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EXAMINING THE EFFECT OF TRANSVERSE MOTION
ON RETINAL BIOMETRIC IDENTIFIERS
RELATING TO SHIPBOARD SECURITY MECHANISMS

by

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Examining The Effect Of Transverse Motion On Retinal Biometric Identifiers Relating To Shipboard Security Mechanisms

by

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Submitted in partial fulfillment of the
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ABSTRACT

The use of retinal biometric identifiers as security devices in shipboard applications was investigated with the use of the DOT 7.5(new version) and DAISY 7.5(old version) scanners of the Eye-Dentify Co. of Beaverton, Oregon. Motion testing was the primary purpose of the thesis. It was the first occurance of dynamic testing on any type of retinal pattern recognition device. A transverse motion(only) simulator that could roll up to fourteen degrees and sustain a cycle per minute(cpm) rate of 6.0 was constructed and utilized. The nature of the experiment was to test the two scanners to determine if there would be significant differences in the characteristics of the two, and their possible uses at sea. Important conclusions were: 1) The best results occured on the DOT 7.5, although five Type II 'RECOGNITION' errors were noted; 2) As period of roll and angle of roll were increased in cpm's and degrees respectfully, results were poorer; 3) Identification threshold settings were allowed to be set too low at +0.60 by the CRT lock manager, and should be raised to approximately +0.70. That way, the probability of the occurance of Type II errors (false RECOGNITIONS/VERIFICATIONS) would be greatly decreased; 4) Retinal scanners are generally, very reliable.

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I. INTRODUCTION

The control of access to computer systems and other vital equipment is becoming increasingly important as they are entrusted with more sensitive applications and more valuable information. Much emphasis has been placed in increasing the accessibility of this equipment in order to accommodate the user and to enhance his ability to interact with it. This has posed new threats to system security and has emphasized the need for more adequate safeguards against unauthorized access (FIPS Pub 48, 1977, p.7). Aboard present Naval and Coast Guard vessels , passwords, cipher combinations, armed Marine guards for access to surface Navy nuclear propulsion spaces, I.D. cards etc. are the safeguards utilized to protect this equipment and space. Should there be more of the same or should government direct future planning towards replacing some of these basic methods with newer technology.

There are three methods by which a person's identity may be established: 1. something a person KNOWS like a password 2. something that he POSSESSES like an identification photograph, I.D. card etc. and 3. something physically ABOUT that person such as height, weight, and fingerprints. Others include hand geometry, voice patterns, finger length, and blood vessel patterns posterior to the retina.

Although weight can be useful in identifying someone, it is not as reliable as other physiological traits because the individual has the ability to change it through gain or loss. An unchanging unique identifier that no two subjects can identically possess, is most reliable when it comes to 'ABSOLUTE identification'. This compared to VERIFICATION of non-physiological items like passwords that are SUPPLIED by the subject attempting to gain access. Because of the vulnerability that the first two methods of identification have to threats such as theft and duplication, much emphasis is presently being focused on the technology of personal identification through physiological and morphological attributes(Rennick , 1975). Morphology is the study of the form and structure of an organism or any of its parts. Method three utilizes this technology.

The scope of this thesis was to determine if the installation of retinal biometric devices to assist in protecting vital areas is feasible in a shipboard environment. Two models of the Eye Dentify 7.5 retinal scanner by Eye Dentify Inc. Beaverton, Oregon were utilized during experimentation. See Figure 1.1 to view the DAISY 7.5 retinal scanner. Figures 2.2 and 2.3 display the newer version DOT 7.5 that has recessed eyeports. A transverse motion simulator with variable speeds and angle of roll up to fourteen degrees was used to simulate vessel motion.

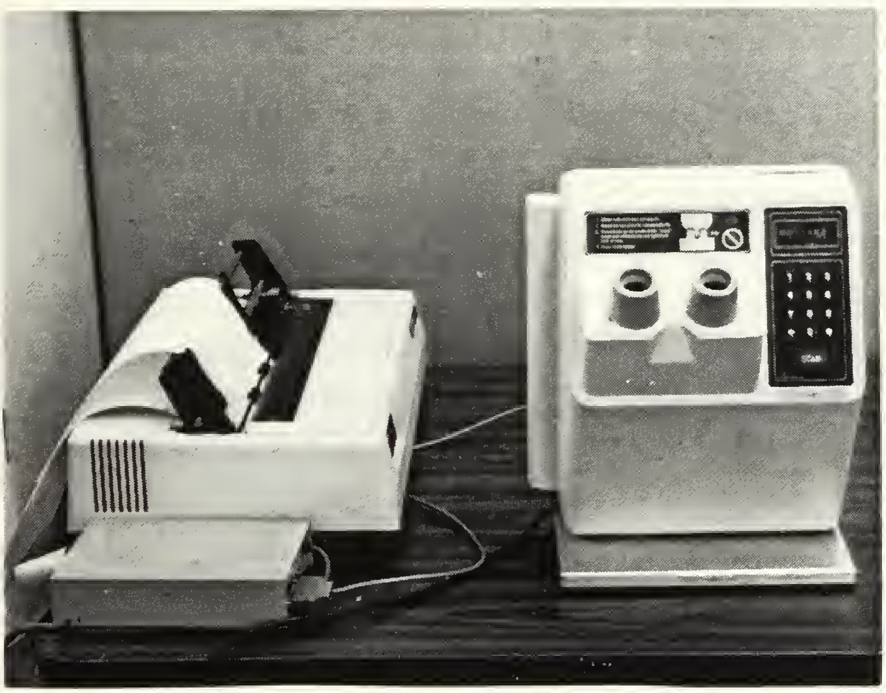


Figure 1.1 Eye Dentify Inc. DAISY 7.5 Scanner

II. THE EXPERIMENT

A. EQUIPMENT

The Eye-dentify machine is based on the concept of biometrics, the application of mathematical-statistical theory to biology. The 7.5 scanner utilizes the retinal patterns of humans as the unique identifier. This identifier is needed to disseminate between subjects trying to gain access to a security area via the 7.5. A study by Dr. Carleton SIMON and Dr. Isadore GOLDSTEIN concluded that,

> the spatial patterns exhibited by the internal blood vessels of the human eye are a highly stable , highly deterministic source of biometric information. (Goldstein, Simon, 1935)

Through the efforts of Dr. Paul Tower(1955), these prior findings were enhanced by his study that showed that the greatest dissimilarities between monozygotic(identical) twins, was in the retinal blood vessel patterns.

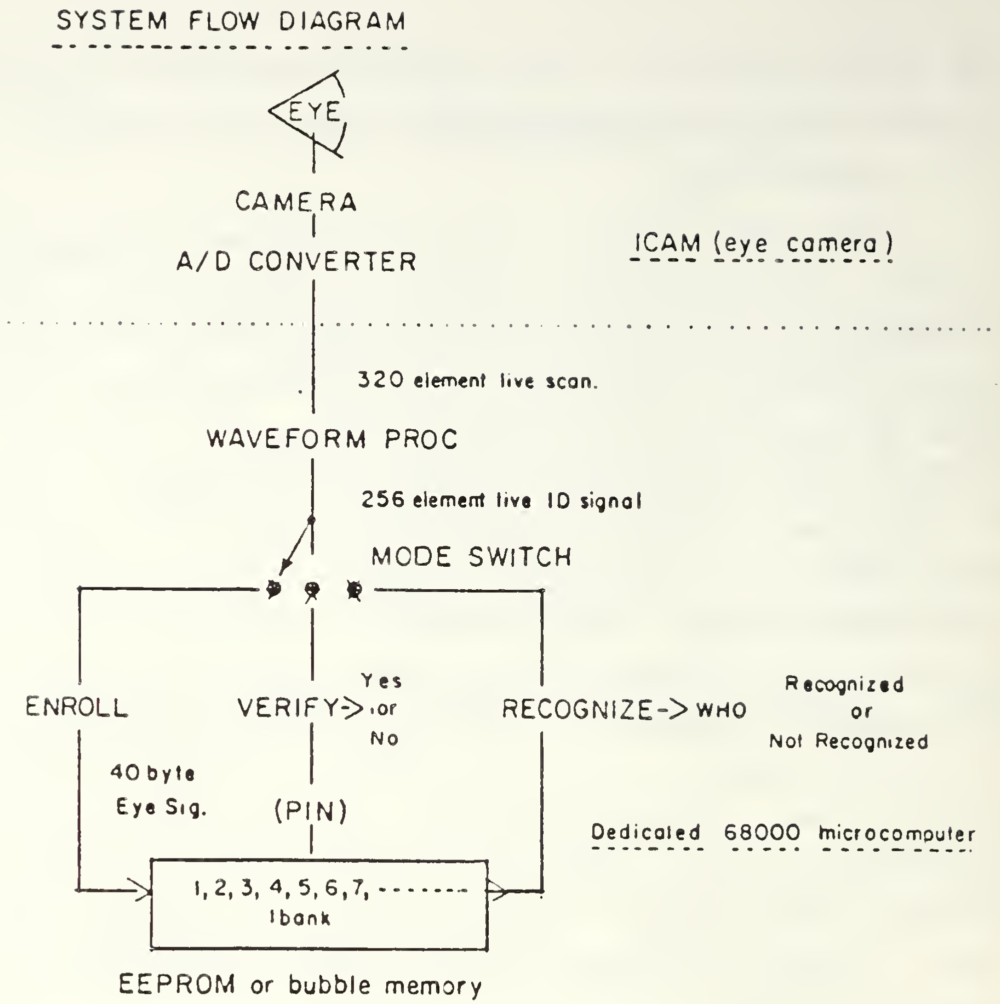
The hardware components for the two 7.5's include a binocular eyepiece for the DAISY and a recessed monocular(right eye) eyeport for the DOT. This difference is the only one between these scanners. Other components are LED display, cast aluminum housing, 12 digit keypad(0-9, # *), SCAN button, internal 68000 microcomputer chip and electronic camera. The weight of a 7.5 is approximately 26 pounds. External to the scanner is a system compatible terminal for I/O interface. A printer option was available through an auxiliary port. A 640K(RAM) microcomputer was used to 'download' data to floppy disk as a 'backup' or 'upload' to the 7.5.

The Eye-dentify 7.5 has internal software that controls the system's operation, and operation of external devices and IBANK storage for the signature templates corresponding to those human eye patterns that have been enrolled.

