

Trial of a special end user terminal that aids field operators during emergency rescue operations

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ABSTRACT

This research is part of an EC Framework VI project called OASIS (Open Advanced System for dISaster and emergency management - <http://www.oasis-fp6.org/>). OASIS involves developing an IT framework for interoperability in crisis management across national and agency boundaries and providing a number of applications to support user requirements.

This paper discusses trials to evaluate an end user system that aids field personnel during emergency rescue operations. The system consists of a Head Mounted Display (HMD), camera, deployable ad-hoc wireless network and a noise reducing earpiece called PARAT which acts as a low noise voice pick-up for voice activated commands. The system presents relevant graphical and textual information to the users through a set of predefined commands and aims to improve communication between the operators. Eight fire-fighters participated in an evaluation trial utilising a simulated "Search and Rescue" scenario. A full system description, integration implications, scenario and results from the trial are presented.

Keywords

Crisis Management, Human Factors, Head Mounted Display, Direct Voice Input, Speech Recognition, Situational Awareness, Workload, Field Operators

INTRODUCTION

Large emergency and disaster operations involve a range of different personnel all dependent on the best IT support for an efficient handling of the emergency. At the forefront are the emergency personnel working in the field. Their role is crucial in both gathering information (to be shared) and in actual dealing with the emergency and solving the crisis. It is therefore important that the field operator has optimal equipment to ensure both situational awareness and enhanced communication with the command Head Quarters (HQ).

Brief experiments were carried out in 2005 and 2006 in order to assess the benefits of presenting information using a Helmet Mounted Display (HMD). The system was then not mature enough to be trialled with real end users. During previous trials Situation Awareness [3] and workload metrics have been developed and applied to evaluate an in-house crisis management exercise. The results of the exercise indicated that the SA tools were useful in highlighting where there were weaknesses in the information provision and flow of information within the team during the exercise (Carver et al. 2006)¹.

The focus of this paper is the evaluation of an innovative end user ICT system consisting of a HMD, intelligent noise-cancelling earplugs called PARAT, and a wireless ad-hoc network called Grey-Box that aid field personnel

¹ Carver, E.M., Dogan, H., Dawson, B., & Hinton, J. (May 2006) Enhancing Communication in Rescue Teams. *Proceedings of the 3rd International ISCRAM Conference*, Newark, NJ (USA), May 2006.

during emergency rescue operations and ensure information flow between field and command Head Quarters (HQ). The paper reports on a field trial and subsequent user evaluation of the HMD-PARAT system, carried out in October 2007 at the Airbus site near Bristol, UK.

Below is a (visionary) illustration of the HMD-PARAT system, seen from a user perspective.



Figure 1. A (visionary) illustration of the HMD-PARAT system

The eight fire fighters involved in the trial were especially interested in whether and to what degree the system might help them with their search and rescue operations in a smoke-filled building in addition to supporting them with navigating the area.

The specific objectives of the trial related to the HMD were to elicit feedback and evaluate:

- the quality of the HMD display in low-visibility (smoke) conditions
- Graphical User Interface (GUI) issues e.g. design, layout and usefulness of information on the HMD display
- the perceived usefulness of the format of the information provided
- the form factor of helmet (ease and comfort of use)
- experienced quality and ease of use of using voice commands to control the display, as well as the appropriateness of the command vocabulary used
- experienced quality of communication between users (fire-fighters and Head Quarters).

The specific objectives of the trial related to the PARAT earpiece system were to elicit feedback and evaluate:

- the perceived usefulness of PARAT as an end-to-end voice communication terminal
- the perceived usefulness of the PARAT earpiece as a hearing protection device
- the quality of voice command recognition, as well as the appropriateness of the command vocabulary used – in both quiet and noisy surroundings
- the form factor of the PARAT earpiece (ease of insertion and use, comfort of use)
- the functionality and form factor of the user interface for controlling hearing and voice output settings
- the perceived properties of PARAT with respect to natural hearing under noise conditions that form no hazard to hearing

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This research is part of an EC Framework VI project called OASIS (<http://www.oasis-fp6.org/>). The aim of OASIS is to define and develop a first version of an open, modular and generic Disaster and Emergency Management (DEM) System in order to improve the effectiveness and efficiency of the management of Disaster and Emergency Operations (DEO). At the core of the work is the design and development of a generic, interoperable and open architecture which will allow easy deployment at every level of the action chain (local, regional, national and European).

