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Conceptual Design of a Device to Measure Hand Swelling in a Micro-gravity Environment

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ABSTRACT

In the design of pressurized suits for use by astronauts in space, proper fit is an important consideration. One particularly difficult aspect of the suit design is the design of the gloves. If the gloves of the suit do not fit properly, the grip strength of the astronaut can be decreased by as much as fifty percent. These gloves are designed using an iterative process and can cost over 1.5 million dollars.

Glove design is further complicated by the way the body behaves in a micro-gravity environment. In a micro-gravity setting, fluid from the lower body tends to move into the upper body. Some of this fluid collects in the hands and causes the hands to swell. Therefore, a pair of gloves that fit well on earth may not fit well when they are used in space.

This paper contains the conceptual design process for a device which can measure the swelling that occurs in the hands in a micro-gravity environment. This process involves developing a specifications list and function structure for the device and generating solution variants for each of the sub functions. The solution variants are then filtered, with the variants that violate any of the specifications being discarded.

After acceptable solution variants have been obtained, they are combined to form design concepts. These design concepts are evaluated against a set of criteria and the design concepts are ranked in order of preference.

Through this process, the two most plausible design concepts were an ultrasonic imaging technique and a laser mapping technique. Both of these methods create a three dimensional model of the hand, from which the amount of swelling can be determined. In order to determine which of the two solutions will actually work best, a further analysis will need to be performed.

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INTRODUCTION

In the exploration of outer space by humans, a need exists for specialized equipment to protect astronauts from the harsh environment encountered. One of these needs includes a fully pressurized suit that the astronaut must wear when he or she is outside the confines of the controlled environment of the space craft. Each of these pressurized suits must be custom made for the individual astronaut.

One aspect of suit design is the fitting of the gloves to the astronaut's hand. A good fit is important in order for the astronaut to be able to function properly. If the glove does not fit well, the effective grip strength of the astronaut can be reduced by as much as fifty percent once the space suit is pressurized.

In order to design a pair of gloves that fit a particular astronaut, a costly iterative procedure is undertaken. This procedure involves designing and manufacturing a pair of gloves for an astronaut and seeing if they fit. If the gloves do not fit, they are scrapped and the process is repeated until a suitable pair of gloves is found. This process can cost in excess of 1.5 million dollars (NASA handout, 1993).

Even if an acceptable pair of gloves is designed for the astronaut on earth, the gloves still may not fit well once in the micro-gravity environment of a low earth orbit. NASA studies have shown that in a micro-gravity environment, fluid from the lower body moves upwards into the upper body. Some of this fluid collects in the hands, thus causing the hands to swell. This hand swelling further complicates the design of a good fitting pair of gloves.

PROBLEM STATEMENT

The problem is to develop a specifications list and function structure for a method and/or device that can measure the swelling of the hands in a micro-gravity environment. After the function structure and specifications have been developed, solution variants will be proposed for each of the sub functions and design concepts will be obtained. These design concepts will then be evaluated and ranked in order of preference.

SPECIFICATIONS

The specifications for the device are given in Table 1 and are explained below. The specifications are broken up into sixteen different categories.

