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SEVENTH FRAMEWORK PROGRAMME

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# Report on the Use and Benefits of Wearable Displays, Sensors and Localization Technologies for First Responder Support

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## Abbreviations

| | |
|---|---|
| BA | Breathing Apparatus |
| C2 | Command & Control |
| COPE | Common Operational Picture Exploitation |
| FOV | Field Of View |
| FRS | First Responder System |
| FRS-C | First Responder System Control |
| FRS-HW | First Responder System Human Wearable |
| GPS | Global Positioning System |
| HMD | Helmet Mounted Display |
| HUD | Head Up Display |
| IC | Incident Commander |
| IR | Infra Red |
| PC | Personal Computer |
| PPE | Personal Protective Equipment |
| SC | Sector Commander |
| Wi-Fi | Wireless Ethernet IEEE 802.11 |
| WMD | Wrist Mounted Display |

**Summary**

The aim of this document is to detail the types of wearable sensors and displays that were used by the first responders in the COPE trial as well as their associated functionalities. This document describes the operational tasks for which the first responders were using the equipment. Finally this document details the advantages and disadvantages of the technologies based upon the analysis of user feedback alongside observed operational results.

# Contents

Page
1 Technologies Used in the COPE Project ..... 5
1.1 Wearable Displays ..... 5
1.1.1 Helmet Mounted Display ..... 5
1.1.2 Wrist Mounted Display ..... 7
1.1.3 Tablet Display ..... 9
1.2 Wearable Sensors ..... 10
1.3 Localization ..... 11
2 Operational Tasks in the COPE Trials ..... 11
2.1 Fireworks Factory ..... 12
2.1.1 Description ..... 12
2.1.2 User Feedback ..... 12
2.2 Brewery Fire ..... 12
2.2.1 Description ..... 12
2.2.2 User Feedback ..... 13
2.3 Ammonia Cloud ..... 13
2.3.1 Description ..... 13
2.3.2 User Feedback ..... 13
3 Advantages and Disadvantages ..... 13
3.1 Wearable Displays ..... 14
3.1.1 Advantage / Disadvantage Summary ..... 15
3.2 Wearable Sensors ..... 15
3.2.1 Advantage / Disadvantage Summary ..... 17
4 Conclusions ..... 18
5 References ..... 19

# Figures

Page
Figure 1 Helmet Mounted Display ..... 6
Figure 2 HMD video example ..... 7
Figure 3 Wrist Mounted Display ..... 7
Figure 4 Outdoor and indoor maps ..... 8
Figure 5 Inertial system flow diagram ..... 10
Figure 6 The Wearable sensors platform ..... 11
Figure 7. Firefighter helmet with mounted thermal and daylight video cameras. ..... 16
Figure 8. Worn sensors were mounted on the helmets and a utility vest for purposes of the evaluation. Here project team members are testing the systems before deployment on the trial. ..... 17

## Tables

Page
Table 1 COPE trials FRS allocation ........................................................................ 12
Table 2 Advantages and disadvantages of wearable displays ................................ 15
Table 3 Advantages and disadvantages of wearable sensors ................................ 17

# 1 Technologies Used in the COPE Project

This section looks at the wearable displays and sensors used by the first responder in the COPE trials. It also looks at how these technologies were used to provide localization and situational awareness for the first responders and their Sector Commanders (SCs) (see Wilkins, 2010, for a full description of the technologies and integration plan for the COPE project).

## 1.1 Wearable Displays

The first responder in COPE has two wearable displays at his/her disposal, a Helmet Mounted Display (HMD) and a Wrist Mounted Display (WMD). The HMD is a binocular set of video glasses that have been mounted under the brow of the fire helmet behind the blast visor. The WMD is a smart-phone that has been mounted in a sports wrist band that is worn on the first responder's wrist.

The SC has one wearable display at his/her disposal and that is a tablet Personal Computer (PC), this is worn on a strap across the body and over one shoulder. This means that it can be stowed beside or behind the user when not required.

### 1.1.1 Helmet Mounted Display

The HMD is a non see-through display and is mounted above the eye-line of the user such that the user has to look up into the display to view its contents. The helmet mounted display is a colour, low resolution display and it is focussed at optical infinity to avoid eye strain. The display format is S-Video which means that it can display both real-time video and symbology.