SYSTEM OVERVIEW

Head Mounted Display (HMD)

The purpose of the HMD is to present relevant graphical and textual information on the HMD to the user (e.g. floor maps) that are visible even in low visibility conditions (i.e. smoke). Live video capture from the helmet camera are fed live to the Head Quarters (HQ) and “whiteboard” functionality enables HQ personnel to guide the field user by e.g. drawing an escape route on the floor map displayed on the HMD. The head mounted display has been selected based on criteria such as resolution, field of view, refresh rate, colour, luminance range and wearability. The selected HMD has a luminance of around 100cd/m2. The HMD solution utilises a high resolution (800 x 600 pixels) display area, and reformats the information to allow ‘see through’ capability. To do this all black backgrounds are used and the information is presented in positive contrast. Font sizes are selected for legibility and colour is sparingly used. The HQ computer in Figure 2 contains four different screen sections: video stream, text instructions, site map and route directions. Any or all of these windows on the Head Quarters display can be displayed to the mobile operator and selected by voice control.

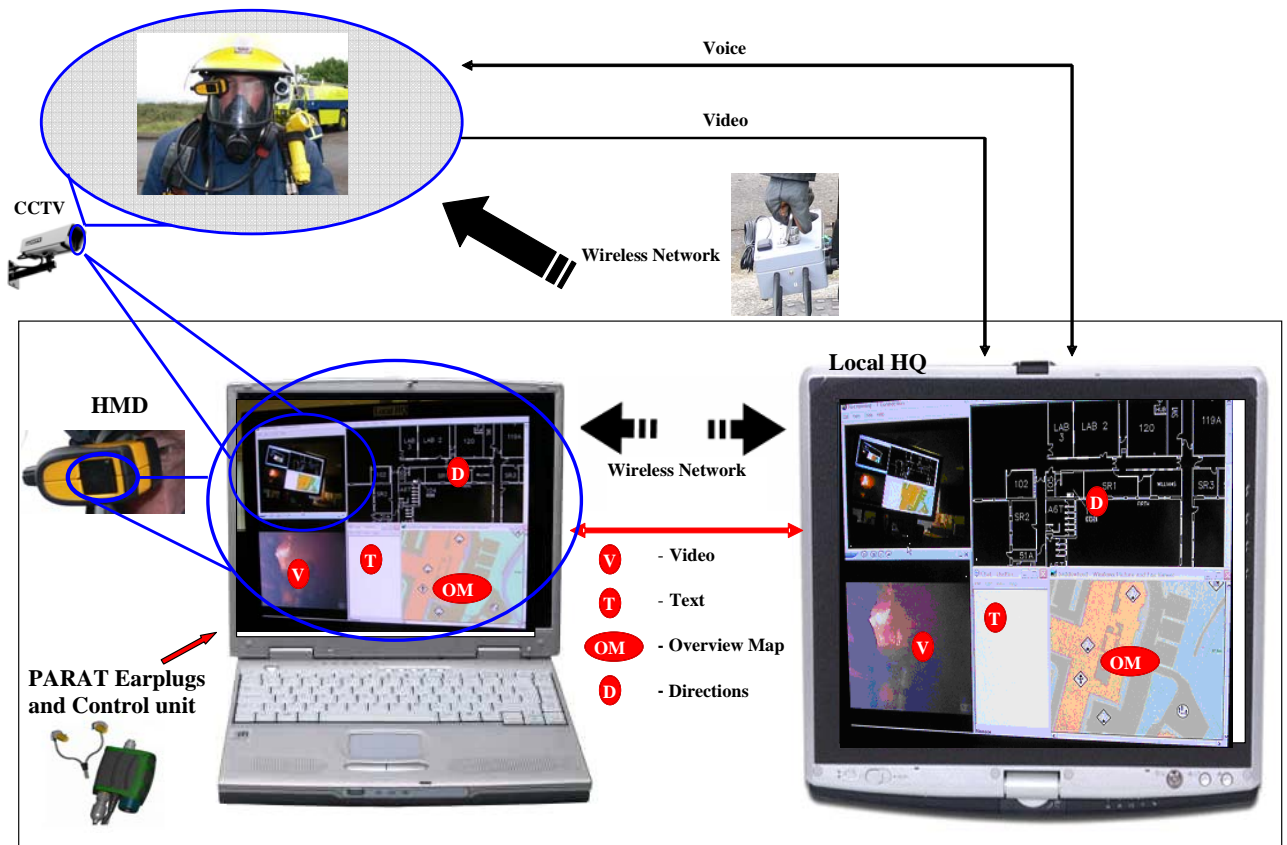


Figure 2. HMD and Head Quarters displays with communication media

PARAT Earpiece

The purpose of the PARAT earpiece system [4] (one earpiece in each ear) is to provide low noise voice pick-up for the voice communication with HQ and for the voice activated commands that control the HMD display. Another function of the PARAT is to provide hearing-protection, as it reduces sound input to the inner ear as noise levels increase to dangerous levels. Each PARAT unit consists of a pair of earplugs connected by cables to a programmable control unit. The control unit has a simple user interface