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Ilene Busch-Vishniac and Mark Frank
Department of Mechanical Engineering
University of Texas, Austin

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Ms. Ilene Busch-Vishniac,

The attached report presents the conceptual design for a hand anthropometry (body measurement) device. The report presents a specification list, function structure, solutions to sub-functions, best concepts, and a decision matrix to determine a final, 'best', concept for the device.

The anthropometry device has one independent sub-function. This is the measurement sub-function. Picking a solution from this sub-function sets the solutions for the other sub-functions. This process gives five possible concepts.

Using a decision matrix, the best concept to pursue was a video recording system with an active background. This system uses a high resolution video camera and a known background (controlled CRT) to determine the dimensions of the hand.

Sincerely,

Robert McMahan

Robert McMahan
ME 366J Student

(NASA-CR-195490) CONCEPTUAL DESIGN OF AN ASTRONAUT HAND ANTHROPOMETRY DEVICE (Texas Univ.) 18 p

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Conceptual Design of an Astronaut Hand Anthropometry Device

Robert McMahan

ME 366J

MWF 12-1

TA: Mark Frank

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ABSTRACT

In a micro gravity environment fluid equalizes throughout the body, causing the upper body to swell. This causes the hands to swell which can cause problems for astronauts trying to do work in pressurized EVA (Extra Vehicular Activity) gloves. To better design these gloves, accurate measurements of the astronauts swollen hands are needed.

Five concepts were developed in this report from an original field of 972 possible concepts. These five concepts were based on mold impression, ultrasound, laser topography, white light photography, and video imaging. From a decision matrix based on nine weighted criteria, the video imaging technique was found to be the best design to pursue.

TABLE OF CONTENTS

INTRODUCTION

NASA has a need to improve its process of producing properly fitting space gloves, or EVA (Extra Vehicular Activity) gloves. If the gloves do not fit exactly, there is a large reduction in grip strength and hand fatigue is increased significantly. Even well fitting gloves can reduce an astronaut's grip strength by approximately fifty percent.

The present process for producing these gloves is an iteration process for each astronaut based on comfort. Each astronaut will try gloves until he/she finds the best fit. NASA wishes to quantify this process so that glove sizes will be based on actual data, and not on a 'comfort measurement'. To do this, an accurate image of the hand must be produced so that gloves can be designed for that hand.

An accurate image of the hand can be produced easily on the Earth, but in orbit an astronaut's hand swells. This swelling is caused by a redistribution of the astronaut's bodily fluids in the micro gravity environment. Precise data on the amount of hand swelling for each astronaut has not been obtained, therefore gloves cannot be produced for the astronaut's swollen hands. An accurate method of imaging an astronaut's hand while in space, while the hands are swollen, is needed so that properly fitting gloves can be produced.

This report outlines the conceptual design phase for producing a hand anthropometry device. Anthropometry is the study of human dimensions; in this case, the dimensions of the hand. A specification list and functions structure are presented for this device. From the function structure, critical sub-functions are identified and solution variants for these sub-functions are determined and listed. These solution variants are combined to produce concepts, which are then filtered to produce a list of the best concepts. These best concepts are described in more detail and are then ranked using a decision matrix. This decision matrix uses various weighted criteria to determine the overall top concept or concepts. This top concept(s) is then suggested as the design to be taken to the embodiment design phase for the hand anthropometry device.

SPECIFICATIONS

The specification list for the hand anthropometry device is shown in Table 1. The list is broken up by topical area and each specification is listed as a demand (shown by a D in the far left column) or as a wish (W). Most of the requirements listed are directly from NASA or are directly related to the functional requirements of the device. Some of the specifications are explained here.

One specification for the device to be used aboard a spacecraft is that the device should not interfere with the ship's operation. This means that no electromagnetic signals or fields that could possibly interfere with the ship's operation or experiments being performed on board should be allowed to escape the device. The device must also provide a means for storage of the data it generates. This could mean transference of data to the spacecraft's computer, internal storage of the data, or production of an object (such as a cast or photograph) which intrinsically stores the data within itself.

Other specifications require no altering of hand physiology due to the measurement, in other words, there should be no residual effect of the measurement on the hand. The noise limit specification is rather high, 55 dB (equivalent to very loud speech), since this device will be used infrequently. However, the device will be aboard a closed ship so the noise limit would preferably be below 35 dB (equivalent to a smooth running refrigerator).