*Figure 1 Helmet Mounted Display*

The data displayed on the HMD contains three categories of information: status information, real-time video and an interior map.

The status bar is visible all of the time at the bottom of the display and shows two items of information. The sector tactical mode is set by the SC and is updated as text on the status bar in real-time. The current time is also displayed next to the tactical mode to second accuracy.

Real-time video from cameras mounted on the user's helmet can be selected to be shown full-screen on the display. The video is registered along the user's forward looking eye-line and could be either standard video or thermal video.

A map of the interior of a building can be selected to be shown on the display. Overlays are drawn on top of the map consisting of a number of types of icons defining hazards, resources, and personnel. The user's own position is drawn on the map based upon positional data from the user's Global Positioning System (GPS)/Inertial sensor.

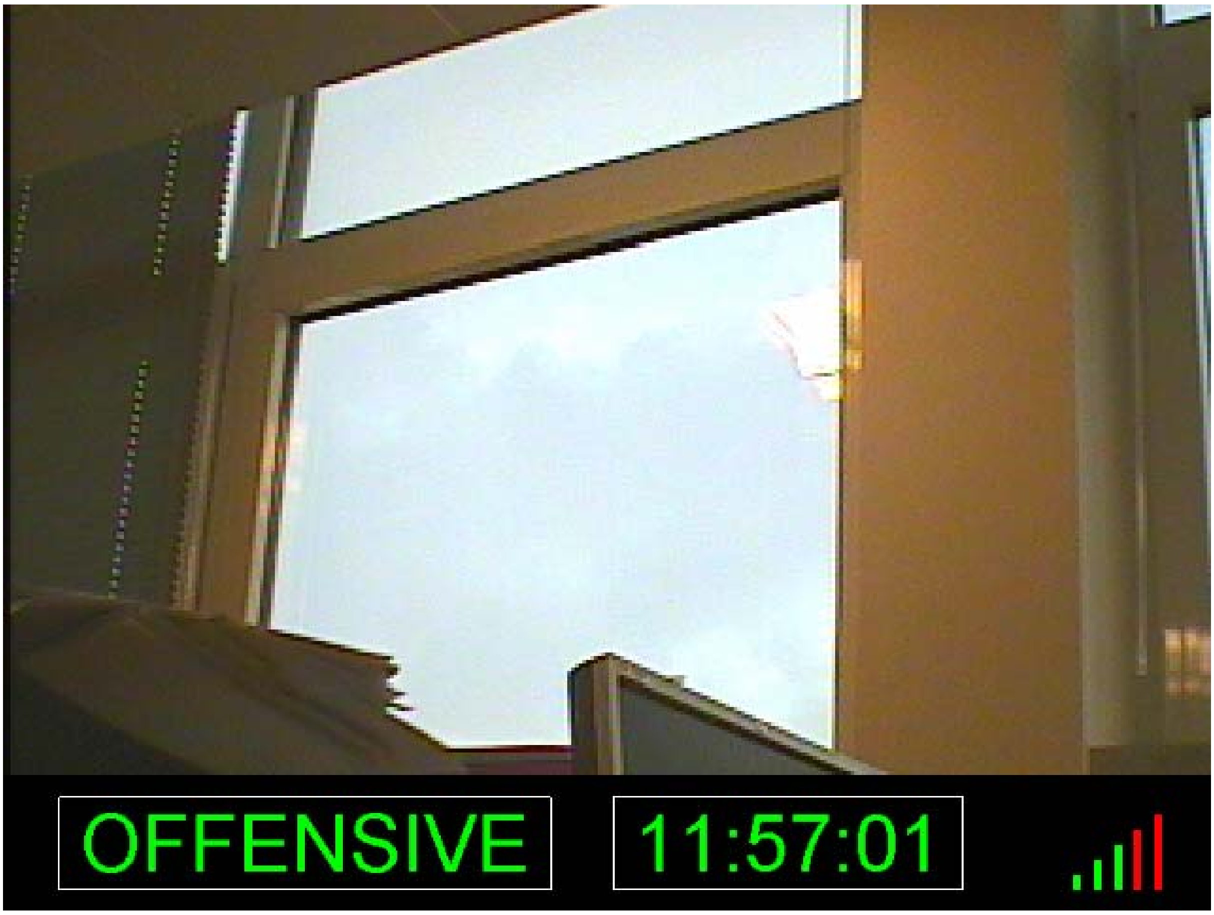


*Figure 2 HMD video example*

#### 1.1.2 Wrist Mounted Display

The WMD is a commercial smart-phone with a Microsoft Windows CE operating system. The WMD has a full colour display and has a touch-screen input. The touch-screen is a resistive technology which means that it can be operated by a user wearing gloves.