and is powered by batteries. The control unit has connectors for interfacing to communication units. Each earplug unit consists of a sealing part, an outer microphone (to monitor and capture sound in the user's environment), an inner loudspeaker (to provide the audio signal to the user, possibly including active noise reduction) and an inner microphone (to pick up the user's voice, for use with active noise reduction, and to monitor the effect of attenuation in the ear canal). Figure 3 below shows a picture of the PARAT headset.

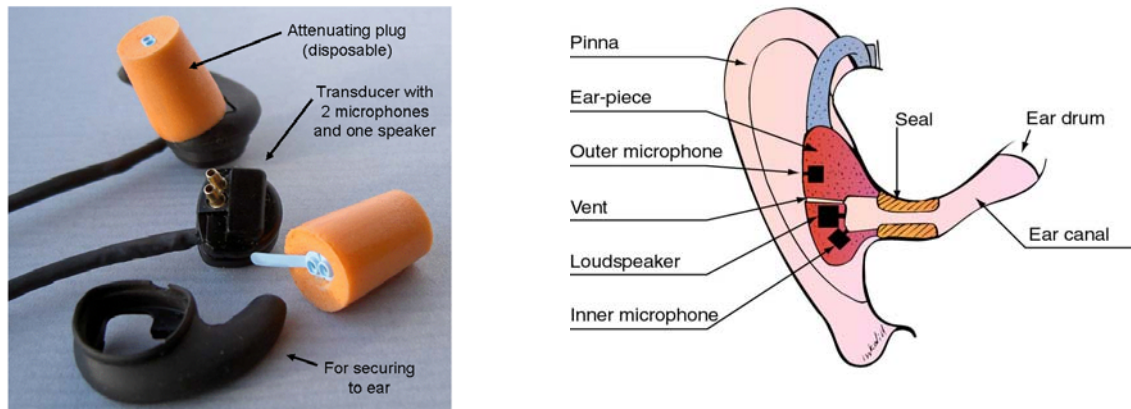


Figure 3. The PARAT headset and earplug transducer configuration

Standard software components

The HMD system described here relies on the use of standard software components, mainly the use of Microsoft NetMeeting for voice over IP communications and videoconferencing for the HMD, and Dragon Naturally Speaking for the DVI (Direct Voice Input). Dragon Naturally Speaking is a speech recognition software package produced by Nuance Communications for Windows PCs. It has a command-and-control mode that allows specification of a limited vocabulary. In this application a set of command vocabulary has been set up for user interaction e.g. "alternate view", "next", "go back" to allow users to switch between text messages and map views as well as to navigate through the set of slides and instructions provided to them.

TRIAL DESCRIPTION

Trial overview

The trial ran over two days, 1st and 2nd October 2007, at the Serco Fire Airbus site in Filton (Bristol, UK). The first day consisted of presentations and demonstrations, and tuning the system to the individual test users and to provide individual training. The second day was the actual trial; where the end users interacted with the system through a scenario. A structured system evaluation was also carried out after the trial.