Table 1. Specifications List

Demand Wish Constraint	Specification	Verification
	Geometry:	
Constraint	Weigh less than 54 lbs (Klute, 1993)	weigh
Constraint	Should fit in a storage locker 14.46 in. wide by 18.67 in. deep by 9.59 in. tall (Klute, 1993)	measure
Constraint	Should be modular to facilitate transport and assembly	pre launch test
	Kinematics:	
Demand	Should secure and position the hand for measurement	pre launch test
	Forces:	
Constraint	Should withstand 3.3 g's launch and 20 g's hard landing (Klute, 1993)	pre launch test
Constraint	Should operate in a micro-gravity environment	design review
Constraint	Pressure on the hand should not hinder accuracy	pre launch test
	Energy:	
Constraint	Power consumption should be less than 100 W (Klute, 1993)	pre launch test
Constraint	Must operate on 28 V DC (Klute, 1993)	pre launch test
	Material:	
Constraint	Working temperature should be 50°F to 80°F with 50 % relative humidity (Klute, 1993)	pre launch test
Constraint	Materials must not off gas in vacuum or pose a fire hazard	Check material specs
Constraint	Material should withstand stress induced by tests	pre launch test
	Signal:	
Demand	Provide system operation and set up instructions	pre launch rev.
Demand	Provide physical dimensions and change in dimensions of hand as output	pre launch test
Wish	Provide dimensions in both SI and customary units	pre launch test
Demand	Provide a visible output display	design review
Demand	Provide a means of storing results	design review
Demand	Have a measurement accuracy of ±1 percent	pre launch test
Constraint	Should not interfere with other space shuttle equipment	pre launch test
Demand	Should measure swelling of both left and right hand	design review
Constraint	Should have resolution of 0.2 mm	pre launch test
	Safety:	
Constraint	Meet all NASA safety criteria	review specs
Constraint	Measurement must not injure subject	pre launch test
Constraint	All components pre tested prior to installation	pre launch test

Demand Wish Constraint	Specification	Verification
	Ergonomics:	
Demand	Ability to use on 5th to 95th percentile of individuals (Klute, 1993)	pre launch test
Demand	Clear visual display	pre launch test
Demand	Should be comfortable to user	pre launch test
	Production:	
Constraint	Production of one unit	count
	Quality Control:	
Constraint	Should be able to stand up to repeated use (1000 hours)	statistical analysis
	Assembly:	
Constraint	Maximum set up time of eight hours	pre launch test
Wish	Set up time much less than eight hours	pre launch test
Wish	Set up by single individual	pre launch test
	Transport:	
Constraint	Transport and use in space shuttle	
	Operation:	
Constraint	The test should take no longer than ten minutes	pre launch test
Demand	Measurements should be taken before leaving earth and no sooner than eight hours into mission	pre launch test
Demand	Should be able to calibrate before each mission	
Constraint	In order for test to be performed, the body must have been in micro-gravity for at least eight hours (Klute, 1993)	
	Maintenance:	
Demand	Modular components to facilitate replacement and repair	
Constraint	Should need major maintenance no more often than once every one year	statistical analysis
	Cost:	
Constraint	Should cost no more than $75,000.00 (Klute, 1993)	cost estimate
	Schedule:	
Constraint	Prototype should be ready in nine months (Klute, 1993)	schedule review
Constraint	Production model should be ready in 2.5 years (Klute, 1993)	

Geometry

Due to weight and size constraints on the space shuttle, the device must be on larger than a certain size and weigh no more than a certain amount. The device should be modular to help meet the storage size constraint.

Kinematics

To maintain the accuracy of the measurements, the hand must be secured in position and prevented from moving.

Forces

The device must be able to withstand the forces exerted on it during take off and landing. The device should not be damaged during take off, as it will need to be used while in orbit.

Since the device will be operating in a micro-gravity environment, it must be designed with that fact in mind. Extra hand holds or anchoring devices might be needed to provide for use in micro-gravity.

The restraints and anchoring systems used by the device should not influence the measurements in any way. Pressure on the hand may give a false reading for the value of swelling that has occurred.

Energy

The space shuttle has a limited supply of power and voltage sources. This device must be able to operate off of the shuttle's electrical system and should not create an excessive drain on the power supply.

Material

The measuring device will be operated in the crew compartment of the space shuttle. The crew compartment has a controlled temperature and humidity (Klute, 1993). The materials selected for the device should be able to operate in the environment of the crew compartment.

Some materials sublime in a vacuum. Sublimation is a process where the material undergoes a transition directly from solid to gas. This process occurs when the vapor pressure of the subliming components is greater than the partial pressures of those components in the surrounding atmosphere (Perry, 1984). The chance of sublimation occurring is increased in the oxygen rich, low pressure atmosphere of the shuttle crew compartment. Sublimation can lead to the release of toxic compounds. The material should not sublime in the crew compartment environment.

The material used should also be capable of withstanding the stresses induced by the use of the device. If this condition could not be met, the device would be useless.