*Figure 3 Wrist Mounted Display*

The WMD hosts the following functions:

- User input functionality
- Interior Map
- Exterior Map
- Tagging
- HMD control

The WMD provides the only method of user input to the system via the touch-screen display and this is tailored to the user through a graphical user interface using large, simple buttons.

As with the HMD the WMD displays building maps with the same overlays however the user can control (by dragging using a finger) the viewing angle of the map as well as having simple zoom controls. Any changes to the view of the map on the WMD are repeated on the HMD also.

The WMD also has an exterior map for viewing a much larger area. This map has the same overlays as the interior map as well as additional information describing areas of interest etc. As with the interior map the user's own position is defined by data from the user's GPS/Inertial sensor.


*Figure 4 Outdoor and indoor maps*

The tagging control allows the user to tag an item of interest such that it can be viewed by the sector commander on his/her map. This tag takes the form of a geo-referenced audio/video clip. The concept behind this is that the user uses his/her sensors to describe an object rather than having to take extra time to write a description. The user would look at the item of interest, hence pointing the helmet mounted video camera at the item, and press the tag button. This starts the recording process and the user can then record a short audio message. On completion of the message the user would press the tag button a second time which stops the recording and automatically sends the message back to the SC. The whole process takes as little as a couple of seconds depending upon the length of the message. The voice recording is supported by a throat-mounted microphone (see Figure 1).

As mentioned in section 1.1.1 the HMD can show either real-time video or the interior map and this selection is made by the user. The HMD control function on the WMD supplies the user with the ability to change the display source data.

### 1.1.3 Tablet Display

The tablet display is a Panasonic CF-19 Toughbook which is actually a convertible tablet/laptop PC. This unit is small and rugged with a touch-screen display that, like the WMD, is resistive hence useable with gloves on.

The First Responder System Control (FRS-C) functionality is hosted on the tablet and is based around two main functions, situational awareness and team management. All user interface functions within the FRS-C are handled through the touch-screen interface. The FRS-C contains the following capabilities:

- Team assignment of First Responder System Human Wearable (FRS-HW) units.
- Tasking
- Outdoor and building maps.
- Breathing apparatus entry control

Team assignment of FRS-HW units allows the SC to assign his/her team members to specific FRS-HW units such that they can then be plotted on the various maps throughout the COPE system. It also allows the SC to de-assign team members from FRS-HW units e.g. at the end of a shift etc.

Tasking allows the SC to receive tasks from the Incident Commander (IC) and conduct a degree of “hand-shaking” including task acknowledgment and status change. It also receives the current incident tactical mode and IC’s statement of intent as well as allowing the SC to set the sector tactical mode.

The outdoor and indoor building maps are the same maps as those provided for the first responder however they have the additional functionality of allowing the user to slew the map around such that he/she can locate team members etc. These maps also have a different subset of overlays tailored to the needs of the SC.

The breathing apparatus entry control functionality allows the SC to assign team members to specific Breathing Apparatus (BA) sets and then set the average remaining usage time corresponding to the amount of air in the tanks. The timer for each set can be started independently and set off warnings as the timer reaches specified times before the air is scheduled to run out.

## 1.2 Wearable Sensors

The first responder has the option of wearing a number of different sensors to help aid their tasks.  For the COPE final trials the users wore the following sensors:

- GPS positioning sensor
- Inertial positioning sensor
- Draeger gas sensor
- Day/Low-light video sensor
- Thermal video sensor

The GPS sensor is the main localisation source and it resets its position periodically from satellites that it has visibility of.  This system only works outdoors as when under cover the sensor's view of the satellites is lost.  In GPS denied environments the inertial sensor is used to localise the user.  This sensor works by measuring the acceleration of the user in any given direction and hence calculates the distance travelled relative to a start position of the last good GPS fix.  The problem with the inertial system is that it is closed loop (see Figure 5~~Figure 5~~) where the input from the GPS is initial only hence once it is active it receives no further update/correction from any external source, due to it's inherent drift characteristics this means that the position of the user has an increasing error introduced to it as a function of time.

