and enhances the consistency of the measuring workload incorporated with the modeling tasks on-site. This particular interaction technique examines designing interfaces to solve the real world problems in both measuring and modeling that has always been separated.

Figure 10. The HandSCAPE in two hands

CONCLUSIONS

We have presented HandSCAPE, a computer augmented measuring tape for digitizing filed measurements. By using orientation-sensing technology, the device can provide the field workers with access to the efficiency of complex measuring tasks such as loading, packing, locating, and configuration in the manner of traditional measuring techniques. Although HandSCAPE an input device is not designed to the most known 3D modeling and animation applications, we believe that modeling primitive 3D objects cooperated with measuring for the specific applications enhances the efficiency of real word measuring tasks.

In the beginning, HandSCAPE attempted to improve the primary concerns of complex measuring tasks along the digital functionality. However the result from combining measuring and modeling as a single seamless step without any extra effort beyond measuring presents exciting avenues for improving comparative efficiency of traditional on-site measuring tasks. Through this project, we realize that augmenting digital functionality on top of familiar tools increases the efficiency of real world tasks that develop with human senses and skills.

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REFERENCES

[1] Balakrishnan, R., Fitzmaurice, G.W. and Kurtenbach, G., Singh, K. (1999) Exploring Interactive Curve and Surface Manipulation Using a Bend and Twist Sensitive Input Strip, In Proceedings of ACM Symposium on Interactive 3D Graphics (I3DG'99), ACM Press, pp. 111-118

[2] Balakrishnan, R., Fitzmaurice, G.W. and Kurtenbach, G., Buxton W. (1999) Digital Tape Drawing, In Proceedings of ACM Symposium on User Interface Software and Technology, UIST'99, pp. 161-169,

[3] Brien D. Dillon (eds.) (1993) Practical Archaeology: Filed and Laboratory Techniques and Archaeological Logistics, Institute of Archaeology, University of California Press: Los Angeles, pp. 33-38

[4] Digibot3™ *Product Information*, Digibotics, Inc. (http://www.digibot.com)

[5] Falconer, P., drury, J. (1975) Building and Planning for Industrial Storage and Distribution, The Architectural Press: London, Introduction

[6] Fitzmaurice, G.W., Ishii, H., and Buxton, W. (1995). Bricks: Laying the foundation for Graspable User Interfaces. In Proceedings of CHI'95, pp. 422-449.

[7] Hinckley, K., Pausch, R., Proffitt, D., and Kassell, N. (1998) Two-Handed Virtual Manipulation, ACM Transactions on Computer–Human Interaction, 260-362

[8] Igarashi, T., Matsuoka, S., and Tanaka, H. (1999) "Teddy; A Sketching Interface for 3D Freeform Desing, In Proceeding of SIGGRAPH'99, pp. 409-416

[9] Ishii, H. and Ullmer, B. (1997) Tangible Bits: Toward seamless Interfaces between People, Bits, and Atoms, in *proceeding of CHI '97*, ACM Press, pp. 234-241

[10] Monkey2™. Product Information, Digital Image Design Incorporated, New York. (http://www.didi.com)

[11] Polhemus 3Ball™, *Product Information*, Polhemus Inc. , Chchester, VT (http://www.polhemus.com)

[12] SHAPE TAPE ™, *Product Information,* Measurand Inc., Fredericton, New Brunswick, Canada. (http://www.measurand.com)

[13] Underkoffler J. and Ishii, H. (1999) Urp: A Luminous-Tangible Workbench for Urban Planning and Design, In *Proceedings of the CHI '99*, ACM Press, pp. 386-393

[14] Weiser, M. "The Computer for the 21 Century." *In Scientific American*, 265 (3), pp. 94-104

[15] Yarin, P. and Ishii, H. (1999) TouchCounters: Designing Interactive Electronic Labels for Physical Containers, in *Proceeding of the CHI '99*, ACM Press, pp. 362-369

[16] Zeleznik R.C., Herndon K.P., and Hughs J.F (1996) SKETCH: An Interface for Sketching 3D Scenes", In *Proceedings of SIGGRAPH '96,* pp. 163-170