Signal

The device should be able to measure the physical dimensions necessary to accurately calculate the swelling of the hand. The device should then be able to store these results for later use. The device should also output the results to some type of visual display.

The device should not interfere with other electrical equipment on board the shuttle. Interference with other systems on the shuttle could cause serious problems with navigation and communication, as well as life support and other vital functions.

Since the amount of swelling varies with the amount of work done, the device should measure the swelling in both the left and right hand. Individuals of one handiness will favor their dominant hand, thus causing the hand to swell more.

Safety

Since the device will be used on the space shuttle, the device should meet all NASA criteria with regard to safety. Other safety considerations state that the device should not injure the test subject in any way. To insure safe operation, all components should be tested prior to installation and use.

Ergonomics

The measuring device should be adjustable for use on individuals falling between the 5th and 95th percentile of the range of sizes with regard to the hand. Designing the device for a wide range of sizes will allow for a statistically accurate sample to be obtained.

The output display of the device should be easily readable. The device should cause as little discomfort as possible to the test subject.

Production

Due to the limited use of the device, production will be limited to one unit.

Quality Control

Since only one unit will be produced, the device should be able to withstand repeated use. The device must also be able to withstand multiple launches and landings, as the experiments will most likely be carried out over several missions.

Assembly

Since the test subject must have been in the micro-gravity environment for at least eight hours before the test can be performed, the maximum assembly time should be eight hours (Klute, 1993). This is not to say that eight hours is the optimal assembly time. A much shorter assembly time would be preferred. Set up by a single individual is also desired.

Transport

The device will be transported and used in the space shuttle (Klute, 1993).

Operation

To measure the swelling of the hand, it may be necessary to take a measurement before launch while the astronaut is still on earth. By making a measurement on earth, some reference point can be obtained on which to base future calculations. The measurement in space will need to be performed no sooner than eight hours after launch. Eight hours is the amount of time needed for maximum swelling to occur (Klute, 1993).

Maintenance

The device should have modular components to facilitate replacement and repair. If a damaged or inoperative component of the device can simply be replaced by a new component, the down time for repairs will be greatly reduced. The device should not require major maintenance more than once per year.

Cost

The device should not cost more than $75,000 (Klute, 1993).

Schedule

The time for the development of the first prototype is nine months. The time for the development of the working device is 2.5 years (Klute, 1993).

FUNCTION STRUCTURE

The most general function structure for the device is given in Figure 1. The hand is considered a flow of materials into and out of the function block. The function is to measure and record the swelling of the hands. Energy is a flow into and out of the system while signals flow out in the form of data.

Figure 2 presents the function structure broken down into the device's most basic sub functions. These basic functions are the set up for the measurement, the actual measurement, and the data acquisition and processing duties.

Figure 3 is the function structure with the essential sub functions shown. From this function structure, the sub functions for which to obtain solution variants are found. The measurement sub function is the most important, but the other sub functions are also critical. As can be seen from the diagram, the hand represents a flow of material through the set up and measurement stages. Signal flows from the measurement sub function to the data acquisition portion. Data acquisition consists of recording the data and providing the data as output.

SOLUTION VARIANTS

Once the specifications and function structure are obtained, the next step is to develop solution variants for each of the sub functions. After the solution variants have been obtained, they will be combined to form possible design solutions. The specifications list will then be used to discard incompatible solutions.

Table 2 presents the six major sub functions and solution variants for each. Notice that the sub function secure hand and release hand have been combined as these two functions are almost identical.

Table 2. Sub functions and their solution variants.

Provide Power	Secure/Release Hand	Position Hand	Measure Swelling	Output and Record Data
1. Shuttle Power Supply	1. Straps	1. Marks	1. Camera	1. Computer
2. Battery	2. Tape	2. Mold	2. Laser Topography	2. Human Recording
3. Human	3. Impression (mold)	3. None	3. Calipers	3. Digital Readout
	4. Glue		4. Magnetic Resonance Imaging (MRI)	
	5. None		5. Electrical	
			6. Change in Volume	
			7. Ultrasound	

What follows is an explanation of the various solution variants.

