Enhanced Situation Awareness in Sea, Air and Land Environments

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Summary

United States (US) military Special Forces teams currently use 2D visual displays for navigation information in the air, in water, and on the ground. These current displays demand the user's visual attention, which can compromise mission effectiveness, and using visual displays in low light visibility environments can cause fatigue, degrade performance, and compromise a clandestine situation. If navigation equipment that is dependent on visual displays were integrated with a tactile display, the need to use vision for navigation could be minimized. The operator could be more effective if his eyes were used to survey the surroundings rather than continuously monitor a visual display.

The Tactile Situation Awareness System for Special Forces (TSAS-SF) was developed to investigate the potential of tactile displays for Special Forces operations. The TSAS-SF will upgrade present 2D visual navigation displays and will provide non-visual, non-audible navigation information to Special Forces personnel by interfacing navigation information with a tactile display. This new capability will provide 2D direction cues to the skin, which will free the user's visual senses for higher priority tasks (e.g. contact identification and classification). Preliminary testing in a High Altitude, High Opening (HAHO) parachute environment and a ground environment, and earlier testing in an underwater environment (McTrusty, Walters, 1997, Rupert, McTrusty, Peak, 1999), have demonstrated that navigation can be performed faster with tactile cues than visual cues, and superior navigational accuracy can be achieved with less mental fatigue on the operator. These results suggest that a tactile display that provides 'eyes free' and 'hands free' air and ground navigation information may provide the opportunity to devote more time to other instruments and tasks when operating in high workload conditions. These effects can increase mission effectiveness. The preliminary results from the air and ground navigation tests justify continued testing and evaluation to extend the capabilities of the tactile display, for use as an operational device for navigation in sea, air and land environments.

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Introduction

United States (US) military Special Forces teams use a variety of insertion methods to advance to their area of operations. One of the methods of insertion involves the use of highly maneuverable square parachutes for High Altitude High Opening (HAHO) parachute operations. HAHO operations involve jumping from an aircraft, opening the parachute at a high altitude, and navigating over a long distance towards a designated target-landing zone. It is common for the HAHO operator to be aloft for 25 minutes, and travel distances of 30 miles. After landing, Special Forces teams must navigate on the ground to the area of operations. Currently, all navigation and altitude information in the air, and navigation information on the ground are provided by 2D visual displays. These displays demand the user's visual attention compromising mission effectiveness. Moreover, using visual displays in low light visual environments can cause fatigue, degrade performance, and compromise clandestine situation.

If current navigation displays were integrated with a tactile display, the need to use vision for navigation could be minimized. The operator could be more efficient if his eyes were used to survey his surroundings rather than continuously monitor a visual display. Preliminary testing for the Very Shallow Water Mine Countermeasure (VSWMCM) detachment (McTrusty, Walters, 1997) has shown that underwater navigation can be performed faster with tactile cues than visual cues, and superior navigational accuracy can be achieved with far less mental fatigue on the operator. It is postulated that a tactile navigation display will have similar benefits for a HAHO and ground operations and allow for 'eyes free' and 'hands free' navigation.

The Naval Aerospace Medical Research Laboratory (NAMRL) developed the aviation-based Tactile Situational Awareness System (TSAS) to reduce aircraft mishaps caused by Spatial Disorientation (SD) and subsequent loss of Situation Awareness (SA). TSAS is an advanced display that exploits the under-utilized sensory channel of touch to provide spatial orientation and SA information to aircraft operators (McGrath, 2000). Results have shown that tactile displays are effective in reducing SD and loss of SA problems (McGrath, 2000; Griffin, Pera, Cabrera, Moore 2001). Further research has also suggested that the application of tactile cues may be expanded beyond spatial orientation issues, to areas such as navigation, communication, warning, and training (Walters, 1998). The TSAS concept is shown in Figure 1. The TSAS system accepts data from various sensors and displays this information via miniature tactile stimulators called *tactors* integrated into flight gear.