A specification listed is that the device must make enough measurement to enable a three dimensional mathematical model of the hand to be assembled. This is needed to produce properly fitting gloves and to provide data for the analysis of upper body swelling in micro gravity.

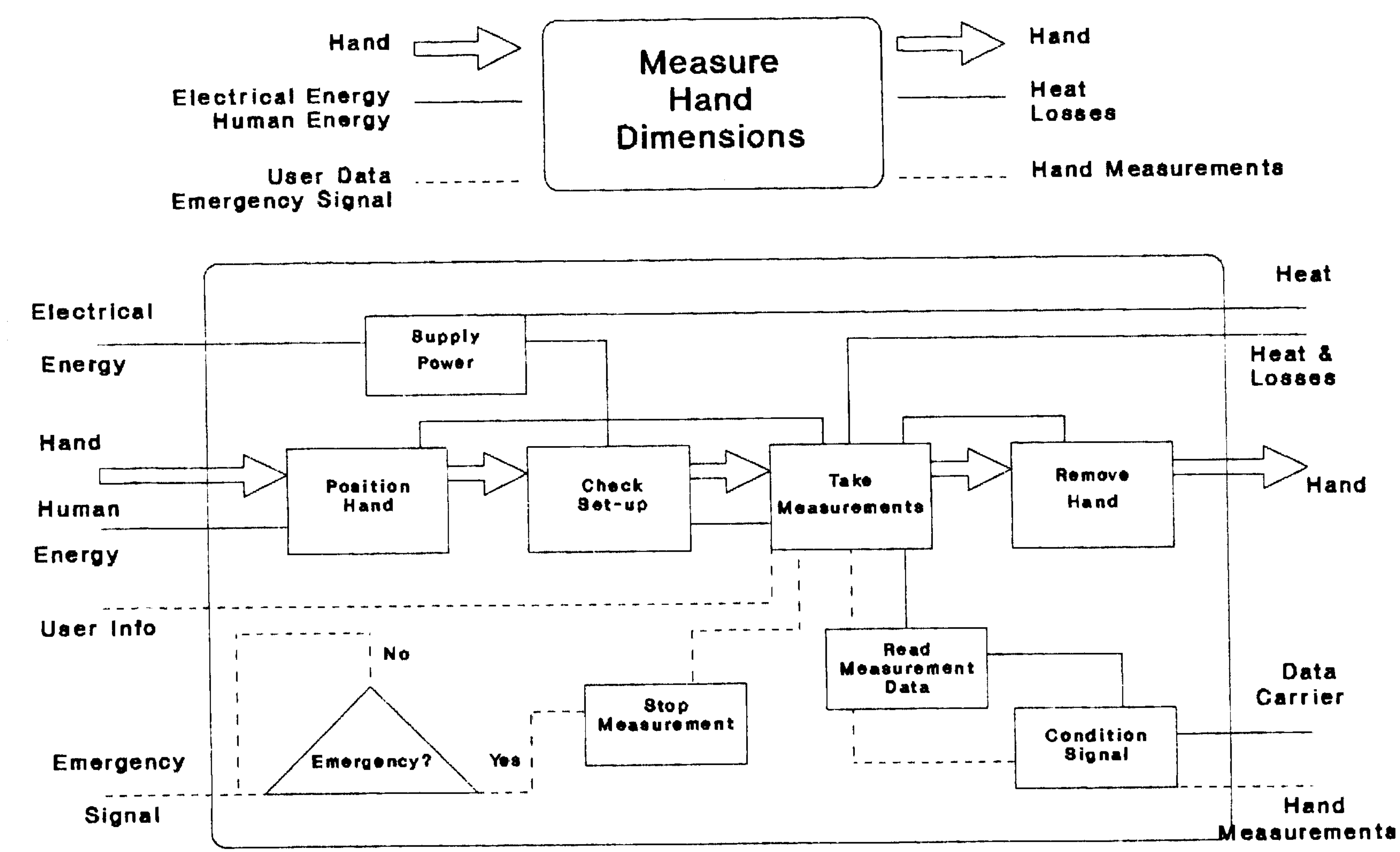
NASA	Table 1. Specification List	
D/W	Requirement	Verify
	Geometry	
D	Storage space < 14.46 X 18.62 X 9.59 inches	Measure
	Forces	
D	Maximum weight: 54 lbs	Weigh
D	Withstand 3.3 g accelerations	Dynamic analysis
D	Withstand 20 g decelerations	
D	Withstand shuttle launch vibrations	Dyn analys
D	Withstand 0 atm to 1.5 atm pressures	Pres test
D	Comply with NASA specs for attachment of movable devices within spacecraft	Records/ test
	Energy	
D	Operate on 28 V dc external power	Power test
D	Power usage: less than 100 W	Test proto
D	Withstand storage temperatures of -40 F to 160 F	Test proto
D	No escaping electromagnetic signals to interfere with station operations	Operate & measure
	Signals	
D	Store data or transfer data to external computer	Test proto
D	Electronic output compatible with station computers	Computer check
D	Measurement accuracy within +/- 10 % of reading	Dynamic test
D	Resolution < .01 inch	Pre-launch test
D	Input/output signals will not interfere with station operation	Test proto
	Safety	
D	No exposure to harmful radiation	Measure rad
D	No exposure to temps > 35 C	Meas temp
D	Provide emergency halt	Test proto
D	No sharp edges	Inspection
D	No off gassing of harmful contaminants	Test proto
D	Flame retardant materials	Material data