1. <u>ICAM Camera</u>

The ICAM(camera) scans/illuminates a fovea centered circle, on the inside posterior section of the eye which includes the retina and choroid. The retina, continuous with the optic nerve, is that part of the eye that receives the image produced by the crystalline lens. The optic nerve conducts impulses from the retina to the brain. The choroid is a delicate, highly vascular layer that is continuous with the iris(color surrounding the pupil) and lies between the sclera(part of the dense external covering of the eyeball) and the retina(Webster's Dic, 1984). The scanned circle has a 0.8 degree radius and its size, expressed as an external field half angle, is ten degrees. Infrared light is the medium used in illumination. The amount emitted is equivalent to the portion of infrared contained in the natural light shining from the bulb in a refrigerator. This same infrared is also found in home smoke alarms and VCR remote controls.

The light that is reflected off the blood vessels, retina and choroid, is passed through a photo sensor. It is then scattered and 320 12-bit measurements are captured along a 450 degree, (450/360= 1.25 rotation), camera lens scan. An analog waveform is developed and then digitized via an A/D(analog-digital) converter. The digital signal is then sent to the microcomputer chip for processing and then stored in IBANK memory as a 320 bit eye signature in PIN verification mode. See Figure 2.1 for an illustration of the system flow diagram.



EYE SIGNATURE - composite of live ID signals acquired during enrollment process. Each eye (left and right) is packed into 40 bytes (320 bits) for storage in the Ibank

ICAM - acquires and digitizes the identification pattern from the subject's eye

IBANK - Storage of all Eye Signatures (reference templates)

PIN - Personal Identification Number. Used in Verify mode to select specific Eye Signature for match

MODE SWITCH - Selects the mode of the 7.5. Enroll mode allows a new individual to be added to the Ibank. Verify compares a live eye with the Eye Signature designated by the PIN entry. Recognition automatically selects best Eye Signature from the Ibank

Figure 2.1 System Flow Diagram,Extrac.(Eye-Dentify 7.5,1984)

In verification mode with 1200 eye patterns on file, verification would take about 1.5(15/10) seconds. Of this time, six tenths(6/10) of a second is for rotational delay as the ICAM spins the 450 degrees(1.25 rotations) required in the scanning process. The remaining nine tenths (9/10) of a second is for processing bits in the microprocessor that are associated with the specific eye signature that is being compared to the 'live eye' just scanned. With recognition mode, the time required for individual processing depends on the number of templates in memory. With fifty templates, response time is approximately two seconds.

2. Recognition Eye Signature Data Structure

The eye signature data structure for recognition mode is 72 bytes (576 bits). Forty(40) bytes are used for verification purposes, thirty two(32) for recognition. The reason for this diversification is SPEED OF RESPONSE. Whenever scanning in recognition mode, whether there are fifty or twelve hundred templates in bubble memory, the five closest templates to the 'live eye' scanned are chosen for further comparisons. An algorithm based on fourier cross correlation is used on the (32 byte) recognize templates. This allows for the fastest possible selection of the five most similar templates. The corresponding time is actually less than 50 milliseconds for a sample of 100 subjects in bubble memory. (Eye Dent letter, Jan 86) Next, verification mode procedures are implemented on the chosen five to select the best template match for the live eye. The first verification that exceeds the threshold requirements is the eye that is considered recognized. The match is then displayed in the LED window and on a printer if connected. This explains why it takes longer to get a response when scanning in the recognition mode. Time for the fast fourier analysis plus the time for 5 verifications. If this method was not available, EACH template in bubble memory would have to be compared via verification methodology against the 'live' eye pattern. This would take an impractical amount of time. For example, with 200 subjects in memory and no fourier analysis, it would take ((9/10 sec/template)*(200 templates)= 3 minutes, and this would only be processing time.

B. THE MOVING PLATFORM

A moving platform was constructed to test how both the DOT and DAISY Eye-Dentify 7.5 would perform in a seaway. Transverse roll would be measured with the use of a protractor mounted horizontally and a plumb line hanging vertically. The platform was designed to roll only in one dimension due to money, time and material constraints. Therefore, this would eliminate the other sensations of motion that any individual riding aboard a vessel at sea would encounter. These would be YAW, angular motion about the vertical axis, and PITCH, fore and aft rotation about the Center of Floatation lateral axis. The testing would be done at rolls of seven degrees and fourteen degrees. These were chosen as being representative of common sea states. The mechanical constructs of the platform, and the output power of the electrical motor used to generate motion, hampered testing at angles greater than this.

The time(sec) from port to starboard to port was also varied on the moving platform. This to model the periodicity of waves as they pass under the hull of a ship and the resultant cycle times ,also known as Period of Roll that occur.(Naval Ships Technical Manual 079 VOL.1 -Stability and Buoyancy, 1983) The height of a wave at sea, and also its length in feet from crest to crest will have an effect on a ship's "ride". To capture this phenomenon, a permanently lubricated ZERO-MAX variable drive attached to a three quarter horsepower, sixty hertz, 1725 rpm electric motor was used. This variable drive was rated to deliver a maximum of 100 inch-pounds of torque to its output shaft. A 10:1 reduction gear was connected to this output shaft to create the desired shaft rotation needed to rotate the 10.25 inch diameter drive wheel that the 19.5 inch drive arm was attached to. This drive arm, that was connected to the platform, required lubrication with graphite bearing grease. Although this was the case, there were two instances where bolts used to connect the drive rod to the drive wheel did fail under load.

To insure that all measurements which dealt with cycle time were noted under a constant regimen, a benchmark scale located atop the ZERO-MAX was utilized. This scale had values ranging from zero to six. With the use of a hand wheel that adjusted the ZERO-MAX, a setting within this range could be established. Simply, a direct relationship between the benchmark setting and the cycle time(sec) occured. The higher the setting, the faster the cycle time. If set at a value of 6, the cycle time in seconds was very small meaning the moving platform would "snap" back and forth from port to starboard. For experimentation purposes, Eye-Dentify 7.5 scans using both DOT and DAISY machines were taken at benchmark values of 1.0 and 1.5. These settings gave respective cycle times of approximately 10 seconds and 20 seconds. The first value representative of a turbulent sea state with rough seas, the second a more moderate , gentle sea state.

The platform was mounted inside a rectangular base used for structural strength. Two plywood mounting braces were installed on either side of the moving platform. One was used as a safety step for students to mount and dismount the platform, the other as a mount for the motor, variable drive and reduction gear. The platform was hex bolt pinned forward and aft, to the rectangular base. It was about these points, that the platform would rotate transversely. Subjects were allowed to mount and dismount only from the right side. This way they would have no interaction with any of the mechanical devices. A chair was mounted centrally on the plywood platform base. Initially, the subjects were to be tested in the standing position, but this proved to be unrealistic. At faster cycle times, they were unable to safely maintain their balance. Also, in the standing position, their weight would be distributed at a higher center of gravity thereby putting undue loads on the slip belt of the variable drive, which inevitably might have lead to a mechanical failure. See Figure 2.2 below and 2.3 on the following page for visual description of the platform and the DOT 7.5 scanner.

Figure 2.2 The Transverse Motion Simulator-Side

Figure 2.3 The Transverse Motion Simulator-Rear

A seatbelt was required at all times when data collection was undertaken for safety considerations. The 7.5 was mounted at a height of 40.5 inches above the platform in compliance with prior guidelines determined at the Sandia National Laboratories, Albuquerque, New Mexico, in June 1985 (Maxwell,undated). This height allowed the least amount of stooping when eye scanning in the sitting position. The system operator controlled the electric motor via a remote switch, and would instruct each person in the operation of both the DAISY and DOT 7.5 prior to starting the motor. Because each subject had been through an earlier explanation during initial template enrollment , this second explanation only had to be done once, saving much time.

Connected to the auxiliary port of the Eye-Dentify was an Okidata u93 serial printer. Output displayed on the printer was subject's PIN(personal identification number),identification code, which can be any letter or number ,whether the person (was/was not) VERIFIED/RECOGNIZED, correlation score and the date. The LED display of either machine will show up to eight of these characters.

C. THE OBJECTIVE

The objective of this experiment was to compute Type I and Type II error rates when subjects were tested under dynamic conditions created when the transverse motion simulator was used. The recognition and verification thresholds would be held constant at +0.60. Results from an earlier test that used the Range Test on Means method (Helle,1985) indicated, little difference in findings between the lowest possible setting of +0.60 and the midpoint setting of +0.72. Therefore, +0.60 was chosen to ascertain how each retinal biometric scanner would perform under the least stringent threshold setting.

This would be the first occurance of a dynamic test on any Eye-Dentify 7.5. All earlier tests were static. As experimentation proceeded, results showed an unusually large occurance of Type II errors with the DOT 7.5, especially in VERIFICATION mode to specific individuals. Therefore, an additional objective was included, to determine if the accuracy of this biometric scanner was worse than advertised.

The research dealt with the possible use of these scanners aboard Coast Guard and Naval vessels in a variety of applications, such as radio and crypto spaces. Other significant potential uses at sea are access to computers and their systems, the CMS(communication security material system) vault, supply office cash vault, the entrance to nuclear engineering spaces, and activation of a weapon launch. Also possible is communication equipment control and security, including authentication and recognition. Additional military applications might include strategic and tactical command control, security for, or part of the nuclear missile launch sequence at our silos.

An added plus, was the availability of the newer version DOT 7.5 scanner to the system operator. Not only could the question of how motion affects the system be investigated, but an additional objective of comparing ease of use, accuracy, and the number of Type I and Type II errors that occur between the DOT and DAISY be scrutinized. These objectives were made as specific as possible to create an atmosphere of simplicity, thoroughness and accuracy.

D. EXPERIMENTAL PROCEDURE

Sixteen subjects were chosen at random from a total of approximately sixty students that were enrolled in the same MAN-MACHINE INTERACTION course at the Naval Postgraduate School. Taking this specific course did not unfairly prepare any of these students for the extensive experimentation that was to follow. Three females and thirteen males(14 military, 2 civilian) were chosen with the use of a random number generator. Their ages ranged from a high of 51 to a low of 27. Those that wore contacts were allowed to wear them during the analysis, while glasses were not. They hampered some subjects during scanning. None of the sixteen stated that they were totally or partially color blind. During the initial enrollment process, all sixty OS3404 class members, became the template database. There were instances where students not involved with the motion testing exhibited either slight color blindness or chronic stigmatism, which caused trouble when trying to enroll them into the DAISY 7.5. This was not the case with the DOT 7.5. None of the sixty had ever used either 7.5 system before.