The trial took place in an underground four room "bunker" at the Serco Fire Airbus site. Smoke simulation machines were also provided to generate the required low-visibility smoke conditions. There were eight different end users (fire-fighters), who went through a predefined search and rescue scenario in pairs for safety reasons.

Scenario and conditions

The trial itself was divided into two sessions, the morning session and the afternoon session. The scenario consisted of the following:

- Fire-fighters enter the smoke-filled compartment (bunker) in pairs, one with the HMD-PARAT system and the other with the standard equipment.
- Two other fire-fighters support them by providing guidance from outside the compartment e.g. inside the HQ vehicle.
- A safety officer needs to accompany the two entering the compartment.

The first four participants were active in the morning session and the remaining four in the afternoon session. They were given a task of locating a hazardous substance trapped in a compartment where a rapidly spreading fire is started towards the end of the search. Users were involved in exchanging data such as images and real-time video to check whether the item found in the area is the hazardous chemical substance that the chemical specialist, earlier called to the area, was looking for. The three scenario conditions are as follows:

- **Condition 1: WITHOUT PARAT/HMD**- i.e. use of standard communications equipment. Full kit e.g. the respirator mask, air cylinder, helmet and radios.
- **Condition 2: WITH HMD ONLY** – using a normal microphone (Condition 1 plus HMD).
- **Condition 3: WITH HMD/PARAT** - the complete system including the HMD and PARAT earpiece, video output, speech control (DVI), directions (floor plan), overview map and text instructions (Condition 1 plus HMD and PARAT).

Each pair of fire-fighters was assigned to run through conditions 1 to 3. Smoke simulations were to be part of the last condition. This is the time-slot when the fire starts while the fire-fighters are searching for the hazardous chemical substance within the compartment. The HMD tools to help the end users with condition 2 and 3 include images such as floor plans of the bunker with room numbers; photo of bunker rooms; photo of objects to be located; and aerial photo of the bunker and vicinity.

EVALUATION METHODOLOGY

This evaluation consisted of the following methods as a result of the availability of the end users:

- **Post test questionnaires:** this was given to the participants at the end of the trial to capture the perceived usefulness; ease of use; perceived compatibility; and advantages and disadvantages of the integrated HMD and PARAT system.
- **Structured debrief session:** this was conducted at the end of the trial after exploring what the “system” can offer. All the participants participated in this structured workshop. Discussions focused on individual situational awareness and shared awareness including complementary awareness between the fire-fighter and HQ, targeting feedback to highlight the trial objectives.
- **Video and audio recording** of the entire trial for further in depth analysis.
- **User observations:** the supplementary operators and the Human Factors evaluators who observed the entire trial were asked to capture user interaction and system specific feedback during the trial. The user evaluators were briefed with a set of predefined topic areas that the trial was concentrating on including the best and worst features and functionality of the system. The feedback captured is consequently analysed and documented.

The test users were given a thorough description and demonstration of the system before the trial, allowing time for both questions and hands-on training,

EVALUATION RESULTS

The results from the questionnaires are presented graphically on the following pages. The questionnaires were structured as a set of (positive) statements about the HMD and PARAT system, and the users gave a score on how well they agreed with the statement, using the following legend:

- 5: Strongly agree
- 4: Agree
- 3: Neither agree nor disagree
- 2: Disagree
- 1: Strongly disagree

The graphs show the mean score for each question with the standard deviation indicated as vertical line; both above and below the mean value. The statements in the questionnaires formed three categories:

- Perceived usefulness
- Perceived ease of use and
- Perceived compatibility.