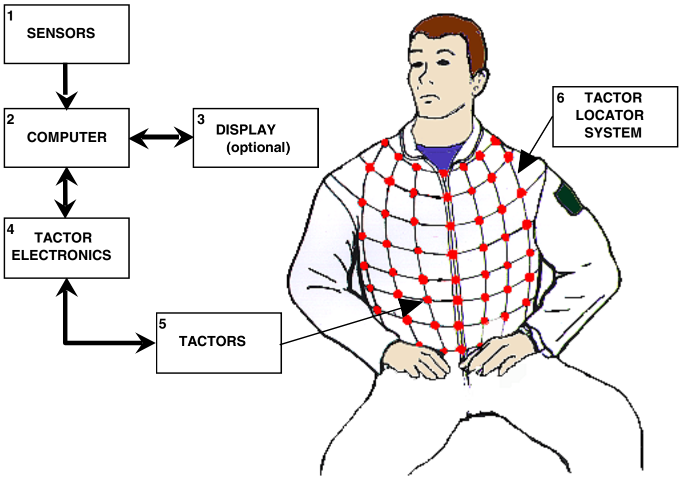

Figure 1: TSAS Concept

The tactile display has been shown to increase SA and provide the opportunity to devote more time to other instruments and systems when operating in task saturated conditions (Griffin, et. al., 2001; McGrath, 2000). The TSAS system reduces user workload and thus has the potential to increase mission effectiveness. TSAS is capable of providing a wide variety of information, including: attitude, altitude, navigation, threat location, and target location.

To investigate the potential of tactile displays for Special Forces navigation, NAMRL researchers developed a tactile display based on the aviation-based TSAS shown in Figure 1. This system, designated TSAS-SF will upgrade present navigation 2D visual displays and will provide non-visual, non-audible navigation information to Special Forces personnel by interfacing navigation information with a tactile display. This new capability will provide 2D direction cues to the skin, which will free the user's eyes for higher priority tasks, such as contact identification and classification. This new capability provides silent navigation cues to the skin, yielding a more clandestine system. This system has the potential to reduce operator workload and improve performance, especially in extreme tactical environmental conditions (low/no visibility, urban operations).

Method

System Description

The prototype TSAS-SF system (Figure 2) is comprised of a commercial off the shelf (COTS) portable global positioning system (GPS) manufactured by Garmin, a COTS PC-104 central processing unit (CPU) (Real Time Devices CMC6686GX233HR-128), a custom 5 channel tactor driver board and five electromechanical tactors (Engineering Acoustics, Inc.). The CPU and tactor drive electronics are housed in a water resistant sealed housing, with data, tactor and operator switch interfaces. The electronics housing is contained in a pouch with straps for positioning on the operator's leg. The GPS is mounted in a pouch with chest strap loops for visual access during testing. For operational use, the system could interface with existing military GPS units or COTS sensors. The system requires only timely digital data from position or direction sensors.

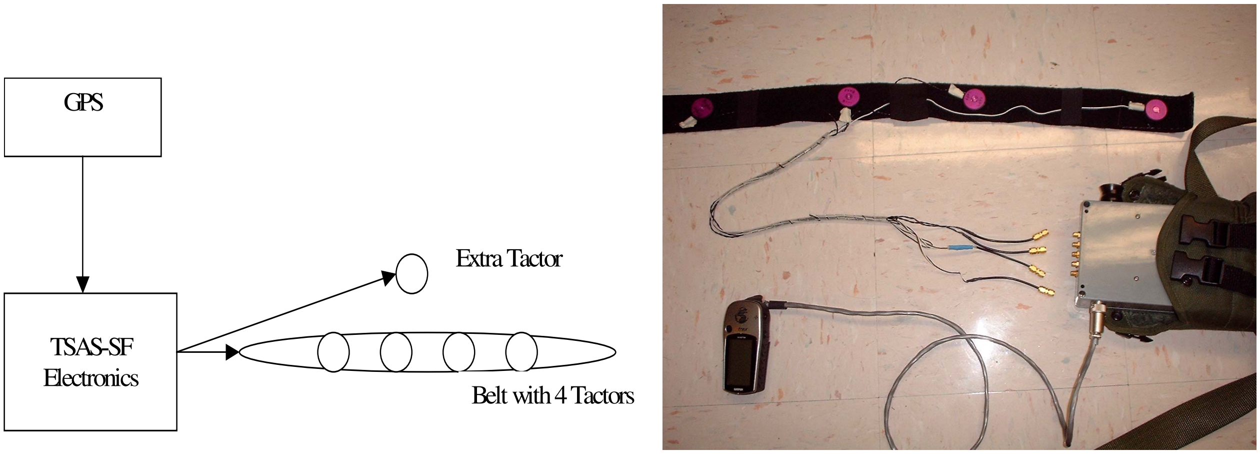

Figure 2. TSAS–SF block diagram (left) and components (right).