1. The Enrollment Process

To implement the enrollment process, a system compatible CRT (Cathode Ray Tube) was required to be connected via ribbon cable to the terminal port of the 7.5. Assuming power has been secured to the system, the operator had to first gain access to the software main menu. This was done by scanning his own eye. This allows access because the system operator was listed under CRT lock management, another name for database management. After this step, enrollment may be initiated by typing E with a carriage return. When enrolling a person, they must be directed to concentrate because very low correlation scores will occur if instructions are not followed. Below are the guidelines to follow when enrolling ONLY on the DAISY wheel scanner:

1. Square the head up to the binocular eye ports.

2. Look into the eye ports and concentrate only on the center of the daisy design to the upper left. Ignore the second one you see to the lower right. The left eye port is blanked off and it slides left and right to provide a comfortable fit. Keep both eyes open.

3. Move your head about, until all red is removed from view with only the greenish-white daisy design remaining. This is where the majority of problems occured with subjects who were slightly color blind to greens or reds.

4. Press the SCAN button on the front of the machine very gently. Erroneous data can occur by moving the machine when pressing too hard if it is not permanently mounted.

The following are guidelines implemented when enrolling ONLY on the DOT scanner:

1. Square the head up to the machine and place forehead on headrest. Notice there are no binocular eye ports, only one recessed eye port for the right eye. The white line adjacent to this eye port is to be used optionally to align the center of the right pupil to the center of the eye port.

2. Once on the headrest, do not move the head up or down, only to the left or right when you have the beam of light in view. You will perceive depth that you did

not sense when using the DAISY. Place the 3 dots of light that appear atop one another in a vertical line. One dot will now appear. Place it in the center of the outer semi-circular ring. For some, the dot will look as if it is the apex of a three dimensional cone. The act of fixating on this dot or the center of the daisy pattern in the older version 7.5 centers the scan circle on the fovea. This is the part of the retina that corresponds to the center of vision.

3. Press the SCAN button gently, as with the DAISY. It is also located in the same position mentioned earlier.

When the SCAN button is depressed, the ICAM camera is activated and a template is created and stored in memory. After the first scan, a message will display on the CRT. At this point the system operator has three choices:

1. Finish enrollment and identify PIN (personal identification number) with a code.

2. Restart the Enrollment Process -

   retaining only the previous retinal scan as the beginning of a new reference template. All previous eye signatures accumulated during the enrollment session are erased. This function is useful when previous correlation scores have been low and the enroller wishes to restart the enrollment process. (Eye-Dentification Inc., 1985)

3. Cancel the current session altogether.

To acquire OPTIMUM memory templates, user manual procedure required the enroller to take at least 5 eye scans where the average correlation score of the entire five was +0.90. These correlation scores appear automatically on the CRT display terminal and they can be ignored or averaged with the person's template stored in memory. All sixteen subjects associated with the moving experiment not only met this requirement but were able to be enrolled with accepted correlation scores never below +0.90, so any average of the five scans taken would be well above +0.90. A <u>correlation score</u> is the mathematical representation computed by the 68000 microprocessor that defines how similar that live eye scan just processed is to the person's most recent template in Ibank memory.

2. Factors Tested

When testing began using the transverse motion simulator, the sixteen subjects were told to report during announced times. They would have to report eight separate times with at least a one hour delay between tests, for learning curve purposes. The commencement date was 08 November 1985 with completion of all phases of the experiment occuring on 27 November 1985. Both the drive arm linkage, DAISY and DOT machines had to be changed and adjusted manually for the duration of the experiment, which is one reason for such an expanded time frame. The drive arm procedure in particular, was considerably time consuming. On the drive wheel, were drilled 7/16 inch threaded holes outward from its center in the form of an arc, through which the connecting 7/16 inch bolt would pass through. Here, the drive wheel and drive arm were attached. The bolt would have to be moved to a new hole along the arc, whenever a change in angle of roll was required in the analysis. Criteria for experimentation required the machines to be scrutinized under the same conditions, chosen on a random basis. These FACTORS are listed below:

1. DAISY Scanner
2. DOT Scanner
3. Angle of roll 7 degrees
4. Angle of roll 14 degrees
5. Cycle time of 10 seconds corresponding to a setting of 1.5 on ZERO-MAX scale.
6. Cycle time of 20 seconds corresponding to a setting of 1.0 on ZERO-MAX scale

A successful recognize was represented by a Y(YES) in the system operator's log sheet. For this to happen, a subject would have to receive a correlation score equal to +0.60 or higher with their personal identification number (PIN) and identification code correctly identified. If the statement NOT RECOGNIZED were to appear, it would mean their correlation score was lower than +0.60. In this instance, no PIN or identification code is printed, only the correlation score and date appear. As noted earlier, if this were to successively happen three times, the warning SEE SECURITY SEE SECURITY SEE SECURITY would flash in red letters on the digital display on the face of either 7.5 machine. Inclusive with this is an audible alarm that would sound for a pre-programmed duration. This sound and L.E.D warning announced the occurance of a TYPE I ERROR, as the individual was attempting to be RECOGNIZED/VERIFIED.

3. Hypothesis Type I Errors

Formally, the HYPOTHESIS for this Type I error analysis is: the subject attempting entry IS located within IBANK memory. This hypothesis is true, but if the hypothesis is true and it is REJECTED, an error has been committed known as Type I error (Freund|Williams, 1982, p.316). The system would NOT allow the individual to gain access, when it SHOULD have. When a Type I error did occur, a notation was made in the log sheet using the symbol N for NO.

At each session, all sixteen subjects were required to complete six trials. One trial is defined as receiving either a Y or N. Two sessions of six trials would have to be finished before the subject was considered done in reference to testing under a specific FACTOR. It was the system operator's responsibility to randomly assign cycle per minute settings of either 6.0 cpm or 3.0 cpm as the subject was being tested in the motion simulator. An example to provide clarity follows.

On day one, subject 0037 reports at 1100am to be tested using the DAISY scanner at a roll of 14 degrees. Before energizing the electric motor, the system operator sets the handwheel atop the variable drive to correspond to a cycle time of 10 seconds. Six trials are to be taken, so the first three trials are noted with the cycles per minute(cpm)at 6.0((60sec/min)*(1cycle/10 sec)). The second three trials are taken with a 3.0 cpm. The system operator was able to vary CPM settings as the platform rotated. This way the student would not be distracted and physically jolted by a constant starting and stopping of the motor.

Initially, many students were inquisitive concerning when they should depress the SCAN button when testing on the transverse motion simulator. Common sense would tell them to do this at either a roll of zero degrees or at the extreme port or starboard angle of roll. It was at these positions, that upright attitude for the former and relative motion for the latter , create the most comfortable atmosphere. All sixteen who participated, were instructed to depress the SCAN button whenever they felt at ease in doing so, ensuring that data would be collected in a RANDOM manner. From the onset, there was never a problem with retaining totally random roll positions that 7.5 scans were taken at. As time progressed, their apprehension was alleviated, because with repetition, they saw how easy it was to scan at any angle.

The format of the four log sheets maintained by the system operator consisted of two columns used to annotate a Y or N score. The left column for data entries corresponding to a shipboard period of roll of TEN seconds and the right a period of roll of TWENTY seconds. The six separate testing FACTORS (DOT, DAISY, roll=7, roll=14, cycle time 10 sec, cycle time 20 sec) made up the log sheets and are noted in the following list.

1. Log sheet 1: Using the DAISY ICAM at seven degree roll

2. Log sheet 2: Using the DAISY ICAM at a fourteen degree roll

3. Log sheet 3: Using the DOT ICAM at a seven degree roll

4. Log sheet 4: Using the DOT ICAM at a fourteen degree roll

As mentioned previously, all scans were taken in the RECOGNITION mode, where that scan would have to be matched against all 576 bit(72 byte templates):

> either stored in the EEPROM (electrically eraseable programmable read only memory chip) for twenty or less enrollees, or BUBBLE MEMORY with a capacity of up to twelve hundred enrollees. (Eye-dent, 1985)

While the VERIFICATION mode provides greater security than the RECOGNITION mode because both an eye scan and a PIN must be correctly accepted by the machine, it was not included. VERIFICATION requires personnel to MEMORIZE and physically KEY-IN their personal identification number(PIN) to the twelve digit keypad on the face of 7.5. This defeated the purpose of investigating a system that does not require the use of a memory code or password. One of the directions that this thesis was determined to take was analyzing this very principle. <u>ONLY THROUGH THE RECOGNIZE MODE COULD THIS BE ACCOMPLISHED</u>.

E. THE RESULTS

NOT RECOGNIZED percentages were computed by counting all scans taken by either the DOT or DAISY scanner at the appropriate angle of roll. This number was then divided into the number of correlation scores that were +0.59 and lower. These percentages are listed in Table 1 . The newly introduced DOT 7.5 clearly shows in its data that when used, queue time drops significantly when compared to the DAISY.

For example, at fourteen degrees inclination, only 13 out of 202 DOT scans(6.44%)were logged as NOT RECOGNIZED (which means that scan was unacceptable), while 66 out of 251 scans(26.29%) was the corresponding percentage for the DAISY. Additionally, for BOTH machines, as the angle of roll increased, the higher the ratio of NOT RECOGNIZED to TOTAL scans . This implies increased queue time, the greater the sea state. Figure 2.4 is a column chart, with NOT RECOGNIZED percentages for the DAISY 7.5 and the DOT 7.5 on the y axis versus angle of roll in degrees on the x axis.