Questionnaire results on HMD/PARAT

The aggregate results for all the questions within a category are shown below:

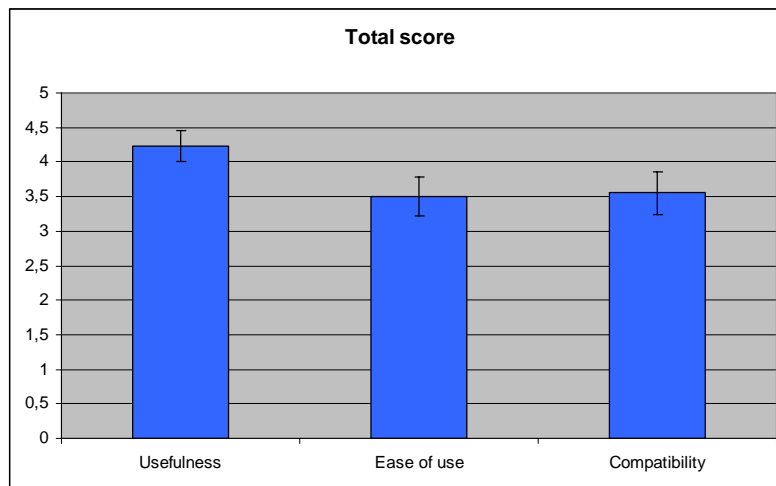


Figure 4. Total score within each questionnaire category

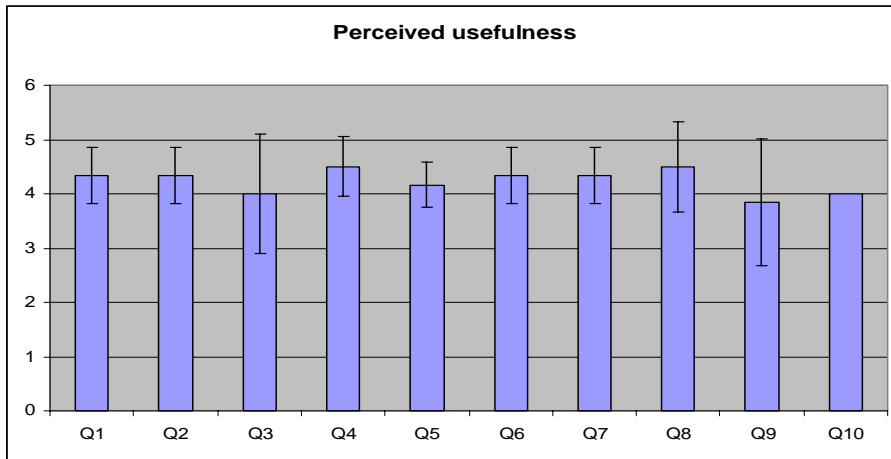


Figure 5. Questionnaire results on "Perceived usefulness"

- Q1. The HMD/PARAT can be useful in my job.
- Q2. Using the HMD/PARAT has the potential to improve my job performance.
- Q3. Using the HMD/PARAT has the potential to increase my situational awareness (I am more aware of what is happening around me).
- Q4. Using the HMD/PARAT has the potential to improve or facilitate information exchange with the HQ.
- Q5. Using images in addition to spoken information has to potential to increase my situational awareness.
- Q6. Using voice commands during an operation is a feasible way of keeping your hands free.
- Q7. The images on the HMD are useful.
- Q8. The PARAT earplugs improve the quality of voice communication with the Head Quarters.
- Q9. I experience situations in my work where I would expect PARAT to help protect my hearing.
- Q10. The advantages of using the HMD/PARAT outweighs the disadvantages.

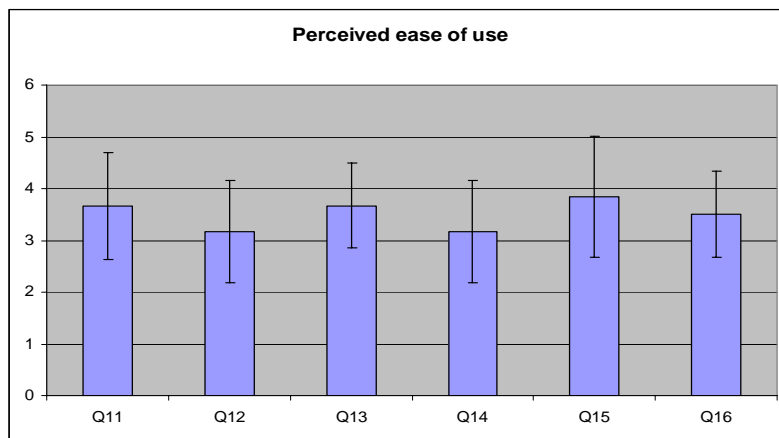


Figure 6. Questionnaire results on "Perceived ease of use"

- Q11. Learning to use the HMD/PARAT system was easy for me.
- Q12. The PARAT earplugs are comfortable to wear.
- Q13. It was easy to control the display using voice commands

Q14. It was easy to switch between using voice commands and talking with the Head Quarters.