The four belt tactors are worn around the operator's waist. The fifth tactor is located near the left collarbone to indicate error conditions and increasing distance from target. To enhance the GPS performance, an external antenna is attached to the top of the operator's helmet after the parachute is opened.

Air Navigation Set-Up

For the air navigation tests, the tactor meanings were mapped as shown in table 1. The tactile symbology used was for the operator to steer away from the stimulus. For example, if the left tactor activated, the operator steered right. If the target overshoot tactor activated, the glideslope was made steeper.

Table 1: Air navigation tactor definitions.

Tactor	Position	Meaning
1	Left	Left of path (steer right)
2	Right	Right of path (steer left)
3	Front	Above glideslope angle (overshoot waypoint)
4	Rear	Below glideslope angle (undershoot waypoint)
5	Extra	Distance to waypoint increasing (moving away or backwards)

In the aircraft prior to the jump, the GPS is pre-programmed with a destination waypoint. After exiting the aircraft and opening the parachute, the operator enables the TSAS-SF system via the power switch. The controller software waits for the initial position data from the GPS. Using the pre-programmed destination waypoint and the initial position data, the great circle course and the distance to the waypoint are computed. Subsequent position data from the GPS are used to calculate cross track distance, distance to go, and glideslope error from the initial position. The glideslope error is recalculated every ten seconds. The left or right tactors fire when the cross track error is greater than the allowed cross track error (tested at fifty feet). The front or rear tactors are fired when the glideslope error angle is outside the glideslope error window (tested at five degrees). The extra tactor fires if the distance to the destination waypoint increases instead of decreases. All tactors fire if no data is received from the GPS within three seconds.

The test plan called for several equipment integration jumps, emphasizing operator safety. The jumps were made from a civilian Cessna 182 light aircraft, using commercial sport parachuting rental equipment. Once familiarized with the equipment and cabling, data collection jumps followed. Nine jumps were made, four equipment jumps followed by five data collection jumps. Distances from destination ranged from two and a half (2.5) nautical miles to six nautical miles, and all jumps were from an altitude of eleven thousand feet above sea level.

Ground Navigation Set-Up

Special Forces teams have ground navigation requirements that are currently met using visual GPS and compass displays. To evaluate tactile displays for ground navigation performance, test subjects walked a predetermined course and completed an additional visual search task. The TSAS-SF for ground navigation only used three of the five tactors. The tactor mappings are shown in Table 2.

Table 2. Ground navigation tactor definitions.

Tactor	Position	Meaning
1	Left	bear left to waypoint heading
2	Right	bear right to waypoint heading
3	Front	stop – waypoint within arrival circle radius

During ground operations, the system was configured to indicate direction to a waypoint. The left and right tactors indicated direction to steer using a “steer towards” stimulus algorithm. The tactors also varied in their pulse rates, pulsing more quickly as heading error increased. Table 3 shows the meanings of the various pulse rates. Once the waypoint was reached, the front tactor pulsed for 3 seconds, indicating waypoint arrival.

Table 3. Ground navigation tactor pulse meanings.

Difference between current heading And heading back to search path	**Tactor fire rate in Pulses per second**
0 to 15 degrees	0
15 to 30 degrees	1
30 to 90 degrees	2
Greater than 90 degrees	4

Results

Air Navigation Tests

For test purposes, a simple direct flight path was chosen. Winds aloft were averaged to reduce cross track errors caused by winds and a straight-line single leg path to the target was flown. Variations from the intended path were taken only to ensure a safe landing area. On all of the jumps, the intended landing area was reached. It was noted that if the operator faced away from the target, the symbology was reversed. This would need to be corrected in actual mission conditions.

The maximum cross track error was twenty feet during the first three data collection jumps. This resulted in too many corrections, and was increased to fifty feet. The glideslope guidance (five degree window) worked well, but was sometimes ignored, due to concerns for operator safety. Representative data for the cross track error and glideslope error data are shown in Figures 3 and 4, respectively. Forested terrain between the aircraft exit point and target inhibited better testing of the glideslope input.