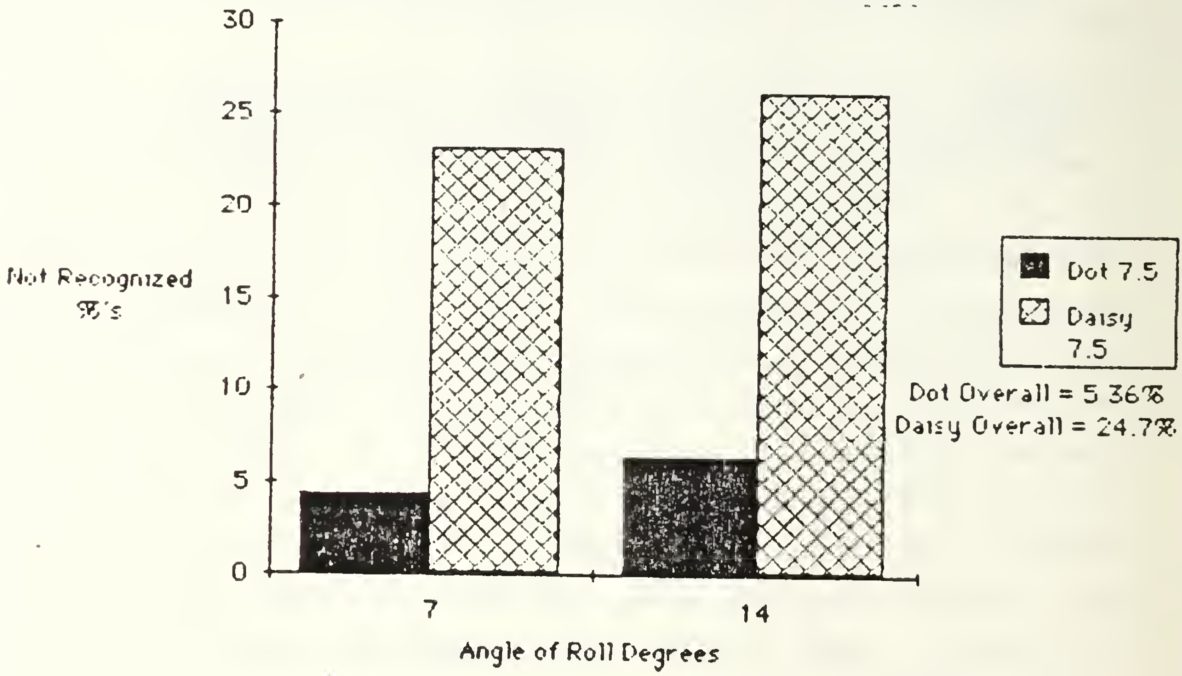


Figure 2.4 Not Recognized Percentages

AVERAGE CORRELATION SCORES for RECOGNIZED PIN's were computed by summing correlation scores(+0.60 and higher), from the appropriate serial printer log sheet and dividing by the number of successful recognized scans. This for a particular Eye-Dentify and its requisite testing criteria. This data is noted in Table 2 . DOT 7.5 scores for seven and fourteen degrees of roll were above the +0.90

TABLE 1

NOT RECOGNIZED PERCENTAGES

DAISY 7 DEGREES: 58 NOT RECOGNIZED OUT OF TOTAL OF 251 SCANS 58/251= .2310 = 23.10%
DAISY 14 DEGREES: 66 NOT RECOGNIZED OUT OF TOTAL OF 251 SCANS 66/251= .2629 = 26.29%
DOT 7 DEGREES: 9 NOT RECOGNIZED OUT OF TOTAL OF 208 SCANS 9/208= .04326 = 4.326%
DOT 14 DEGREES: 13 NOT RECOGNIZED OUT OF TOTAL OF 202 SCANS. 13/202= .06435 = 6.435%
DAISY OVERALL: 124 NOT RECOGNIZED OUT OF TOTAL OF 502 SCANS 124/502=.2470 = 24.70%
DOT OVERALL: 22 NOT RECOGNIZED OUT OF TOTAL OF 410 SCANS 22/410=.0536 = 5.36%

plateau, (+0.912, +0.906 respectively) easily surpassing the maximum allowable RECOGNITION threshold setting of +0.85. The system operator might want to implement this setting(+0.85) for maximum security requirements. The DAISY 7.5 was in the low "eighties", (+0.823,+0.802) respectively and would not have met this limit. It is noteworthy to realize that these are only AVERAGES, nonetheless this comparison between the two machines does imply a definite trend that they have differing performance characteristics.

Both DOT and DAISY machines had AVERAGE correlation scores for NOT RECOGNIZED scans in the same range of (+0.41 - +0.44). Figure 2.5 is a column chart of average CORRELATION scores for the DAISY 7.5 and DOT 7.5 on the y axis versus angle of roll in degrees on the x axis.

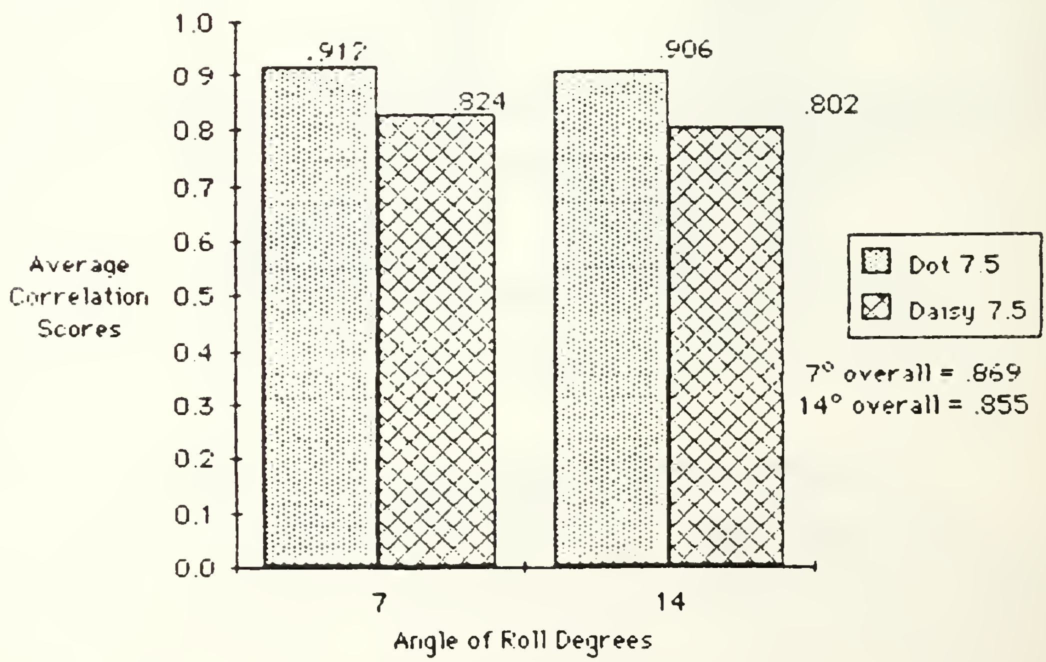


Figure 2.5 Ave Correlation Scores

TABLE 2

AVERAGE CORRELATION SCORES

DAISY 7 DEGREES: AVE CORRELATION SCORE FOR RECOGNIZED WAS 159.21/193= +.8249

AVE CORRELATION SCORE FOR NOT RECOGNIZED WAS 25.68/58=.4427

DAISY 14 DEGREES: AVE CORRELATION SCORE FOR RECOGNIZED WAS 148.37/185= +.8020

AVE CORRELATION SCORE FOR NOT RECOGNIZED WAS 29.51/66=.4471

DOT 7 DEGREES: AVE CORRELATION SCORE FOR RECOGNIZED WAS 181.51/199= +.91211

AVE CORRELATION SCORE FOR NOT RECOGNIZED WAS 3.73/9 =.4144

DOT 14 DEGREES: AVE CORRELATION SCORE FOR RECOGNIZED WAS 171.37/189= +.90671

AVE CORRELATION SCORE FOR NOT RECOGNIZED WAS 5.75/13=.4423

AVE CORRELATION SCORE FOR 7 DEGREES WAS 340.72/392= +0.8692

AVE CORRELATION SCORE FOR 14 DEGREES WAS 319.74/374= +0.8549

AVE CORRELATION SCORE FOR CPM OF 3.0= +0.8508
AVE CORRELATION SCORE FOR CPM OF 6.0= +0.8377
DAISY OVERALL AVE CORR. SCORE 307.58/378= +0.8137
DOT OVERALL AVE CORR. SCORE 352.88/388= +0.9095

As stated earlier, a trial was complete when either a Y(yes) for a RECOGNIZED eye scan was logged or a N(no) which represented a TYPE I error(three successive NOT RECOGNIZED eye scans) was noted. A binomial distribution was expected concerning the data dealing with these trials, where the number of trials was fixed, the probability of a success was the same for each trial, and that the trials were all independent (Freund|Williams, 1982). The trial results collected on each subject were logged in groupings of six, and each had a particular cycle per minute speed setting, angle of roll and 7.5 machine associated with it. Data points could then be found by solving for the ratio of Y(yes) trials in the numerator divided by 6 total trials in that grouping. Three proportions were noted. They were (6/6)= 1.00, (5/6)= 0.833 and (4/6)= 0.666. There were a total of 128=(768 trials/6) separate data points. The mathematical transformation formula y= 2arcsine(sqrt(x)) was used to stabilize the variance in the data (Winer, 1971). To utilize this equation, the values 0.666, 0.833 and 1.00 had to be converted to radians. These radian values were 3.1416(pi), 2.3006 and 1.9106 respectively, and were entered as (x) in the transformation formula. A level of significance of 0.05 was selected when using F tables.

A four way analysis of variance(AOV) done by a computer AOV 'package' was implemented on the data. The results are listed in Table 3 .

The analysis showed that the effect of both A(angle of roll) (F= 5.7870, DF= 1,15) and Su x Sp x A (F= 2.8070, DF= 15,15) were the most significant relationships measured.

TABLE 3

ANALYSIS OF VARIANCE/EYE-DENTIFY 7.5 RECOGNITION RATE

SOURCE	DF	SS	MS= SS/DF	F= SS/MS|err	F ratio from tables	
Su(Subjects)	15	1.1877	0.0792	1.9850	2.40	
Sp(Speed)cpm	1	0.0012	0.0012	0.0301	4.54	
A(Angle)	1	0.2309	0.2309	5.7870	4.54	*sig*
M(Machine)	1	0.1101	0.1101	2.7594	4.54	
Su x Sp	15	1.3376	0.0892	2.2356	2.40	
Su x A	15	0.7543	0.0503	1.2607	2.40	
Su x M	15	0.8750	0.0583	1.4612	2.40	
Sp x A	1	0.0130	0.0130	0.3258	4.54	
Sp x M	1	0.0012	0.0012	0.0301	4.54	
A x M	1	0.0335	0.0335	0.8396	4.54	
Su x Sp x A	15	1.6793	0.1120	2.8070	2.40	*sig*
Su x Sp x M	15	0.9839	0.0656	1.6441	2.40	
Sp x A x M	1	0.0336	0.0336	0.8421	4.54	
Su x A x M	15	0.5979	0.0399	1.0000	2.40	
ERROR	15	0.5979	0.0399			
TOTAL	127	8.4371				

Level of significance = 0.05

III. DISCUSSIONS

A. ERRORS

1. Type I Errors

The listing shown in Table 4 and Table 5 gives the breakdown of Type I errors that occured, given a particular Eye-Dentify machine, cycle per minute rate(represented by ZERO-MAX settings of either 1.0 or 1.5) and angle of roll. The numerator of the fraction, contains the number of false rejections(three NOT RECOGNIZED scans sequentially by the same person) and the denominator, the total scans attempted by the individual under these criteria.