Q15. It was easy to understand and read the information given on the display.

Q16. Using the HMD/PARAT does not take too much time and effort away from my operational tasks.

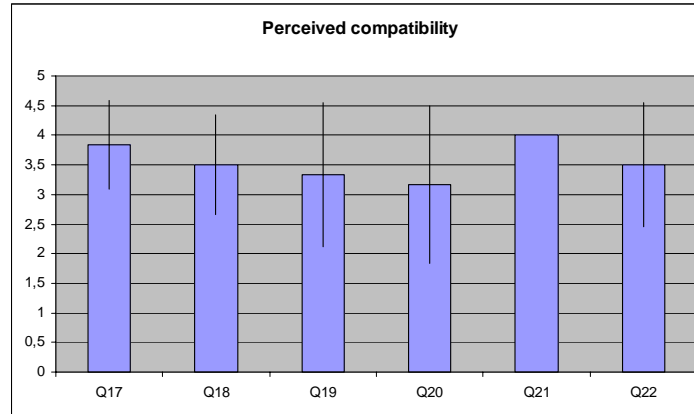


Figure 7. Questionnaire results on "Perceived compatibility"

Q17. The HMD/PARAT system is compatible with the way I work.

Q18. Using voice commands in the field does not interfere with the way I work.

Q19. The HMD does not affect my ability to see.

Q20. The PARAT earplugs do not affect my ability to hear or communicate

Q21. The HMD/PARAT system in the field only marginally increases my mental workload (e.g. thinking, deciding).

Q22. It is easy to see the images on the HMD and still be aware of the surroundings.

DISCUSSION

HMD centric discussion

The prototype is trialled to explore the potential for use by fire-fighters. The discussions here focus on the problematic features with the current configuration and potential changes requested by the end users. For example, the users mentioned the importance of integrating a Thermal Imaging (TI) camera. The current system will be significantly useful with TI cameras in supporting search and rescue operations in large buildings with more escapes. They have also emphasised that this is a great system to be used in urban search and rescue and also earthquakes operations.

Situational awareness and operator workload

The users were asked open ended questions about their workload and Situational Awareness (SA). They were satisfied with the amount of information provided but emphasised the importance of providing information about the oxygen cylinder content and temperature of the room. In addition, the users mentioned that their physical workload was acceptable and the voice commands were easy to remember. The floor plans were perceived as the most useful feature on the HMD to increase Situational Awareness and improve navigation. It was also emphasised that only specific information relating to the incident should be pushed to the user e.g. only floor plans when inside the building rather than aerial photos and maps.

Screen formats, layouts, navigation and operation of display controls

The users were also very positive about the feature that the operator in the HQ could help their navigation by drawing directly on the floor plan or map, directing them to a specific area within the building. However, the efficient use of these features is considerably dependant on access to updated floor plans at all times, and that outdated floor plans might represent a safety risk. A positioning or personnel tracking system indicating the current

location of the fire-fighters or the teams would be very beneficial. The system is very useful in marking the danger areas and the areas that have been cleared. Therefore, creating a cordon and directing the fire-fighters by drawing the shortest route on the HQ PC are essential features of the system.

Voice command interaction and information exchange reliability with a boom microphone

Technical problems hindered a full scale test of the voice commands. Only the HMD boom microphone was tested for this functionality as some unforeseen technical problems hindered the correct training with the PARAT earpiece. The users were satisfied with the boom microphone voice command interaction but mentioned the preference of having an alternative interaction medium e.g. buttons to control the GUI rather than voice input controls. The users were unable to use the boom microphone with Breathing Apparatus (BA). Intelligent clothes and wrist-worn computer based interaction are alternatives that are worthy of investigation.