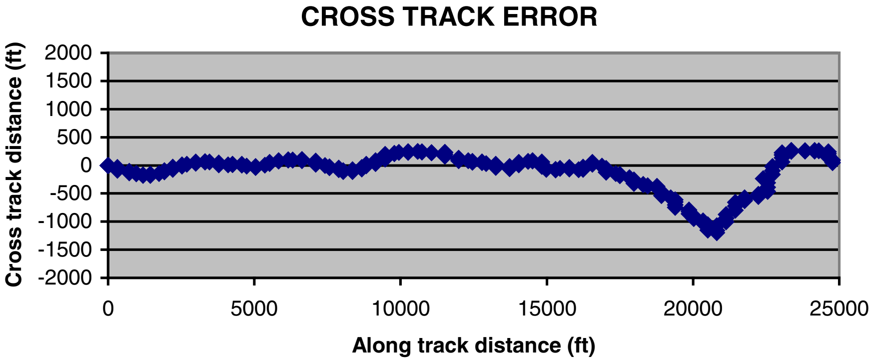

Figure 3. Air navigation cross track error.

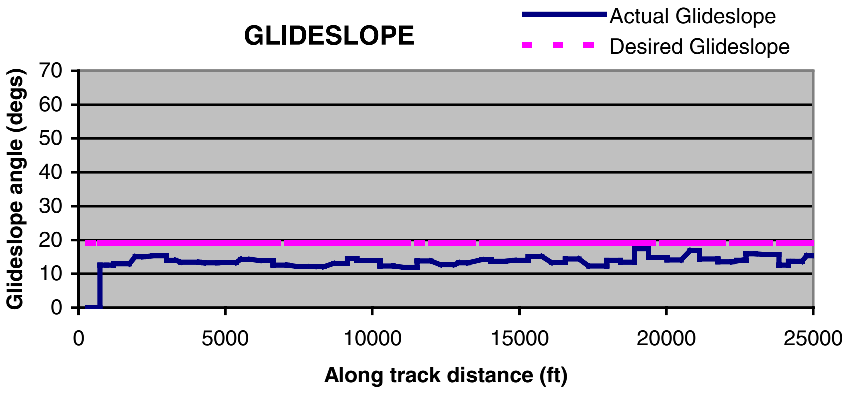

Figure 4: Air navigation glideslope angle.

Ground Navigation Tests

During ground tests, a five-minute, sixteen tenths of a statue mile, three-leg course was mapped. Each subject first navigated the course using the TSAS-SF tactile display, and second using only the visual display on the GPS. For this preliminary investigation, no attempt was made to minimize order effects. For additional visual tasking, a number of small objects, ten green and ten black were placed along the route. A count of the number of objects of each color observed on each run was taken. Table 4 summarizes the results.

Table 4. Ground navigation test results.

Subject	**Time TSAS On (mins)**	**Time TSAS Off (mins)**	**Object counts with TSAS On**	**Object counts with TSAS Off**
1	4.0	5.0	4 green + 6 black = 10	4 green + 1 black = 5
2	4.0	4.0	4 green + 3 black = 7	3 green + 2 black = 5
3	5.0	7.0	5 green + 7 black = 12	4 green + 3 black = 7
4	5.0	4.0	5 green + 3 black = 8	3 green + 1 black = 4
Average	4.5	5.0	9.25	5.25

Preliminary data showed that the number of objects correctly identified is higher with TSAS-SF rather than with only a visual display. This result suggests that the use of the tactile navigation allows the subject more "heads up" time, improving search capability. Figure 5 shows a representative plot of ground track for TSAS-SF on and TSAS-SF off. The ground track data and the object count data in Table 4 suggest that using TSAS-SF improves navigation performance.