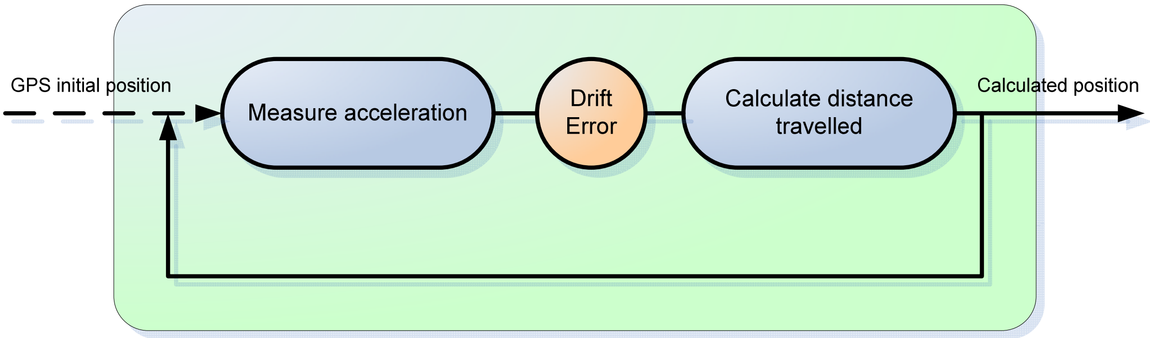


*Figure 5  Inertial system flow diagram*

The Draeger gas sensor constantly tests the local air supply and checks for concentrations of CO2, CH3, NH4 and NO2.  When particular concentration levels are reached for any number of these gases then an alarm is sounded to warn the user.

The day video sensor is mounted on the helmet along the forward looking line of sight of the user and provides him/her with a view on the HMD.  The day sensor has good low-light sensitivity hence can show excellent details in areas of particularly poor lighting conditions.  The thermal video sensor provides and Infra Red (IR) image on the HMD, this is particularly useful in aiding navigation in dark and smoky environments and is particularly useful indentifying heat sources e.g. casualties, hot surfaces etc.  Both video sensors are streamed back to the SC so that the SC can view what all of his/her team are looking at any one time.


*Figure 6 The Wearable sensors platform*

## 1.3 Localization

As mentioned in section 1.2 the main sensor used for localisation is GPS. This provides a simple coarse position of the user that allows people to view the user's location on a map. GPS is accurate up to 5m with a good fix, however as the presence of local obstructions obscures the sensor's view of the satellites the fix will degrade causing the positional error to increase.

When operating in a GPS denied environment the GPS fix is lost and at that point the inertial sensor will take over. The inertial sensor relies on having a good initial position and then measures movement, over time, away from that initial position. The challenge for the inertial sensor is to minimise its error characteristic such that it can be used for an acceptable length of time before the positional error causes the system to be unusable e.g. the system plots the user's position on the wrong side of a wall etc. (see Cullingford & Simpson, 2010 for further discussion of the issues related to emergency responder localization and operations in GPS-denied environments).

# 2 Operational Tasks in the COPE Trials

The COPE trials enabled users to test the supplied technologies in a number of realistic operational scenarios. The scenarios that the first responders were involved in are detailed below. Along with a description is listed our interpretation of the feedback given by the various end-users involved in each scenario.

The equipment used in each scenario is listed in the table below:

| **Scenario** | **Number of FRS-C units** | **Number of FRS-HW units (day)** | **Number of FRS-HW units (thermal)** |
|---|---|---|---|
| Brewery Fire | 1 | 1 | 1 |
| Ammonia cloud | 1 | 1 | |
| Fireworks Factory | 1 | 1 | |

*Table 1 COPE trials FRS allocation*

Please note that the feedback discussed in the following sections is not a series of direct quotations from the end-users, it is an interpretation of user comments from a series of interviews conducted immediately after the trials.

## 2.1 Fireworks Factory

This section describes, at a top level, the incident at the fireworks factory and then summarises the feedback from the users involved in the scenario.