The four column charts that follow Table 4 and Table 5, display Type I error results. Figure 3.1 charts the NUMBER of Type I errors on the y axis versus DOT and DAISY scanners on the x axis. Figure 3.2 charts the NUMBER of Type I errors on the y axis versus the period of roll in cycles per minute on the x axis. Figure 3.3 charts the NUMBER of Type I errors on the y axis versus the angle of roll in degrees on the x axis. Figure 3.4 charts the Type I error PERCENTAGE for this experiment only, on the y axis versus the corresponding DOT and DAISY scanner on the x axis.

The overall Type I error rate was thirteen errors out of a total of 768 trials or 1.69%. Brochures from the Eye-Dentify company(1985) state that, "the chance of a false rejection(Type I error) is AS LOW AS 0.1% dependent on the system threshold setting and proper use." (Eye-Dentify Inc., 1985) No formal experiment was published which indicates that this probability was tested (Helle, 1985). A company spokesman did elaborate though, that this value could be achieved under ideal conditions , consisting of

TABLE 4

TYPE I ERROR RATES

	14 DEGREE ROLL DOT SCANNER	
Cycle/Min rate --	3.0	6.0
TY. I ERROR/TRIALS	2/96= 2.08%	1/96= 1.04%
	14 DEGREE ROLL DAISY SCANNER	
	3.0	6.0
	3/96= 3.13%	4/96= 4.17%
	7 DEGREE ROLL DOT SCANNER	
	3.0	6.0
	0/96= 0.00%	1/96= 1.04%
	7 DEGREE ROLL DAISY SCANNER	
	3.0	6.0
	1/96= 1.04%	1/96= 1.04%

TABLE 5

BREAKDOWN OF TYPE I ERRORS

TOTAL NUMBER OF TYPE I ERRORS (N)= 13
DAISY TYPE I error = 9 out of 13
DOT TYPE I error = 4 out of 13
14 DEG ROLL TYPE I = 10 out of 13
7 DEG ROLL TYPE I = 3 out of 13
CYCLE TIME 10 sec = 7 out of 13
CYCLE TIME 20 sec = 6 out of 13
768(96*8) TRIALS LOGGED DURING TESTING
OVERALL TYPE I FAILURE =13/768=.0169=1.69%
OVERALL SUCCESS =1-.0169=.9830= 98.30%
DAISY TYPE I ERR% = 9/(768/2)= 2.34%
DOT TYPE I ERROR % = 4/(768/2)= 1.04%