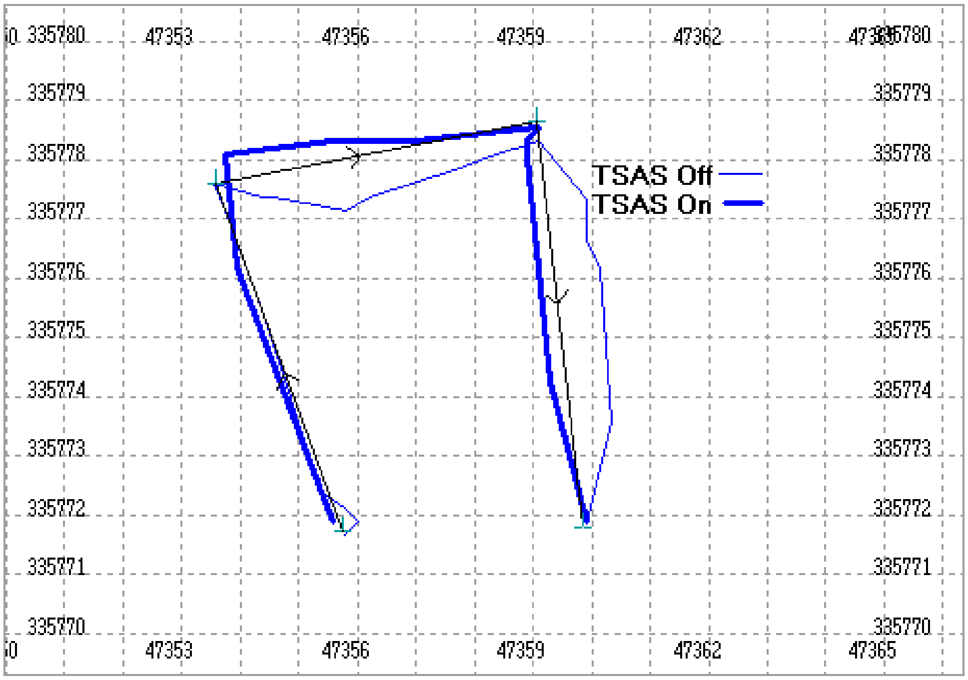

Figure 5. Example of ground navigation using either visual or tactile cues.

Each subject completed a questionnaire and the tabulated results are shown in Table 5.

Table 5: Ground navigation test questions.

QUESTION	**Yes**	**No**
1. Were you confident in your ability to navigate with the VISUAL display?	3	1
2. Were you confident in your ability to navigate with the TACTILE display?	4	0
3. Do you feel you were properly trained to perform these tests?	4	0
4. Did the VISUAL equipment operate properly?	4	0
5. Did the TACTILE equipment operate properly?	3	1
6. Was the tactile stimulation strong enough?	4	0
7. Do you think you can perform a visual search using the navigation system with the VISUAL display?	3	1
8. Do you think you can perform a visual search using the navigation with the TACTILE display?	3	1
	Visual	**Tactile**
9. Which search method do you feel is easier to use?	0	4
10. Which navigation method do you feel produced the best search?	1	3
11. Which search method do you prefer?	0	4
	Yes	**No**
12. Do you feel tactile navigation would increase your search capability?	4	0
13. Were the tactile signals ambiguous or inadequate?	0	4

Discussion

These preliminary tests were intended to develop the requirements for hardware, software and concept of operations of tactile cueing for air navigation. The air navigation testing did not reflect actual operational complexity. The flight paths tested were straight lines, and did not simulate threat avoidance or multi-leg routes. When using tactile information, the test parachutist demonstrated localizer and glideslope navigation to a given landing zone. These preliminary results indicated that tactile cueing for air navigation is feasible and further work is warranted. Additional tests are scheduled using the NAMRL tandem parachute system. Using the tandem system will allow testing of tactile air navigation with additional visual tasking by the subject, with the tandem instructor serving as the safety pilot.

As part of the planning for the HAHO TSAS air navigation test, informal interviews with active duty HAHO personnel were conducted. During these interviews, military personnel indicated the following interest in the navigation capabilities of the tactile display for canopy flight:

- Current glideslope indications would be especially useful for avoiding arriving at the waypoint too high.
- Left - right steering cues would assist separated team members in avoiding one another.
- Waypoint steering cues would be useful in ground operations in various situations.

In addition, active duty HAHO personnel postulated that the following additions to the TSAS-SF tactile navigation system would improve mission effectiveness:

- A mode assisting the jumpmaster in aircraft spotting.
- A mode for groundspeed indication and altitude indication below a trigger altitude for help during the landing sequence.