	Ergonomics	
D	Means to secure hand to device	Test proto
D	Device does not irritate skin	Matl data
D	Maximum measurement time: 10 minutes	Test proto
D	Adjustable to humans within 95th percentile	Measure
D	Measurement does not alter hand physiology	Test proto
W	Usable by single astronaut	Test proto
	Operation	
D	Operate in: 18 - 30 C 50 % relative humidity	Test proto
D	Measure adequate hand dimensions to produce mathematical 3-D image	Test proto
D	Set up time < 25 minutes	Test proto
D	Fully functional in 1 micro-g environment	Dynamics
D	Noise limit: 55 dB	Measure
W	Noise limit: 35 dB	Measure
	Maintenance	
D	Lifetime > 12 months	Mathematic apx
D	Good for at least 30 hand measurements	
D	Maintenance < 1 hr per orbiting month	
	Production	
D	Prototype design time: 9 months	Records
D	Final production time: 2 1/2 years	Records
	Costs	
D	Total cost less than $75,000 U.S.	Records

SOLUTIONS

The 'black box' function structure and the generalized function structure for the hand anthropometry device is presented in Figure 1. From the function structure, three critical sub-functions were chosen to look for solution variants. The three critical sub-functions are position hand, take measurements, and send/store the data. The other sub-functions are either simple (remove hand), highly dependent on another sub-function (check set-up), or set by the specification list (supply power).

Figure 1. Function Structure for Flight Hand Anthropometry Device



Solutions for each of the three sub-functions were determined and are listed below. The solution variants with asterisks next to them are the ones which are eliminated in the next step of the design process. This will be explained in the following text.

<u>Position Hand</u>

1. Restrain with straps (velcro)
* 2. Restrain with straps (clasp)
* 3. Restrain with clamp
4. Place in pre-made impression
5. Visual placement in measurement area
* 6. Restrict with pressure (squeeze hand between surfaces)

<u>Measure</u>

* 1. Tape measure
* 2. Adapted calipers
3. Mold impression
4. Ultrasound
* 5. Sonar with hand in viscous medium
* 6. X-Ray
* 7. Radioactive isotope injection and detection
* 8. Heat sensing device
* 9. Magnetic Resonance Imaging (MRI)
10. Laser scan topography
* 11. 1 X 1 Macro photography
12. White light grid photography
13. Video recording with active background
* 14. Electrical resistance
* 15. Stocking type glove with measurement bands
* 16. Glove with piezoelectric pressure sensors
* 17. Sized tester gloves
* 18. Glove with pressurized compartments to measure hand shape/pressure at various positions

Send/Store Data

1. Store measurements electronically internally
2. Condition signal and send data to external computer

   Visual display:

* 3. Electronic

* 4. Dial

* 5. Inspection (ruler type)

* 6. Audio display

7. Mold of hand
8. Photographs
9. Video

The solution variants listed above were narrowed down by a systematic elimination process. First, those solutions that would not conform to the specs were eliminated. This is the reason the MRI measurement option was eliminated. The MRI's large magnetic field would interfere with spacecraft operation and it would require too large of a device to sufficiently shield such a device. Also, some measurement techniques were eliminated in this fashion because they did not have the proper accuracy or resolution.