Interoperability between different command and control entities

The real-time video feed that fed the HQ with continuous updates on the fire-fighters status and safety was identified as one of the best and useful features of the system. The users also envisioned this feature as being relatively useful in initial crime scene or air crash investigations, for the preservation of evidence. Another useful feature identified was taking still images and saving them. The users mentioned having real video feed and voice communication enhanced interoperability between the control centre and the team in the field. The users also emphasised the importance of integrating these systems with the live feed from e.g. a police helicopter or CCTV camera to the fire HQ controller depending on the situation. This can be possible through the ad-hoc wireless network and hence an internet connection.

The form factor: compatibility, ease and comfort of use

The integrated system should be rugged, resistant against heat, water and falling objects and built into the current kit. Some compatibility issues were raised by the users. The system has to be used with and without the breathing mask and chemical suit. There are also handling issues – the system has to be ready and adjusted within a short time period. The HMD is adjustable and the see through option can be switched off but the users experienced problems with having both the HMD and BA. The eye piece needs to be extended out over BA mask for better position in the visual field. The HMD can be positioned directly in front of the eye or in the upper part of the visual field. In addition, weight was another constraint due to carrying laptops but this can be mitigated in the future by having smaller machines e.g. palm computers.



Figure 8. HMD at the Trial

PARAT centric discussion

Speech communication with PARAT

The users were very positive about the quality of the speech communication they achieved with the PARAT system. Both the HQ controller and the fire-fighters judged that the PARAT system improves communications between the two.

Currently the Serco fire-fighters use handheld radio terminals in their standard operations. One of the main challenges with this is to achieve good quality and intelligibility even when a BA (Breathing Apparatus) is worn. The fire-fighters are used to talking (or having to shout) through the BA, which results in muffled speech with low intelligibility. The users were therefore generally impressed by the PARAT speech quality, and especially in the cases where BAs were worn.

Voice command interaction and reliability with PARAT

The voice command interaction was based on Dragon Naturally Speaking (DNS), which is software for general dictation purposes with a conventional boom microphone. As a part of the training all users went through an enrolment session. Dragon Naturally Speaking has its own mechanism for this, and during this session it verifies the match between the read material and the underlying acoustic models.

However, serious problems were encountered with enrolment of the trial test users, to the extent that testing of DVI with PARAT had to be taken out of the trial. The reason for this was probably that the PARAT microphone sits in the ear canal, producing a speech signal that is very different to what a conventional microphone will capture. It will therefore inherently be a substantial mismatch in the initial phases of the enrolment, which has to be handled specifically. Another possible reason for the enrolment failure is that the Dragon Naturally Speaking acoustic models were prepared for UK English, and accents deviating from standardised language will lead to larger mismatch during the enrolment stage, possibly leading to failure.

Due to these problems, the voice commands were not tested with the PARAT front-end during the trial. However, the SINTEF research team have overcome the problems since the trial, and carried out laboratory tests of the DNS-PARAT speech recognition functionality. These tests indicated that a good DVI (Direct Voice Input) performance is achievable with the DNS-PARAT system, even in quite severe noise, given that the PARAT inner microphone is used for voice capture. The results show that the performance deteriorates quickly with the conventional microphone solutions in noisy conditions. These results support the findings from previous research [5].

Natural hearing and hearing protection with PARAT

PARAT is designed to maintain natural hearing to the degree that it is safe with respect to the risk for noise induced hearing loss. When asked to rate the statement “the PARAT earplugs do not affect my ability to hear or communicate”, some people seemed to agree, while others disagreed. Some might have rated the experienced (and correct) shut-down of hearing that happens when ambient noise exceeds a certain level, as negative. Others might have referred to the reduced communication with their partner in the field: since only one of the test users in field had the earplugs on at any one time and was busy communicating with HQ, the natural communication between the fire-fighters in the field was suffering. This is an issue for further investigation.

The fire-fighters were somewhat reluctant to say to what degree they experience situations in their work where they need hearing protection. In the trial there was no need for this. However, this is an issue that has received quite a bit of attention in research on occupational health, and several reports have been published that suggest that the noise exposure for fire-fighters is an issue. This was also stressed by some of the fire-fighters during the debrief session, that the combined noise of water pump engines and the water itself amounts to quite high levels.