Provide Power. Three possible methods have been considered to supply power to the measuring device. One method is the internal power supply of the space shuttle. A second alternative is to operate the device off of some type of chemical battery. The third alternative is to power the device using some form of human power source.

Secure/Release Hand. There are several possible ways to secure the hand in place. These ways include using straps or tape to restrain the hand. Another alternative involves the use of some type of glue that would be suitable for use on humans. A mold could also be made in the general shape of the hand to prevent the hand from moving.

Position Hand. Two alternatives have been suggested to position the hand. One alternative is to use a mold, similar to that described for the Secure/Release Hand sub function. Another method would be to use makings or some other reference frame so the user would know where to place his or her hand.

Measure Swelling. The measurement of the swelling is the most crucial sub function, and therefore has the most design alternatives. These alternatives are explained in more detail below.

One method of measuring swelling is by using some type of visual technique. A camera could be used to obtain pictures before and after swelling had occurred and from these photos the necessary dimensions could be taken. The image could be digitized and stored in a computer. The computer could then measure the dimensions of various landmarks on the hand (Ghosh, 1983).

Laser topography would use a laser to measure the distance from a particular point on the hand to the laser. The laser could be made to scan over the entire hand. From this data, an elevation map of the hand could be made before and after swelling. A computer could then be used to measure the amount of swelling from this data.

Calipers could be employed to measure the amount of swelling present at various locations.

Magnetic resonance imaging (MRI) equipment could be used to generate an image of the hand. From this image, a computer could compute the change in dimensions of the hand and thus determine the amount of swelling.

An electrical technique is another alternative for measuring the swelling of the hand. This technique would use strain gages, attached to various points of the hand before launch. From the strain indicated by the strain gage, the change in the dimensions of the hand could be computed.

Two castings of the hand could be made, one prior to launch and another after swelling had occurred. By comparing the two castings, the change in volume of the hand could be determined, and this volume change could be related to hand swelling.

An ultrasonic technique could be used to generate an image of the hand, similar to the image generated by the MRI. From this image, the change in the dimensions of the hand could be found.

Output and Record Data. Two alternatives have been suggested for the output and recording of data. The first is the use of a computer to record all of the data points, calculate the swelling, and display the data on some type of display monitor. The second would involve the actual recording of the data by an astronaut by writing the data down or entering the data into some type of storage device. The third technique would simply involve some type of digital read out and would also require an astronaut to record the values.

Variant Selection

The next step in the process is to narrow down the number of solution variants and develop a reasonable number of design concepts. Solutions are discarded by comparing the solutions with the specifications and deleting those solutions which violate any of the specifications. If the solutions need to be narrowed down further, a binary decision matrix may be used.

Several of the solution variants do not meet all of the specifications. The battery solution variant would probably not meet the weight or size constraint. In order to provide 100 W of power, the batteries would have to be quite large and massive. The magnetic resonance imaging system would require large chillers to cool the super conducting magnets down to temperatures near absolute zero. These would undoubtedly weigh more than 54 lbs and the entire system would cost well in excess of $75,000.

Now that some of the solution variants have been eliminated, a binary solution matrix will be used to narrow the field of solutions for the measurement sub function. This matrix is presented in Table 3. The matrix reads, column n is better/worse than row m. A '1' represents better and a '0' represents worse. The score for each solution variant is tallied at the bottom of each column.

Table 3. Binary solution matrix for the measurement sub function.

	Camera	Laser topo.	Calipers	Electrical (strain)	Change in volume	Ultrasound
Camera	X	1	0	0	0	1
Laser topo.	0	X	0	0	0	1
Calipers	1	1	X	1	0	1
Electrical (strain)	1	1	0	X	0	1
Change in volume	1	1	1	1	X	1
Ultrasound	0	0	0	0	0	X
SCORE	3	4	1	2	0	5

From the solution matrix, the top four solution variants were chosen. These solution variants were ultrasound, laser topography, camera, and electrical (strain). These four solution variants are then combined with reasonable combinations of the solution variants for the other sub functions to develop the design concepts.