### 2.1.1 Description

The fireworks factory was the source of the incident where a terrorist group had planted explosives. The destruction caused by the explosives caused a number of raw materials containers to explode. This ultimately resulted in the total destruction of the factory as well as igniting a number of vehicles in surrounding roads. A number of fatalities and casualties resulted from the explosions.

### 2.1.2 User Feedback

Unfortunately technical issues relating to the communication of data meant that the FRS was not functioning correctly in this sector hence operational feedback was not available.

## 2.2 Brewery Fire

This section describes, at a top level, the incident at the brewery and then summarises the feedback from the users involved in the scenario.

### 2.2.1 Description

The brewery was situated near the fireworks factory and most of its windows and glass was destroyed during the first explosion. Subsequent flaming debris and embers from the fireworks factory ignited areas of the brewery. During the incident the onsite ammonia tank ruptured.

#### 2.2.2 User Feedback

The fire fighter commented that the HMD would have been very useful however he was unable to see it properly in its mounted position, this is believed to be due to integration issues with the BA face mask. The same fire fighter said that the WMD was very functional however he could see practical issues with the device sliding inside the glove. He suggested that it may be better mounted on the glove.

The fire fighter suggested that it was difficult to test the practical uses of the thermal sensor because dummy's were used as casualties as opposed to real people hence there was no body heat signature to sense.

The fire fighter suggested that the WMD was easy to use and not time consuming, he also suggested that the menus were intuitive. It would have been a comprehensive fire fighter system if the devices had all worked correctly.

### 2.3 Ammonia Cloud

This section describes, at a top level, the ammonia cloud incident and then summarises the feedback from the users involved in the scenario.

#### 2.3.1 Description

During the explosions at the fireworks factory the ammonia tank based at the brewery was ruptured. The ammonia gas, leaking from the tank, formed a poisonous cloud that drifted, with the wind, across the incident ground.

#### 2.3.2 User Feedback

The SC mentioned the issue that the fire fighter's HMD was difficult to see whilst wearing a BA face mask. He also mentioned that the video appeared blurry on the FRS-C and that he could not adequately carry out his task using the video as he could not see the location of the fire fighter. He did say that if the fire fighter wearing the video sensor moved slowly then the image was moderate. The SC suggested that the progress of using streaming video was moving in the right direction.

The first fire fighter mentioned that if all of the protective equipment was to be worn then he would not have been able to see the HMD.

A second fire fighter suggested that an auto tilt HMD with voice control might be a good idea however he also mentioned that this might be an issue in an operational environment as audibility is very low.

## 3 Advantages and Disadvantages

This section lists the advantages and disadvantages of wearable displays and sensors based upon experience, trials results and user-feedback

## 3.1 Wearable Displays

The role of a display is to communicate information to the user. The user can potentially have a number of different information sources, radio, HUD, WMD etc. One of the real benefits of wearable displays is that the information is durable whereas with radio communication it is instantaneous/temporary i.e. Once the user has been sent a message over radio he/she has to remember the information, whereas when using a wearable display the information can remain on the screen allowing the user to refer back to it when required. In the same vein using wearable displays with a well designed user interface, the system can display information in much more efficient ways than traditional communications methods e.g. information displayed in picture format such as maps and charts etc. can be interpreted and processed by the user much quicker than radio messages communicating the same data. A good summary for these differences is that a wearable display can effectively present information in parallel to the user and can retain that information for review whereas the radio communicates information in a serial fashion and that information is not retained for review.

In this document we are concerned with wearable displays and one of the biggest advantages of them is that they can predominantly be used hands-free. For the COPE fire fighter a HMD was used which allowed the fire fighter to view data by simply looking up at the brow of the helmet. Likewise with the WMD the fire fighter can view data by looking down at his/her wrist.

The big disadvantage of wearable displays is that they are still a relatively immature technology when compared to other equipment that first responders regularly use, because of this the size & environmental capabilities do not yet meet the requirements of the emergency services e.g. The main markets for wearable displays are based in the military and gaming/entertainment domains. With this in mind military technologies are developed to perform in extreme environmental conditions however the impact of this is that they are generally quite large and bulky and are relatively very expensive. The gaming/entertainment technologies although generally quite compact and low-cost will not meet the harsh environmental requirements of the emergency services. A technology that is small, rugged and low-cost is still some years away from being brought to market.