Preliminary results, both qualitative (Table 5) and quantitative (Figure 5) suggest that the use of the TSAS-SF for ground navigation allows the subject more “heads up” time. This “heads up” capability can improve search capability of both hostile and friendly factors. When combined with an additional visual task, tactile cues show the potential to be an effective alternative, or enhancement to visual displays. The majority of subjects preferred TSAS-SF to the visual only display, because TSAS-SF was easier to use and provided enhanced navigation. This capability would be invaluable to Special Forces operators to increase mission effectiveness. .

The results for the air and land navigation testing are in agreement with previous underwater navigation testing (McTrusty, Walters, 1997; Rupert, McTrusty, Peak, 1999). To determine the feasibility of tactile navigation in an underwater environment, a test was conducted with the Very Shallow Water (VSW) Mine Counter Measure (MCM) unit. Divers conducting VSW MCM operations must navigate using the Swimmer Inshore Navigation System (SINS) while monitoring mine detection sensor displays. TSAS was integrated to the SINS to provide underwater tactile navigation data. The subjects navigated a triangular course. The navigation cues were provided visually via the SINS display or via tactors attached to the divers’ wrists. Example data shown in figure 6 compares subject navigation tracks using both methods.

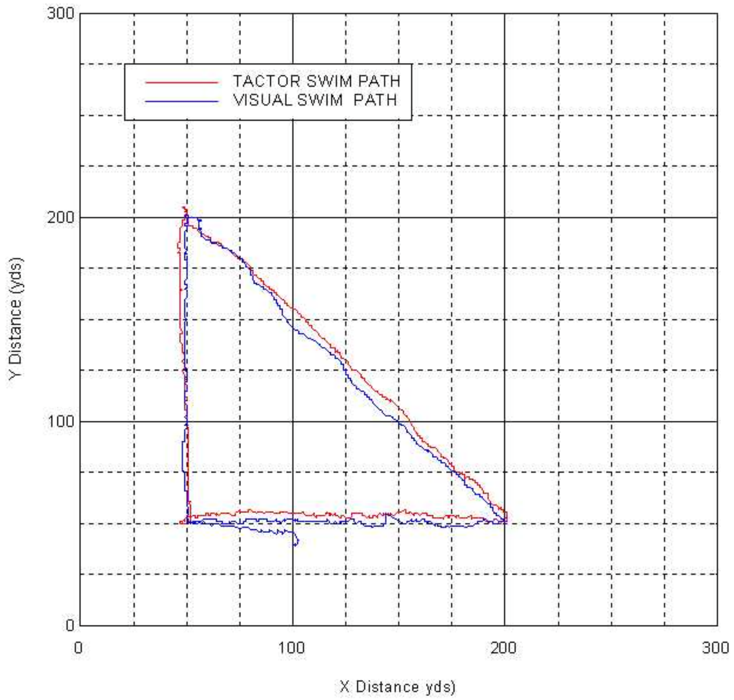

Figure 6. Example of diver navigation using either SINS-visual or tactile cues (from McTrusty, Walters, 1997).

Results of the underwater tests and subjective evaluations, showed that:

- Tactile cues were an effective alternative, or enhancement to visual displays.
- Cross track error was insignificant for both methods.
- The majority of subjects felt that TSAS was easier to use and provided enhanced navigation.
- All divers indicated that operational navigation capabilities could be enhanced with tactile technology.

Conclusions

Currently, the US military Special Forces use 2D visual navigation displays for air, ground and undersea operations. The use of a tactile display for navigation information frees the operator from a heads down position while under canopy, moving on the ground, or swimming under the water. This capability has the potential to improve performance and mission effectiveness, and reduce workload and fatigue.

TSAS hardware could be integrated into current mission equipment loads with minimal added weight or discomfort. The navigation algorithms can be easily updated to account for changing environmental conditions or mission objective parameters. Preliminary results from the air and ground navigation tests justify continued testing and evaluation to extend the capabilities of the tactile display, so that it may be used as an operational device for navigation in sea, air and land environments.

TSAS-SF, equipped with appropriate sensors, could have further Special Forces operational applications for cueing team member location and threat direction. Similarly, communication between squad/platoon members could be achieved in an intuitive, clandestine manner using a tactile display vice a traditional audio display.

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