DESIGN CONCEPTS

The feasible design concepts are shown in Table 4. The possible solution variant for each sub function is shown, with each column comprising a design concept.

Table 4. Design concepts.

	Concept #1	Concept #2	Concept #3	Concept #4	Concept #5
Provide power	Shuttle power supply	Shuttle power supply	Shuttle power supply	Shuttle power supply	Shuttle power supply
Secure/ Release hand	None	None	Glue	Glue	None
Position hand	Marks	Marks	None	None	Marks
Measure swelling	Camera	Laser topography	Electrical (strain)	Electrical (strain)	Ultrasound
Output Data	Computer	Computer	Computer	Digital readout	Computer

The five design concepts are described below. The concept is describe and a brief discussion is included regarding the design specifications.

Concept #1. Concept #1 involves using a visual camera to take a picture of the hand. The concept is detailed in Figure 4. The photo can then be digitized and stored in a computer. From this digital information, the computer can construct a model of the hand or make precise measurements of various features. Since the camera shutter speed is large compared to that of the motion of the hand, no securing mechanism is required. The resolution the camera system can be as great as ±0.2 mm (Ghosh, 1983).

Concept #2. Concept #2 involves using a laser to develop a three dimensional model of the hand. This concept is shown in Figure 5. Again, if the scan rate of the laser is large compared to the motion of the hand, no securing mechanism will be required. The accuracy of this device is high as long as the dimension to be measured is large compared to the wave length of the laser light. A computer would be used to generate the model. There may be a problem with powering the device, however. A laser will need to be found that can operate on 28 V DC. The optics required for such a system will also need careful calibration.

Concept #3. Concept #3 involves gluing a series of strain gages onto various features of the hands before launch. As swelling occurs in the hands, the output of the strain gages will show a voltage. This voltage can be input into a computer and the change in the dimension that the strain gage is measuring can be computed. For instance, if the strain gage is glued around one of the fingers, the change in circumference would be measured. This change in circumference could then be used to calculate swelling (Sanders, 1987).

Concept #4. Concept #4 is essentially the same as Concept #3 but instead of a computer, a digital read out will display the voltage of the strain gage.

Concept #5. Concept #5 makes use of ultrasonic equipment to generate an image of the hand. The three dimensional image can then be displayed and processed by the computer. Ultrasonic imaging is also a highly accurate technique with resolutions of ±0.1 mm (Wells, 1983). There is some concern about the cost of this device and how much the device might weigh. The ultrasonic technique is shown in Figure 7.

CONCEPT SELECTION

The final step of the conceptual design process is to rank the design concepts. The evaluation of the design concepts will be accomplished by using a decision matrix. Each of the design alternatives will be evaluated against five weighted criteria. These criteria with their associated weights are cost (0.1), accuracy (0.35), maintenance(0.2), size (0.1), and signal type (0.25). The weights represent the relative importance of each of the criteria.

The weights for the above criteria were determined qualitatively as follows. At this stage of the process, most of the design concepts met the size criteria. The only remaining question was how much one weighed or how large one was when compared to another. Therefore, not much weight was given to this criteria. This argument would also hold for the cost criteria.

Accuracy was seen as an important design consideration, and therefore was given the most weight. The usefulness of the device will depend on how accurate the readings are. The more accurate the readings, the more useful the data obtained will be. High accuracy will allow NASA to develop a realistic model of hand swelling.

Maintenance is an important issue, though not as critical as accuracy. Having to repair the device while in orbit would be an unacceptable situation. Breakdowns while in space would be extremely costly. Therefore, maintenance is an important criteria.

Signal type refers to the value and quality of the information received with regard to the hand. The more detailed the information, the better the signal type. Signal type was given a high criteria for a similar reason that accuracy was. The better the signal type, the more realistic the model of the hand swelling will be.

The decision matrix is shown in Table 5. In this matrix, each of the design concepts are assigned a value between 0 and 10 against each of the criteria. The values are then multiplied by the criteria weights and the total score is found. The best design concept obtained from this process is the concept with the highest score.