Any display has to be powered and the power requirements to allow wearable displays to be driven bright enough to be sunlight readable are quite considerable. This means that the user would have to carry around a battery large enough to power the display and it’s surrounding systems for an acceptable length of time. This will invariably add significant weight and bulk to the fire fighter. Following on from that a HMD requires an umbilical cable to connect the display to the processing unit that would be mounted somewhere on the body. This umbilical cable can be restricted and is a natural mechanical weak point as it is constantly under movement. This disadvantage could be overcome by using wireless communication between the helmet mounted technologies and the body mounted technologies however this would mean that a separate power supply would need to be mounted on the helmet to power the helmet mounted technologies.

### 3.1.1 Advantage / Disadvantage Summary

The following table summarises the advantages and disadvantages of wearable displays.

| Number | Advantages | Disadvantages |
|---|---|---|
| 1 | Displayed information can be resident and enduring on the display | Units that meet the size, environmental and cost requirements of the emergency services do not yet exist. |
| 2 | Effort required to interpret and process information can be less | Displays have significant power requirements. |
| 3 | Displays can be used hands-free | HMDs currently require an umbilical between the users head and body. |

*Table 2 Advantages and disadvantages of wearable displays*

## 3.2 Wearable Sensors

Wearable sensors are used to extract information from the user and his/her immediate environment. This information can provide a wealth of information to be used by the first responder and the higher command and support chain e.g. visual information about the operating environment, information about the local air quality and enhanced vision with the use of thermal video etc. Wearable sensors have the potential to enhance the situational awareness of the first responders as well as the higher level command which could significantly improve the decision making process. For the first responder enhanced senses, provided by wearable sensors, could aid the first responder in completing the current task in a much more efficient manner and most importantly in controlling the danger more quickly or identifying the need to leave the danger zone more quickly, for example thermal video may provide the user with a much better view of the scene within smoke filled areas hence allowing the user to move more efficiently, likewise thermal video may significantly aid the user in identifying casualties by picking up their body heat. It has been noted by end users however that thermal imagery can only supplement the other senses/sensors for purposes of moving around a building because, for example, a hole in a floor is not visible in the thermal spectrum.

As with the wearable displays, wearable sensors need to meet particular size and environmental requirements; only the toxic gas detection module a COTS product - specifically designed for the fire-fighters use – integrated into the COPE sensors platform is compliant. Currently, particularly with the visual sensors (cameras, thermal sensors etc.) units that meet the required size and environmental requirements are accompanied by a significant cost. The user should not have to interact at all with any of the wearable sensors and they should be invisible to the user i.e. not impact the user’s ability to carry out his/her tasks. In the COPE trials the fire fighter had a sensor unit strapped to his chest, a video camera attached to the side of his helmet and a thermal sensor attached to the front of his helmet (See Figures 6 & 7) . This installation was bulky and heavy and added a significant weight to the front of the helmet. This installation also meant that the helmet mounted sensors were being placed under more significant environmental conditions e.g. by being knocked against objects.