Other issues

Ad-hoc Wireless LAN communication solution

The WLAN communication was not part of the trial evaluation. However, it was clear that an ad-hoc communication solution like the one used during the trial was beneficial. The fire-fighters reported that they often experience problems with their existing solution, e.g. inside (thick-walled) concrete buildings. The advantage of the

trial communication network was that it could be set up in an ad-hoc manner; dropping relays at critical locations to enabled communication between fire-fighters and HQ even when they were inside the concrete walled bunker.

CONCLUSIONS AND FUTURE WORK

Conclusions

This report contains the results from a trial by fire-fighters using an integrated HMD and PARAT earpiece for a search and rescue mission in a smoke filled bunker.

The feedback received from the end users indicates that the integrated HMD and PARAT would greatly improve communication and situational awareness in search and rescue scenarios for fire-fighters, compared to equipment they use today. The OASIS team were very pleased at the general high level of enthusiasm for the system expressed by the fire-fighters throughout the trial, despite the technical difficulties that were experienced. Comments like: "overall it is a great piece of kit which will greatly assist the role of a fire-fighter", "the system enables better information sharing" and "a lot better communications (than today)" indicates that the system is on the right track and should be pursued for further development. This was supported by explicit statements by test-users stating that they hope to see the real product developed in the near future.

The perceived "top three" system features are:

- Floor plan image on the HMD combined with the feature that HQ operator can in real-time draw a line or mark off central objects on the map ("It is easy to follow floor-plan to find my way about")
- Live camera feeds from fire-fighter to HQ operator ("I can see what they see", "It improves situational awareness")
- Overall quality of communication between fire-fighter and HQ operator ("found communications crystal clear with head quarters, did not have to use up valuable energy by shouting into microphone")

The positive statements cited above are supported by the questionnaire results on "perceived usefulness" which received an overall high score (4.2 out of 5). "Perceived ease of use" and "perceived compatibility" received lower scores (3.5 and 3.6) reflecting the fact that the prototype system will require some improvement and adaptations of both form-factor (e.g. a smaller laptop to run the system) and user interface (e.g. buttons must be operable with gloves on) before it is fully operational.

Recommendations for further work

Based on the feedback received from the fire-fighters, our recommendations concerning future system development are as follows:

Form factor

- Current laptop attached to the fire-fighter's belt must be replaced by a smaller palm unit and carried on back (e.g. fitted beside oxygen cylinder).
- The HMD eye piece needs to be extended to be able to fit over the BA mask. The solution chosen needs to be adaptable to use both with and without the mask.
- The system must be better ruggedised and made resistant against heat, water and falling objects. Battery charging is also an issue.
- PARAT earpieces should be custom-made to improve comfort for wearer.

User interaction solutions

- An alternative interaction medium e.g. buttons to control the HMD GUI rather than voice control, should be considered, since user feedback indicates that the number of required HMD views are very limited. E.g. a single button could be used such that when pressed the screen toggles between the different images on the HMD.
- Buttons must be made bigger to be operable with gloves on. Positioning of buttons must be carefully considered.

- Just as for the fire-fighters, the HQ operator needs a “push to talk” button when communicating with the fire-fighter in the field, to screen fire-fighter from other noises and conversations at HQ.

New “must-have” system features

- Thermal imaging camera should be integrated into system for easy detection of casualties. This could save lives.
- Temperature of environment and remaining gas cylinder content should be displayed on HMD, for added safety, e.g. as green/yellow/red light warnings
- Images on HMD should be reduced to a minimum to simplify operation. Floorplans and text messaging are the two core views in addition to temperature and gas cylinder content as mentioned above.

Other issues

- PARAT earpiece system must be worn by all fire-fighters in field, to enable unhindered in-team communication.
- To show the floor plan on the HMD is a great and useful feature, but it is only as good as the correctness of the plan. Outdated floorplans might even pose a safety risk. An infrastructure has to be built up to ensure that the system gets access to updated floor plans at all times.
- In large scale emergencies, the system must be able to also communicate with other emergency entities like the police; e.g. to receive live feed from a police helicopter.

ACKNOWLEDGEMENTS

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