Table 5. Decision matrix

	Concept #1	Concept #2	Concept #3	Concept #4	Concept #5
Cost	7	5	8	9	5
Accuracy	7	8	6	6	8
Maintenance	6	5	7	8	7
Size	8	8	8	9	7
Signal Type	8	9	7	5	9
SCORE	7.15	7.35	6.85	6.75	7.65

From the decision matrix, the design concepts are ranked from best to worst. The value for each of the functional criteria are explained below.

Cost. The electrical resistance measurements were considered the least costly, and therefore were given the highest cost rating. The camera system would be the next least costly, and both the laser topography system and the ultrasonic imaging system would both be expensive.

Accuracy. In terms of accuracy, the laser topography system and the ultrasonic imaging system would be the most accurate. Both of these systems should be able to obtain an accuracy of ±0.1 mm. The camera system would not be quite as accurate, but could be acceptable depending on the type of camera used. Both of the strain gage techniques would not be as accurate and would be more sensitive to errors caused by such environmental factors as temperature.

Maintenance. The strain gage with the digital read out would require the least amount of maintenance. The computer associated with the strain gage and the computer with the ultrasonic imager would be comparable. The optics associated with the laser and the camera systems would require more extensive maintenance and cleaning.

Size. The strain gage with the digital read out would be the best device in terms of size. The strain gage using the computer for data acquisition would be slightly larger. Both the camera system and the laser system would be comparable in terms of size. One would simply need to interchange the camera for the laser. The ultrasonic imager would be the largest of the design concepts since it would require the most hardware.

Signal Type. In terms of signal type, the best choices would be the ultrasonic imaging technique and the laser topography system. Both of these concepts would produce three dimensional models of the hand. The camera system would produce a fairly detailed model, but more work would be required to build a three dimensional model. The strain gages would simply give the values of the hand dimensions at discrete points.

The ranking of the design concepts is given in Table 6.

Table 6. Ranking of design concepts.

RANK	1	2	3	4	5
CONCEPT	Concept #5	Concept #2	Concept #1	Concept #3	Concept #4

One can see from the ranking that the ultrasonic technique and the laser topography method are the two solutions that merit further study. In order to determine which solution will be the best suited for the problem, the design concepts will need to be developed further and a more detailed analysis will need to be performed. This process will involve refining the design concepts further and determining which solution is better with regard to new set of criteria.

After the final design concept has been chosen, the actual design of the device will occur. In this design new problems may arise that will force the designer to return to one of the previous stages of the process. This cycle will be repeated until a working solution is obtained.