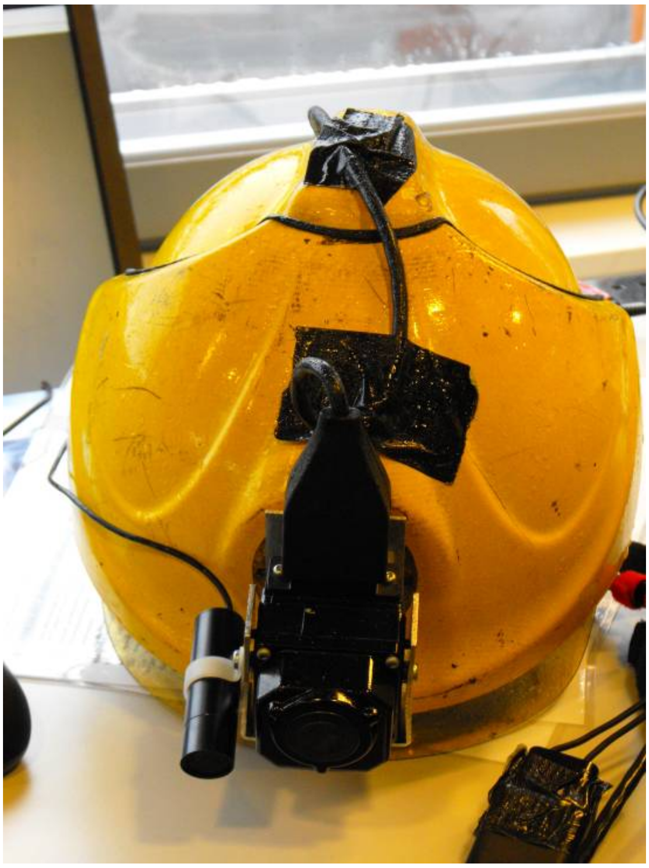

*Figure 7. Firefighter helmet with mounted thermal and daylight video cameras.*

*Figure 8. Worn sensors were mounted on the helmets and a utility vest for purposes of the  evaluation. Here project team members are testing the systems before deployment on the trial.*

### 3.2.1 Advantage / Disadvantage Summary

The following table summarises the advantages and disadvantages of wearable sensors.

| Number | Advantages | Disadvantages |
|---|---|---|
| 1 | Wearable sensors potentially enhance situational awareness | Units that meet the size, environmental and cost requirements of the emergency services can be very expensive |
| 2 | Can increase task efficiency | Can add significant weight to the user |
| 3 | Extend the user's senses | Can impede the users when moving about |

*Table 3  Advantages and disadvantages of wearable sensors*

# 4 Conclusions

When looking at the end-user feedback from the COPE trials there are a number of negative comments however these are predominantly about the mechanical fit of the equipment as well as data communication, typical issues that are common to technology demonstrator programmes and issues that were understood within the project. After looking past the comments related to prototype equipment it can be seen that the users thought that the wearable displays and sensors were useful and intuitive and, arguably more importantly, have significant potential.

Evidence from the entire COPE process suggests that user opinion is divided as to the benefits of certain applications of wearable displays and sensors and significant work would be required to develop them such that they become an integrated part of the fire fighter's personal equipment.

- Sensors must be miniaturised and ruggedised (to withstand extreme temperatures as well as knocks and bumps).
- Displays must be ruggedised (see above).
- HMDs must offer appropriate adjustment and fit to allow integration with Personal Protective Equipment (PPE).
- All technology needs to be "intrinsically safe which means it has a protection certification for safe operation with electronic equipment in explosive atmospheres.

The biggest area of user contention has been with the use of streaming video. End-users interviewed during the requirements capture process suggested that real-time video is a tool that should be used with caution and has the potential to misleading commanders into making incorrect decisions. End-users at the trials suggested that real-time video would be an extremely useful tool if it worked correctly. Either way the use of real-time video relies on a few key principles in order to be of use.

- The video sensor must be of an appropriate type for the environmental conditions that it is being used in e.g. low light, thermal etc.
- The video sensor must be of an appropriate resolution to provide an image with the required level of detail.
- The display must be of an appropriate resolution to display the image correctly to the user.
- The display must have a sufficient field of view such that the image can be viewed at a sufficiently large size.

What is evident from vendor experience, trials results and end-user feedback is that wearable sensors and displays have the potential to significantly increase situational awareness of first responders at all levels of the command chain when used correctly. These are tools that have a large scope for use and procedures should be put in place by the end-user community to govern their use to ensure that they enhance, not hinder, the understanding of the situation and thus the decision making process.

What is also evident is that wearable sensors and displays are not completely new technologies for emergency services. Various devices have been trialled in different agencies at different times throughout Europe, very few of which have been used on a large scale. This is predominantly due to issues with reliability and usability.

Wearable sensors and displays need to be extremely reliable if first responders are to rely on them. A good example of this is to ask the question: If you were asked to navigate your way into a burning building knowing that your eyesight could fail at any moment would you enter?

Wearable sensors and displays need to be integrated and intuitive in order to aid the tasks of the first responder. The first responder's workload is extremely high and he/she does not have the time to operate complicated user interfaces or interpret complex data from a display. It is the responsibility of vendors, in close consultation with end-user groups to design applications and functionalities that use the wearable sensors and displays in a manner that meets the end-user requirements.

Wearable sensors and displays are technologies that show significant potential within the emergency service arena both through functionality and cost however development is still required to provide rugged and integrated devices that will operate reliably in the operationally hostile environments of the first responder.

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