Second, those solutions which were intrusive were eliminated. For a proper measurement of hand dimensions, the hand must be measured in its undisturbed state. Third, the send/store data solutions which could not handle the amount of information produced were eliminated. To properly measure the hand, large amounts of data are generated (easily millions of bits of information); therefore, a visual or audio display of the information would have to be recorded by hand, a huge and undesirable undertaking. Lastly, any clearly inferior solutions were eliminated. For example, velcro straps in hand are clearly better than a clamp for restraining a hand in micro gravity.

CONCEPTS

The remaining solution variants can be combined to get 75 (3x5x5=75) possible concepts. These 75 concepts can quickly be reduced to five concepts. This is because for this device there is only one truly independent sub-function, the measurement sub-function. Ideally, each sub-function should be independent, but in this case all the other sub-function solutions greatly depend on the measurement solution chosen. Two examples will illustrate this point.

Say we choose the mold impression solution for the measurement sub-function. Only the visual placement solution for the position hand sub-function and the mold of hand solution for the send/store data sub-function will work with the mold impression solution. There cannot be straps or some pre-form in a mold type device, and the obvious output is a mold.

Now, say we choose the laser scan topography solution. Now, only the visual placement solution (there cannot be any obstructions such as straps of an impression for the laser scan to operate properly) and the electronic output solution (needed for the sheer amount of data this process generates, internal storage would make the device unnecessarily large, expensive, and complicated) will work.

This process leaves us with five possible concepts to explore. They are 5-3-7, 5-4-2, 1-10-2, 5-12-8, and 5-13-9 as referenced to above. These concepts were researched to determine their technical feasibility, benefits, and faults. Also, the concepts were compared to the specification list to make sure they were acceptable. After this process, none of the five concepts were eliminated. These five concept, along with some pros and cons of their use, are briefly explained below.

Mold Impression

The goal of the mold impression technique is to produce a true size, three dimensional image of the hand. The process would be to create a mold in space which would then be brought down to earth to be used to make casts of the hand. These casts could then be scanned by any manner available to produce a mathematical three dimensional representation of the hand or used directly to create a proper size glove.

To make the mold, the astronaut would coat his hand with a substance so the visco-elastic mold material (typically some type of epoxy-resin) would not stick to the hand once it hardens. The astronaut's hand would be engulfed into the mold material and then the material would be allowed to stiffen. Once this occurs, the mold would be broken in half to release the hand and the mold would be complete (in two halves).

This process is inexpensive and simple, but takes time to finish. Also, the procedure for making the mold would need to be nearly flawless and a near perfect design for the mold to reach the precision demanded in the specifications.

<u>Ultrasound</u>

Ultrasound is a technique whereby a pulse of sound is sent from a transducer on the skin surface, or a small distance away, into the hand. This sound pulse is partially reflected whenever it crosses into an area of different acoustic properties. The time for this reflected wave to return to the transducer, which also has a device for receiving the reflected sound waves, is measured and an image of the hand is formed. The transducer can be moved, or aimed, to different parts of the hand to produce enough data for a three dimensional image of the hand.

This process is easy to use and the data is available immediately, but, a very sophisticated ultrasound device and technique is needed to achieve the resolution demanded by NASA in the specification list. This level of sophistication would make the ultrasound device bulky (extra equipment needed) and expensive.

<u>Laser Scan Topography</u>

For the laser scan topography method, the astronaut would simply place his/her hand in a 'box' (the scanning unit needs to be in closed container since laser light of this magnitude can be damaging to the eyes, but not the skin) and wait. The device measures the dimensions of the hand by moving a laser spot over the surface of the hand. As the spot moves, the objective of the lens, which controls from where the laser is pointing, also moves. A computer simultaneously record the position of the objective, the location of the laser spot, and the amount of reflected light which depend on the distance and directional facing of the surface being observed. This information can be assembled to produce a three dimensional layout of the scanned object.

This technique is precise, easy to use, and accurate. It does require the astronaut to be very still while being scanned, a process that could take upwards of ten minutes. This is a difficult prospect in micro gravity, even if the astronaut's hand is strapped to the machine. Also, this process is expensive and fairly bulky.

White Light Grid Photography

The white light grid photography method projects a grid composed of white light lines onto the surface of the hand. A picture is then taken of the hand. In the photograph, the grid lines appear distorted due to the curvature of the hand. By comparing the illuminating light (white grid light) and the line of sight determined by the camera location, the location of the grid points, and thereby the skin surface, can be found in three dimensions. By taking photographs at different hand and grid positions, enough data can be gathered to create a three dimensional image when the photographs are analyzed back on Earth.