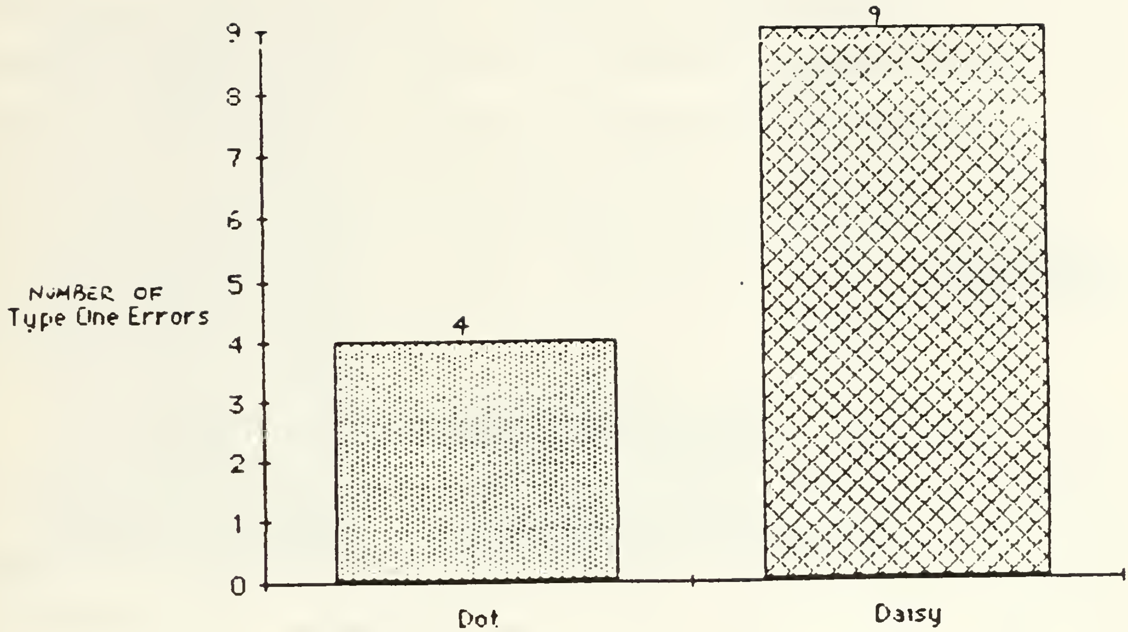


Figure 3.1 Dot/Daisy Type I Errors

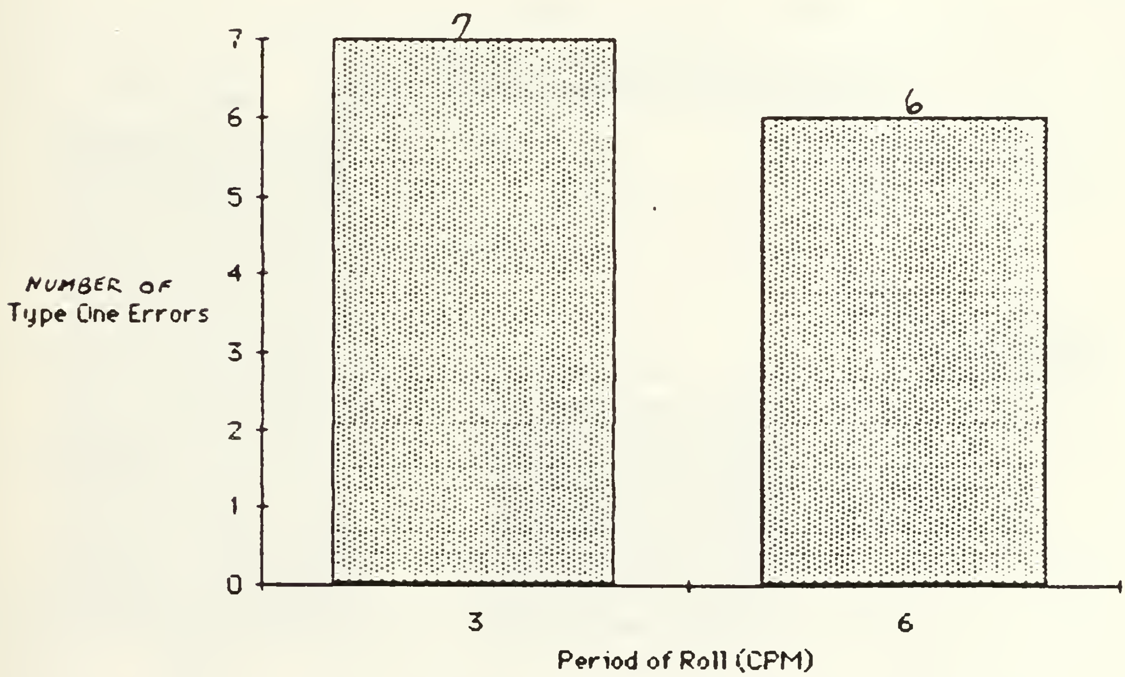


Figure 3.2 Cycle Rate(cpm) Type I Errors

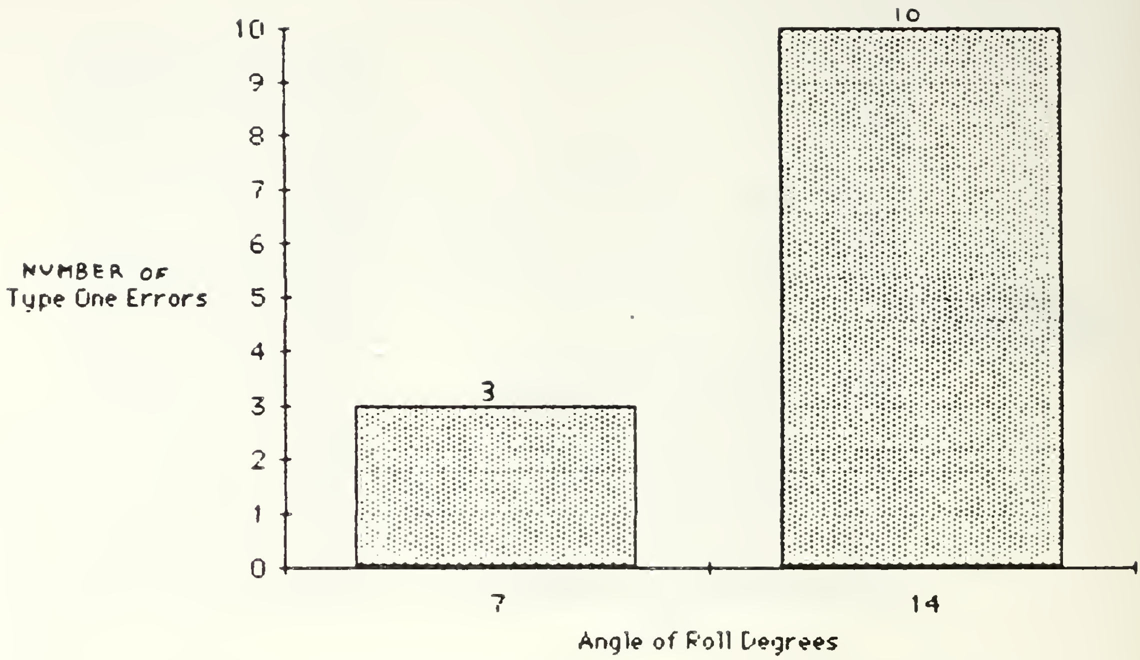


Figure 3.3 Angle of Roll(degrees) Type I Errors

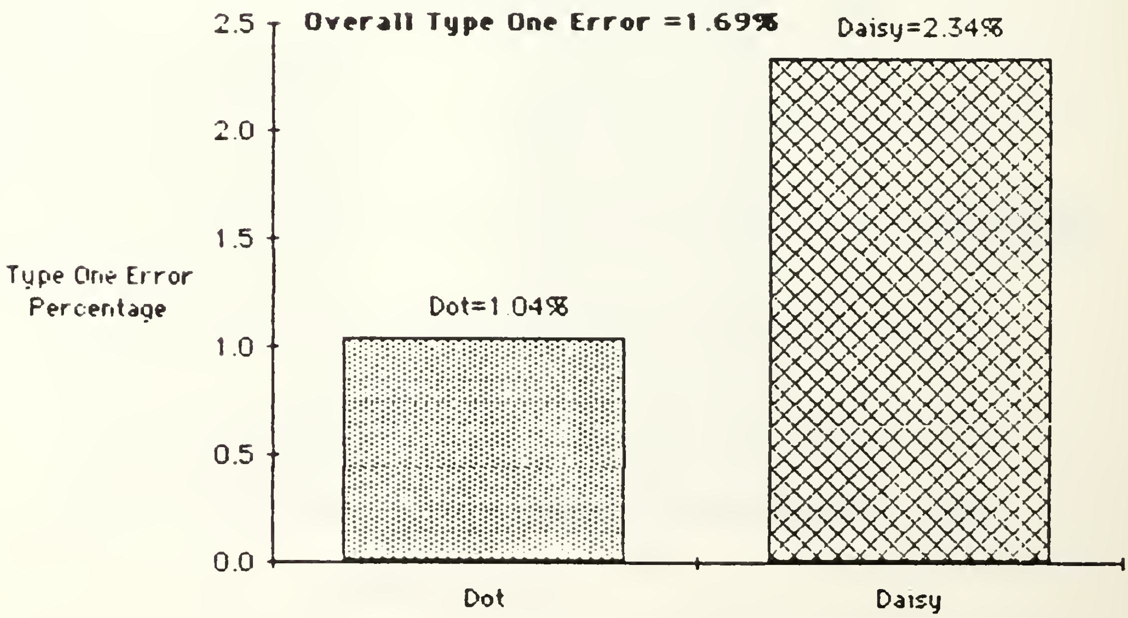


Figure 3.4 Retinal Scanner Type I Error (Percentage)

excellent enrollments and proper scanning procedures. Since this test measured the accuracy of both DAISY and DOT machines at the lowest possible RECOGNITION threshold setting of +0.60, increasing the setting would increase the Type I error rate. Proper use of the machines and the strict following of user instructions is an extremly important aspect to consider when discussing/dissecting these results. The enrollment procedure and concentration by the subject being scanned, are just a few variables that can effect the outcome.

The most substantial relationship discovered in the transformation variance computations was that of increasing the angle of roll on the transverse motion simulator. The computed F (SS/MS error) was 5.7870. The value from the F tables(level of significance = 0.05) was 4.54. Ten of thirteen(10/13) Type I errors occured when roll was increased from seven to fourteen degrees. While other relationships were not as significant as this, (i.e., no significance surfaced when examining the variance analysis), certain outcomes should be noted. Fifty percent (8/16) of the subjects tested did not have any occurance of Type I errors. Of the remaining eight subjects that had Type I errors, 4 of the 8 had 69.2% of the errors.

The newer version machine(DOT) had fewer Type I errors (4/13) than the DAISY, which might be attributed to the fact that fifteen out of sixteen subjects preferred using the DOT 7.5, feeling more confident when using it. One felt that with his poor eyesight, "it was difficult to distinguish the daisy pattern, yet could line up quite easily the blurry cone with the three green dots." Those that are color blind to greens and reds will have problems with the DAISY 7.5, but they will function with the DOT where depth perception and not color is important. The one subject, PIN(0038) that preferred the DAISY, had three of the total thirteen Type I errors(23%). Two of those three occured on the DOT. The remaining fifteen subjects liked the three dimensional cone/dot depth alignment system on the DOT over the two dimensional plane view of the greenish-white daisy wheel provided on the DAISY.

For health reasons, it would seem wise to utilize the recessed eye port construction of the DOT because the eye does not come in contact with anything. The forehead is placed on the headrest. With the DAISY, the eyeball and possible tears have a greater chance of coming in contact with the rubber protection guards, promoting the possible spread of a virus or germs to others. Overall Non-Recognition percentages for DOT were (5.36%) and (24.70%) for DAISY. This implies, a person using the DAISY 7.5 is inevitably going to have to scan many more times to gain the same amount of acceptances allowed through the use of a DOT 7.5.

Slightly more Type I errors occured (7 out of 13), when the 'period of roll' was increased implying that in heavy seas, the machine's performance could be downgraded because of problems with keeping the head still. A solution to this might be to shape a curved recess into the forehead rest of the DOT 7.5, to allow one's forehead to fit within it for greater stability in rough seas. The DAISY does not allow this option, due to its outwardly radiated eyeport construction. One student stated however, that resting the sockets of the eye on the rubber guards atop these eyeports does help keep the head still. Installing handles close to both machines would aid in stabilizing oneself in a shipboard environment.

In every instance but one a logical outcome appeared as the factors were adjusted when testing the machines aboard the transverse motion simulator. All results were poorer as angle of roll was increased, period of roll(sec) was increased and when the older DAISY 7.5 was used. An example of this, noted earlier(Table 2), would be the large difference between the machines when comparing OVERALL average RECOGNIZED correlation scores. DOT = +0.9095, DAISY = +0.8137, the difference being +0.0958. The one exception to this logic was the occurance of five (Type II) RECOGNITION false acceptances ONLY on the DOT 7.5. This exception is discussed in the following text.

2. Type II Errors

Type II errors did occur in both the RECOGNIZE and VERIFY modes. Formally, the HYPOTHESIS for this Type II analysis can be stated : the subject attempting entry IS located in Ibank memory and wants to be identified by matching his/her own personal identification number (PIN) OR BY MATCHING ANY OTHER AVAILABLE PIN in Ibank memory to gain access. This hypothesis is of course FALSE because the machine is designed to accept subjects only against their own PIN. If this FALSE hypothesis is ACCEPTED by the machine as TRUE, an error has occured. This is known as a TYPE II error (Freund|Williams, 1982, p.316). In 'laymens' terms, someone is allowed access (false identification and acceptance) by the 7.5. Although the subject was located in Ibank memory, he SHOULD NOT have been recognized/verified under ANOTHER subject's PIN.

In strict probabilistic terms, Type II errors can mathematically happen, but are not expected to occur, because

> every person, even an identical twin , has a widely divergent , unalterable retinal eye pattern. The chance of false acceptance in the VERIFICATION mode is 0.0001%(one in a million), with the phase correction on (normal operation). The correlation coefficient being +0.70. The purpose of the software implemented phase corrector is to compensate for eye rotation about the visual axis. This eye rotation is the result of tilting the subject's head with relation to his/her orientation

during the enrollment process. (Oregon Museum of Science and Industry, 'White Paper', 1984)

The corresponding odds of a false acceptance(Verification mode) with the correlation coefficient set at the minimum +0.60, is approximately one in sixteen-thousand five hundred and two(1/16,502) or +0.00606%. This minimum setting(+0.60) was used throughout the experiment. The odds were derived from studies at the OREGON MUSEUM OF SCIENCE AND INDUSTRY in Portland, Oregon 10 October 1984. The odds represented here is the result of a revision to their findings by the Eye Dentify company. Originally their report had stated these odds were one in forty five thousand(1/45,000) or 0.00222%.

The probability of a Type II error is hard to fixate in the RECOGNITION mode because it depends on the population size in bubble memory and the correlation threshold setting that is assigned by the system manager. For example, the LOWEST security provided would occur with the correlation threshold set at +0.60 in the RECOGNIZE mode and 1200(the maximum) individuals stored in bubble memory. As memory population increases from 0000 to 1200(0000,0001,0002,...1200), the greater the odds that a Type II error may occur because more eye patterns are available to be compared/matched against. This dilemma does not lend itself to VERIFICATION mode, because this method requires the entering of the personal identification number. A one to one eye template match is then attempted. Therefore, an INDIRECT relationship between this coefficient and the occurance of Type II error is documented. The smaller the identification threshold coefficient, the greater the probability of a false acceptance. With Type I errors, the reverse is true;(DIRECT relationship). The larger the threshold coefficient, the greater the odds that false rejections will occur because the administrator is 'tightening' security.

In the initial motion experiment, utilizing the sixteen students, one male (personal identification number 0060) was falsely recognized under another male's code;(PIN 0025). The DOT 7.5 was used in this instance. NO false RECOGNITIONS were EVER noted during the motion experiment using the DAISY 7.5. Neither male had difficulties during the enrollment process, with the exception of a machine "lock-up" that required the system operator to re-start the enrollment process with PIN 0060. A "lock-up" connotes that keyboard commands and 'carriage returns' are not accepted by the Eye-Dentify software. To alleviate the situation, power was secured and re-energized, and the entire process reinitiated. To insure that possible bad templates were not located in IBANK memory under PIN 0060, all IBANK records were listed and checked. None were found in memory for this particular male. No difficulties were encountered during the second enrollment of PIN 0060. It is extremly important to grasp that the ONE false RECOGNITION occuring on 8 November 1985, was related to PIN 0060's <u>SECOND</u> <u>ENROLLMENT</u> <u>AND</u> <u>NOT</u> <u>HIS</u> <u>DELETED</u> <u>FIRST</u>.

The correlation score associated with this specific Type II error was +0.67. He was being tested with the angle of roll set at a maximum of fourteen degrees, and cycle per minute values of 3.0 and 6.0. At all sessions, as noted earlier, six trials were taken. He was successfully recognized the first three scans, FALSELY on the fourth(cpm=3.0) and successfully on the latter two. The 72-byte 'recognize' signature templates of the matched males, were separated by a margin of (0060-0025 = 35) PIN positions in bubble memory.

On the same day, a female(0067) was falsely RECOGNIZED, three successive times with scores of +0.61, +0.60, +0.63 under the PIN of another female(0063). These were initially considered questionable because 0067 had some difficulties enrolling. She DID meet the requirements of the enrollment process stated in the user's manual. Many enrollment scans had to be rejected via a NO(N) response to the question OK TO AVERAGE? shown on the cathode ray terminal, because they were not at least +0.90. The system operator was eventually able to acquire five scans above +0.90 in reasonable time. A decision to re-enroll was made however, to try to attain better eye templates. The former scans were ignored and deleted from the system operator's log and IBANK memory respectively when she enrolled a second time very easily. The log was later recalled as a record that the three scores were legitimate Type II errors. This due to additional 'VERIFICATION' false acceptances between PIN 0067 and 0063 in later trials, that implied a probable similarity between the eye patterns of these two female subjects. No additional false recognitions were logged with this particular female or any other person related to the transverse motion simulator test up to this point.