Figure 3. Final Function Structure

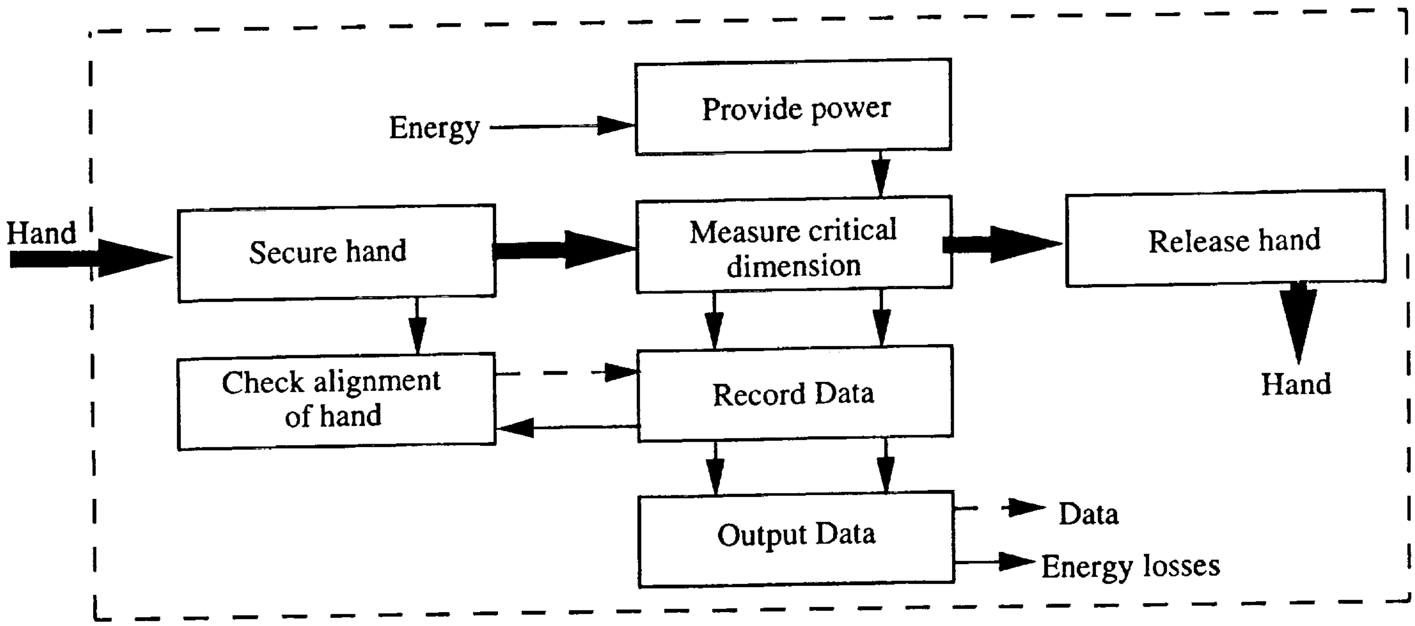


Figure 4. Concept #1. Camera.

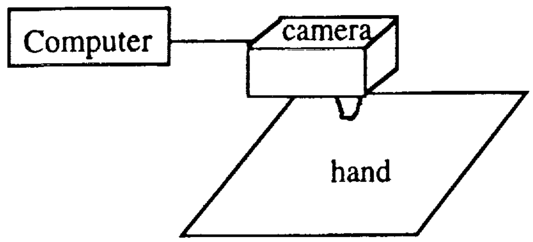


Figure 5. Laser topography.

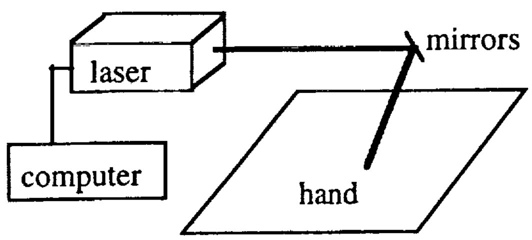
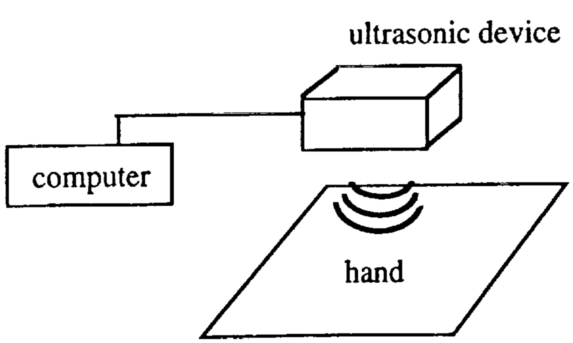


Figure 6. Ultrasonic Imager.



References

Ghosh, Sanjib K., "A Close-Range Photogrammetric System for 3-D Measurements and Perspective Diagramming in Biomechanics" Journal of Biomechanics, vol. 16, no. 8 (August 1983), pp 557-674.

Klute, Glen at NASA Johnson Space Center (Austin: March 8, 1993), telephone interview

Mechanical Engineering Department, "NASA Project 2," handout (Austin, TX: University of Texas, 1993)

Perry, Robert H., Perry's Chemical Engineers' Handbook (New York, NY: McGraw-Hill, Inc., 1984).

Sanders, Mark S. and Ernest J. McCormick, Human Factors in Engineering and Design (New York, NY.: McGraw-Hill, Inc., 1987).

Wells, P. N. T., "Ultrasound Imaging," in Non-Invasive Physiological Measurements, ed. Peter Rolfe (London: Academic Press, 1983), pp. 313-352.