This process is inexpensive and lightweight. It does require some knowledge of how to operate the device and may require some fine tuning to the technique and final design to get the resolution required in the specification list.

Video Recording With Active Background

This video process uses a high definition video camera and an active background. An active background is a high definition screen to which the signal is precisely controlled. The hand to be measured is placed between the camera and the active background (screen). The screen provides a high contrast between the edge of the hand and the background. The camera records in a 1 X 1 'macro' mode, whereby the recorded image can be played back to show the hand at true size. A computer attached to the camera and the active background compares the picture sent to the background and the image seen through the camera. From this, the computer can determine the two dimensional measurements of the hand. By moving the hand, many two dimensional 'pictures' can be taken which can be combined to form an accurate three dimensional model of the hand.

This process is easy, quick, and can generate a three dimensional image rapidly. However, the equipment is fairly expensive and bulky. The resolution just falls within specifications so should be precise enough for the device function.

<u>EVALUATION</u>

The five final concepts now have to be evaluated in respect to each other. To accomplish this, a decision matrix is used. The completed decision matrix is shown is Table 2. The concepts are given in roman numerals across the top of the matrix. These numeral correspond to how the concepts were presented in the text (I-Mold II-Ultrasound III-Laser IV-White Photo V-Video).

To determine the decision factors and their relative weights, the most important function of the device was looked at first. The function of the device is to accurately measure the hand, to do this it must have resolution and accuracy for reliability and confidence in the measurements. These two decision factors are weighted the heaviest and combined make up 34% of the design rating.

Next in weight is cost and size/weight. These geometrical properties are important in comparing the concepts against each other. The measurement time is important so as to not waste valuable astronaut time. The ease to make a 3-D model is important to the main function of the device, to make a model accurate enough to design a glove from. The ease of use is equally important because if the device is difficult to use, more errors will appear in the taking of data. The durability, resistance to unforseen damage and shocks, and data transfer characteristics are minor but still important factors.

Table 2. Decision Matrix

Design ----------->	wt	I	II	III	IV	V
Resolution	0.17	4	6	9	6	6
Accuracy	0.17	5	9	9	6	8
Cost	0.13	9	4	4	9	8
Size & Weight	0.13	8	5	5	8	7
Measurement Time	0.10	4	7	6	6	9
Ease to Make 3-D Model	0.09	9	7	8	6	8
Ease of Use	0.09	4	8	5	6	8
Durability	0.06	9	5	5	7	7
Ease of Data Movement	0.06	5	8	8	6	7
Weighted Sum ----->	1.00	6.15	6.6	6.78	6.71	7.51

Scale (1-10)

1	Unsatisfactory, doubtful to meet specs
4	Just meet specifications
6	Satisfied
8	Very Satisfied, confident with performance
10	Above and beyond what was expected or required

To determine the weights, all the decision factors were assigned arbitrary values relative to each other. These values were summed and each decision factor value was divided by this sum to get its percent weight. The scale (given below the decision matrix), shows how grades were given to the concepts. The specific grades given to each concept for the nine decision factors were determined from discussions within the design group. The grades reflect the pros and cons of the concepts which were presented in the last section.

Looking at the weighted sums for the concepts, concept V, the Video Recording with Active Background technique, had the highest grade. The grade is far enough above the other grades to recommend this technique for further design work. However, the grade is not large enough, in comparison with the other grades, to totally disregard the other four methods. These other four methods should not be ruled out. Perhaps with more in-depth knowledge, research, experimentation, and technology advances these other methods may indeed become a better choice. A decision has to be made with the information available, so the video technique is chosen to continue the design process.

CONCLUSION

During the conceptual design for the hand anthropometry device, it was found that only one sub-function was truly independent and that all the other sub-functions depended on this sub-function. This primary sub-function was the measurement sub-function. The solution choices for the measurement sub-function determined the solution choices for the other sub-functions. Therefore, when the solution variants to the measurement sub-function were narrowed to five, the final, 'top contender', concepts also numbered five.

When the final five concepts were compared in a decision matrix, the results were quite close. The technique of video recording with an active background did score higher than the other concepts. The score was high enough to choose this as the concept to proceed with, but not without reservations because of the near scores of the other concepts.

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