A decision was made to change over to VERIFICATION mode on 25 NOV 1985 and test ONLY four specific individuals. Those two subjects (0060,0067)that had Type II recognition errors occur in the motion test, along with the two other subjects(0025,0063) that they had been matched up against by the DOT 7.5. This strategy included a second enrollment of all four individuals. This time existing templates would NOT be erased. Now all four would have two separate templates in bubble memory. Of these four, only one (0060) had both a Type I error and a false RECOGNITION(Type II) occur during testing.

The system operator programmed the DOT 7.5 for verification parameters and then tested whether a false match might be achieved by scanning the eyes of one person against the two eye patterns of their match stored in IBANK memory. To do this, the four digit PIN of the person trying to be matched was entered in the numeric keypad of the Eye-dentify machine. The purpose of re-enrolling, was to double the chances of noting false verifications and to ELIMINATE/REDUCE the probability that system operator error was responsible for the THREE false RECOGNITIONS between PIN(0067) and PIN(0063) and the ONE false RECOGNITION between PIN 0060 and PIN 0025 reported earlier. This, in addition to the coincidence that the only occuring software/hardware "keyboard lock-up" on 8 November 1985 happened to that same individual, namely 0060. Males only tested against males, females only tested against females. Testing under these circumstances, provided the results noted in Table 6 .

For Table 6, MALE 1(0060) is represented by PIN's(0060,0069). MALE 2(0025) is represented by PIN's(0025,0071). FEMALE 1(0063) is represented by PIN's(0063,0070). FEMALE 2(0067) is represented by PIN's (0067,0072). The first PIN (O,) is the older enrollment, and the second PIN (,N)the newer.

On 25 NOV 1985, a false VERIFICATION was recorded with a correlation score of +0.64. The significance of this particular scan, was that it was the first time one had occured against a NEWLY enrolled PIN. Many more were to follow;(See Table 6). These new PINs, with their corresponding 40 byte 'verification' templates in IBANK memory, were created under the most carefully scrutinized enrollment procedures. The thesis advisor witnessed the routine followed. The occurance of this particular Type II

DOT TABLE (6) TYPE II ERRORS- VERIFICATION ONLY

0060- MALE 1, trying to match MALE 2, (old PIN 0025, new PIN 0071)

false verification scores: .60 .65 .61 .63 .64 .64-(0025)
.67 .60 .64 .65 .64 .65

.63 .64 .67 ------------(0071)

15/58 = 25.86% 15 scans out of 58 were false verifications.

0025- MALE 2, trying to match MALE 1, (old PIN 0060, new PIN 0069)
.62 ---------------- (0060)

false verification scores of: .64 .60 .62 .63 .65 -(0069)
.62

7/44= 15.91% 7 scans out of 44 were false verifications.

0063- FEMALE 1, trying to match FEMALE 2, (old PIN 0067, new PIN 0072)

false verification scores of: 1(.60) 4(.61) 5(.62) 2(.63)

4(.64) 1(.65) -------(0067)

5(.60) 3(.61) 2(.62) 6(.63) 2(.64) 3(.65) 1(.66)--(0072)

39/59 = 66.10% 39 scans out of 59 were false verifications.

0067-FEMALE 2, trying to match FEMALE 1, (old PIN 0063, new PIN 0070)

NONE --------------(0063)

false verification scores of: .61 .63 .61 -------(0070)

3/11= 27.28% 3 scans out of 11 were false verifications.

VERIFICATION error seemed to eliminate improper enrollment procedures as a cause for all the false acceptances. Also on that same date, a FIFTH Type II error under the RECOGNIZE mode happened when on the fifth of six trials, PIN 0060 was again incorrectly recognized as PIN 0025, with a correlation score of +0.63. ALL FIVE TYPE II RECOGNITION ERRORS OCCURED ON THE DOT 7.5 , with the motion simulator activated.

Initially, these tests had not been performed on the DAISY 7.5 because NO false recognitions occured during normally scheduled simulator motion testing. Upon request from the Eye-Dentify company of Beaverton Oregon, identical experimentation was completed on the DAISY scanner. The reason they were requesting this continuation of testing, was to determine if the numerous Type II verification errors that were consistently occuring to these four subjects, only on the DOT 7.5 along with five false recognitions, were caused by a defective camera. Internal feedback from the DOT's hardware or software was also considered. This might have created poor enrollment templates.

If identical FALSE recognitions/ verifications on the DAISY scanner were to prevail, this might disprove their theory, or at least make them test much more extensively. CROSS TALK, a coding system used by the company on all their machines was found to be correct in the DOT machine. The value was +0.044, which was stenciled in its internal cabinet. This number matched the value displayed on the terminal monitor when the command (Control-K) was input along with a password when at the main menu listing on the monitor. The cross talk value for the DAISY was +0.060, but no value was found stenciled inside the cabinet to compare with.

All four subjects were enrolled a second time on 27 NOV 1985 into DAISY 7.5 bubble memory. The same requirement of keeping the older templates in memory in addition to these newly created ones was followed. The VERIFY threshold was at +0.60, a constant that did not change throughout all testing. Cross checking of the two males and two females was completed in the same manner that prevailed with the DOT 7.5. There was no reason to cross check male to female, because no connection was evident. Out of curiosity, a few female to male cross checks were attempted. Resultant correlation scores were well below +0.45(+0.00 - +0.45). Testing under male/male, female/female conditions, provided the results listed in Table 7.

For Table 7, MALE 1(0060) is represented by PIN's(0060,0028). MALE 2(0025) is represented by PIN's(0025,0072). FEMALE 1(0063) is represented by PIN's (0063,0071). FEMALE 2(0056) is represented by PIN's (0056,0070). The first PIN (O,) is the older enrollment, the second PIN (,N) the newer.

Male subject 0060 was scanned more than any other,three hundred and thirty eight(338) instances, because of consistent scores in the "fifties" (+0.50 - +0.59). At one point, the system operator turned off all the lights in the laboratory to see if that would assist 0060 in getting a false verification by matching 0025. Although it did seem to help when focusing in on the daisy wheel pattern, there were no pronounced changes in correlation scores. Additionally, the day before 0060 had 'enrolled' his second time, the PIN being 0072. He was able to correctly identify against this NEW PIN of his quite easily, but was unable to match when verifying against his own OLD PIN 0060 created two weeks earlier. The attempts were made over a two hour time duration. Apparently the night before 0060 received only 5.5 hours of sleep and stated he had been tired all day. The following morning, 0060 repeated the same procedure after a normal nights sleep and was identified against his OLD PIN

DAISY TABLE(7) TYPE II ERRORS- VERIFICATION ONLY

0060- MALE 1 trying to match MALE 2, (old PIN 0025, new PIN 0072)

false verification scores: .60 --(0025) NONE ----(0072)

1/338= 0.29% 1 scan out of 338 was a false verification. 128 out of the 338 (37.87%) scans cross referencing PIN 0060 against PIN 0025 had scores in the range of (.50 -.59). The ave. was +0.534. There were 0 in this range for the eleven scans cross referenced against new PIN 0072. The average correlation score for the new PIN was +0.32, with two highs of +0.49.

0025- MALE 2 trying to match MALE 1, (old PIN 0060, new PIN 0028)

false verification scores: NONE ---------(0060)(0028)

0/28 = 0.00% 0 scans out of 28 were false verification

The highest correlation score was +0.53 occuring once.

0063-FEMALE 1 trying to match FEMALE 2, (old PIN 0056, new PIN 0070)

false verification scores: .61 -------------------(0056)

.60 -------------------(0070)

2/25 = 8% 2 scans out of 25 were false verifications. There was a gap of four NOT VERIFIED scans, before the second Type II error was recorded. She also had 3 scans in the "fifties".

0056- FEMALE 2 trying to match FEMALE 1, (old PIN 0063, new PIN 0071)

false verification scores: NONE ----------(0063)(0071)

0/31=0% Zero scans out of 31 were false verifications. Her highest correlation score was +0.31.

---

with consistent scores in the nineties(+0.90 - +0.99). This implies a possible connection between FATIGUE and being acknowledged by the Eye-dentify 7.5.

There were FIVE misRECOGNITIONS (Type II) out of 934(0.535%) recognition scans for this experiment(.67,.63,.63,.61,.60) on the DOT 7.5. There were SIXTY-FOUR misVERIFICATIONS (Type II) out of a total of 172 verification attempts utilizing the DOT 7.5 which computes to 37.21%. There were THREE misVERIFICATIONS (Type II) out of a total of 422 verification attempts utilizing the DAISY 7.5 which computes to 0.71%. There were NO misRECOGNITIONS on the DAISY. One can see that there was a great disparity in the number of false VERIFICATIONS(Type II) on the DAISY 7.5 (3) versus the DOT 7.5 (64) , when cross checking between the four subjects. Those three (3 out of 422) imply quite a lot though. If none had occured, then one might have surmised that the reason for so many false verifications on the DOT 7.5 was defective hardware/software (and/or) that the particular machine was possibly a 'lemon'.

Another reason might be that the DOT may create more accurate/defined signature templates, because the three dimensional dot/cone alignment method seems to have proven its superiority over the two dimensional daisy pattern. The proof being earlier listed results. This allows subjects to enroll under better conditions. When cross checking is done in VERIFICATION mode, one on one, the different templates relating to the paired individuals have a greater likelihood of matching up. Although few in number, the occurance of those THREE false VERIFICATIONS on the DAISY implied that there WERE eye pattern similarities between these four specific individuals. Two of the three matches occured in the female/female link. One on the old PIN 0056, one on the new PIN 0070. The remaining misverification obviously related to the male/male matching, and was tied to the old

PIN 0025. Future research could investigate whether subjects of the same sex have a greater chance of matching up against one another.

It must be noted that no other Type II RECOGNITION/VERIFICATION errors have occured on these particular machines from APR 1985 to the present. The machines have been in the Man-Machine Laboratory(Root Hall 107) Naval Postgraduate School, Monterey, California, undergoing testing on a continuing basis. If the number(5) of Type II RECOGNITION errors were evaluated over the entire timeframe that the DOT 7.5 has been tested at the USNPGS, the Type II false recognition rate would be significantly lower. All rates presented in this work are a result of this specific thesis experiment only.

B. OTHER OCCURANCES/FORMULATIONS

The highest correlation score relating to the verify and recognize Type II errors of this experiment was +0.67. Raising the lower identification threshold limit that the CRT lock manager sets, from the present +0.60, to possibly +0.70 <u>WOULD INSURE THAT THESE FALSE ACCEPTANCES WOULD HAVE NEVER HAPPENED</u> ($+0.70 \geq +0.67$). A spokesman from Eye-dentify Inc. stated that they were in the process of revising their policy of not allowing the correlation threshold to ever be set below +0.71 for this reason. A negative aspect of this policy would be increased queue time because correctly RECOGNIZED/VERIFIED scores in the +0.60-+0.70 range would now be treated as unacceptable(NOT RECOGNIZED) by the 7.5, requiring additional eye scans that take more time.

A theory was formulated after consultation with Eye-dentify Inc. that dealt with enrollment procedures. It was thought that accepting only very high enrollment correlation scores(+0.90 - +0.99) might have a negative effect on the digitized waveform that is processed and stored as the signature template. This waveform is created from reflected light generated from the beam of the ultra-low infrared light during the scanning process. This theorized negative effect was mentioned as a possible cause of recurring Type II errors. In response, all sixty original enrollees were entered into the system under the same stringent conditions of accepting only enrollment scans in the 'nineties'. This policy MET the requirements of the user's manual: "that the five enrollment scans taken should average at least +0.90." No deviations were ever allowed.

In addition, the swapping of template data located in the bubble memories of the DOT and DAISY was considered. This to assist in determining the cause of the Type II errors 'only' occuring on the DOT 7.5. Refer to Table 7 for DAISY Type II error figures i.e., (3 out of 422). The procedure was to 'download' the eye templates from DOT bubble memory to floppy disk using the ' BACKIB BASIC ' language program and then 'upload' to DAISY bubble memory. Tests would be run and then the procedure reversed. The four subjects would try to get false acceptances in both modes. It was never done because in the interim, the three false verifications(+0.61,+0.60,+0.60) occured on the DAISY. This enhanced the belief that some similarities between eye patterns were evident and that the identification threshold coefficient would have to be permanently raised to decrease the probability of recurrent Type II errors.

A floppy disk that stored the hexadecimal values of the eye pattern templates belonging to the four (Type II) error subjects was forwarded to the Eye-Dentify Co., Oregon. They were able to investigate and compare signatures to the bit(binary digit-0,1) level, to ascertain how similar the eye patterns actually were. Verbal reports to the thesis advisor indicate there WERE similarities in the eye patterns.

IV. COSTS/BENEFITS

The cost of the Eye-dentify 7.5 retinal biometric scanner is $10,000.00 as of January 1986. No other firm manufactures such a product and the U.S. military does not own or maintain this type of device aboard ship. They are now being tested by research facilities like the Naval Postgraduate School for possible future uses by the Department of Defense. Because there is a lack of competition presently between manufacturers, its price is relatively expensive. As more competitors join this market though, a lower equilibrium price should eventually be attained for retinal scanner hardware. The software needed for a shipboard computer system interface would depend on the size of the application required. No specific price is available, because retinal scanner applications have not been developed for shipboard use. As technology is developed though, and as all retinal biometry applications are perfected, this price should decrease also. Numerous examples of products from the computer and electronics industry can be cited to support this claim. The most profound is the advent of microcomputers. When the LISA business office system was first introduced by Apple Computer Inc. of Cupertino, California, the price was $10,000.00. In a very short time prices were drastically cut(more than a third). This was due to intense competition and a lack of market interest in the LISA. Eventually it was discontinued as a production item.

As Research and Development(R+D) costs are distributed by increasing competition and amortized over increased sales revenue in retinal scanners, the unit cost of each machine should decrease, making the system increasingly affordable and attractive. The U.S. Government is usually the first buyer of this type of equipment in large amounts. This allows the private sector to study its successes/failures through government use before they have to buy in any quantity.

1. Applications

Some obvious applications aboard ship would be security and access control. An example mentioned earlier, would be to locate a retinal scanner at the main entrance to the nuclear propulsion space on either an aircraft carrier(CVN), surface combatant(CGN) or a submarine(SSN/SSBN). The scanner would have its own battery backup for emergency power generation should there be a loss of the ship's electrical load. If it was decided that the scanner alone would not provide adequate security, a password system or cipher lock could be used in parallel with the scanner. This 'double protection' system has more distinct advantages than a cipher lock or password system alone. A disadvantage to consider is the additional time required to successfully gain access to a system guarded with 'double protection'.

2. Shortcomings

Cipher lock combinations can be compromised, as can passwords, I.D's etc. Human retina, choroid and blood vessel patterns are not, as long as the database manager(CRT lock) is honest and proficient. This manager(s) is the only person(s) with the capability to circumvent via the manipulation of parameters, or by enrolling someone that does not have authorization. The key difference is, with passwords everyone with access must MEMORIZE it, thereby having the ability to give the password to someone else. With retinal scanning, although you may have access, you cannot give someone else your eye signature template stored away in bubble memory.

Common shortcomings of passwords regarding the security of a computer system , especially with the advent of 'hackers', is the ability to control the dissemination of the password and the need to constantly change it. The use of retinal identification alleviates this need because the scanner operates as a secure stand alone system and can also be installed as a network of units reporting to a host computer.(Eye-Dentify, 1985) It could be used to simplify the logon procedure for a computer user. Instead of typing the user ID and access code, the user simply scans and gets logged on automatically.

Certain systems needing enhanced security might only require a retinal scanner by itself, while others may need double protection provided through 'paralleling'. Another option to consider if 'paralleling' is not feasible, is the use of one machine in the dual eye mode, i.e., (one subject scanning BOTH left and right eyes simultaneously). The DAISY has this option, the DOT does not. Also, two machines can be modified so that the correct identification of two DIFFERENT subjects is necessary to allow access. This technology would be ideal for two person control of very sensitive functions. Envision two separate 7.5's to be used by watch officers in a missile silo to scan in sequence before their system could be activated.

In June of 1981, Columbia Broadcast System(CBS) news aired a multi-faceted evening documentary titled, The Defense of the United States . In one episode, viewers were given the chance to explore the realm of a watch station in a nuclear missile silo. The officers on duty had certain procedures to be followed should they ever receive the order from the President, to follow through with what they were trained to do. It would seem reasonable that, with the use of a retinal scanner in parallel with existing activation procedures, this would enhance security. This would occur because there would be a reduction in the probability that an imposter or crazed watchstander could successfully breach all authentication procedures(now to include a retinal scanner), gain access and launch.

To estimate the total cost of this specific piece of HARDWARE and needed peripherals for a 600 ship Navy and selected Coast Guard vessels is beyond the scope of this thesis. Some ships would require more retinal scanners because the equipment they store and the information they process warrants it. Large amounts of secure information are handled, high level communication and computer equipment must be guarded, nuclear spaces protected etc., therefore more scanners are needed. Fewer scanners need to be installed where the mission of the vessel does not include the storage/dissemination of VAST amounts of high level secure information, equipment or computers.

A ship classification hierarchy based on security requirements would need to be developed to determine how many scanners each would be allocated. Possible groupings would include: all nuclear powered combatants and conventional aircraft carriers(CVN,CV,SSN,SSBN,CGN), conventionally powered combatants large(CG,DD) and small(DDG,FF,FFG), the auxiliary force(AO,AOE,AFS,AOR,AE). Others are the amphibious force large(LHA,LPH,LKA) and small(LST,LSD,LPD), command and control(LCC,MSC), battleships(BB) and support tenders (AD,AR,AS). Coast Guard cutter groupings would be High Endurance Cutters(WHEC), Medium Endurance Cutters(WMEC) and Icebreakers(WAGB).

Additional costs would include needed maintenance beyond contracted warranty. Also application software costs for the particular requirements at hand, would be quite considerable.

V. CONCLUSIONS

In general, the use of this device is ONLY acceptable when the physical security of the space will preclude access via any other means. Cost is always a consideration. It would appear a fairly minor one in this instance, given the sensitive data, information and equipment a scanner would assist in protecting. This opinion is enhanced by the recent spying cases under investigation throughout the United States Navy and other government agencies. A recent Navy spy case involves a Navy civilian counterintelligence analyst, and his wife. He for allegedly spying for our ally Israel, and his wife charged with relaying top secret data to Red China. Non-Navy employees arrested include a man who was convicted of selling CIA information to Chinese intelligence agents for more than thirty years. Another man is charged with delivery and attempting to deliver national defense documents to an adversary. One document was a transcript of a hearing of the House Armed Services Committee classified as top secret.

The need for enhanced security is understandable. It must be noted though, that with retinal biometrics along with the other biometric devices(fingerprint,palmprint, finger length etc.), the human element is still relied upon. Human systems cannot be considered infallible when a CRT database administrator is capable of being careless or dishonest when enrolling individuals. Money can still be used as a bribe to circumvent the system. With this system though, fewer individuals have access to controls which could make a difference.

A. USES ABOARD SHIP

In an area aboard ship requiring maximum security, with a limited number of people requiring access IMMEDIATELY, the retinal biometric measuring device would be ideal. It should provide a more reliable method of identification than a photograph, ID, cipher or password because it cannot be compromised as readily. Its use could also be considered aboard ship, where the total access list is small to medium in number, immediate access is NOT so critical, and entry times are STAGGERED to alleviate the chance of a queue forming. During an alarm, certain individuals such as the commanding officer might have to bypass, if possible, for immediate access. The greater the number of subjects needing access to a space or system in a shipboard application, the greater the possibility that large queues might form. This would be counterproductive.

Physical maintenance of the 7.5 should not be a concern. The system is compact, and capable of being mounted on a table top or protruding from a bulkhead. It would be treated like any other valuable electronic equipment; located within the interior of the ship away from the elements, i.e., salt/sea spray, extreme temperatures etc.. There would be a need for software maintenance as updates are needed.

Although costs and benefits were discussed in the prior chapter, it was not a comprehensive investigation, but only a general overview. It is beyond the scope of this thesis to dissect the subject any further. An entire thesis could be dedicated to a cost/benefit analysis of installing retinal biometric scanners aboard U.S. Navy ships and Coast Guard cutters.

Retinal scanners should become commonplace in future years. Individuals will want to know the long term effects of exposure to the infrared light. Although Threshold Limit

Testing(TLV) has shown the effect to be harmless, many will still continue to be concerned.

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