Real situations of wearable computers used for video conferencing – and implications for terminal and network design

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Abstract

Within five years it will be possible to transmit real-time high quality audio and video from almost anywhere to anywhere. With wireless videoconferencing equipment this information could also be transmitted while the users move. This is the most demanding scenario for network operators. If the network is dimensioned for this, all applications should work. Based on case studies in the offshore oil business and road construction industry, remote inspection situations were studied to answer the question: What are the real situations for such an application and the implications these situations have for the terminal and for the network? It was found that the situations with the highest perceived cost-benefit were 'Decision support', 'Guidance and demonstration' and 'Work planning'. These situations gave requirements for the terminal that has now been built. The terminal should have access to a digital broadband network that is reachable everywhere and that has characteristics that support person-to-person communication in both two party and multiparty configurations.

1. Introduction

Next generation mobile networks such as UMTS (Universal Mobile Telecommunication System) and 4G mobile networks will support broadband communications and will be available everywhere. It is currently unclear, however, why such networks should have broadband characteristics and, in particular, what the new applications are that will be welcomed by the users. To date there is very little published material concerning requirements for and implications of mobile videoconferencing on a WAN (Wide Area Network) [1]. Manufacturers of network equipment currently emphasise that people will access the web (with HTML or WML) (e.g., Siemens, Alcatel). Some segments of the industry are aiming to transmit speech over such a network (e.g., ETSI TIPHON, Intel). Some network operators and equipment manufacturers present videoconferencing as the 'killer application' although do not indicate for what

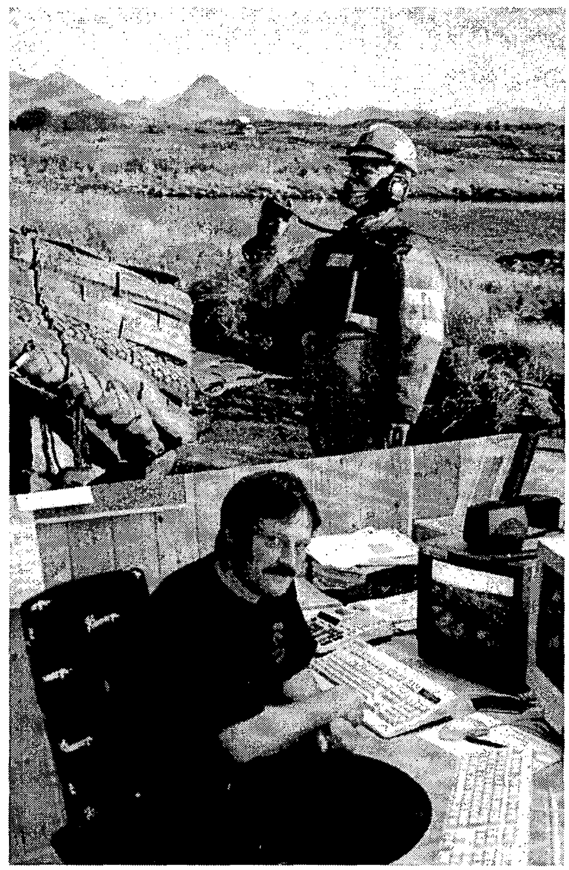

Figure 1: A mobile field worker videoconferencing with a desktop expert in a remote inspection situation.

purpose it will be used. In such cases the terminal is either presented as a mobile telephone with a camera on top (e.g., Korean Telecom, Panasonic) or persons are shown having a videoconference while walking in the park or while driving their car (e.g., Ericsson, Nokia).

Despite these criticisms of lack of novel vision, it is believed that videoconferencing will play an important role for the next generation of mobile networks because there are situations for which videoconferencing is particularly innovative and useful. A situation proposed and investigated below is that of remote inspection over IP. As a subset of the total set of videoconferencing situations, remote inspection can be considered the most demanding scenario from a network's perspective. If videoconferencing technically works well, then applications such as e-mail, web browsing, access to company specific applications, telemetry, broadcasting, video-on-demand, multimedia-on-demand and telephony should also work.

As studied here Remote Inspection is typified by a person in need of assistance and who therefore communicates with another person who can help but is at a different location. The person needing assistance will have a mobile terminal as they are engaged in some activity requiring mobility. The person who is able to help has access to a stationary terminal, although the helper may also be mobile and there may be more than two sites involved. The problem is discussed in real-time by the participants, with the innovative feature being that the collaborators can also see what they are talking about.

To the current authors' knowledge there is very little published work addressing remote inspection as here defined. Kraut et al addresses a bicycle repair application [2] with video and full duplex, only full duplex audio and video with half duplex. They found that help of an expert made the results quicker and more accurate and that there was no media sensitivity in the task. In addition there are wearable computer video applications used for indoor navigation and positioning [3, 4], but which are not relevant to the current application areas. Although there are studies about distance maintenance [5] and case studies from the oil industry [6], they are only of minor relevance because they only partially concern remote inspection.

2. The remote inspection project

The main aim of the study was to identify the real situations for the application of remote inspection. Within this aim the two key objectives were to identify the implications of this application area for the terminal and the network. Usage situations were studied by a case study approach for a range of work activities through collaboration with 6 companies in the oil industry and Norway's principal road construction company.

For inclusion of both stationary and mobile terminals in the studies Telenor collaborated with Tandberg AS and Hitec O respectively. The results will therefore be used in commercial products.

2.1. Oil business

Case studies at offshore oil installations were performed with Aker Offshore Partner (on Saga's fixed Snorre platform), Baker Hughes (on the Scarabeo float rig, owned by Saipem and operated by Statoil), BP Amoco (on the Valhall platform), Phillips (on the Ekofisk fixed platforms), Schlumberger Geco Prakla (on the seismic vessel Geco Angler) and Shell.

Figure 2: A field worker providing remote inspection at an oilrig in the North Sea using an early prototype.

Three case studies were performed on stationary installations at which two had optical fibre connected to onshore networks. One study was performed on a movable float rig, which was stationary during operation. A final installation was a seismic vessel that moved all over the world during operation.

Oil workers operate within a culture of self-dependency promoted by the physical isolation of their work location relative to the 'rest of the world'. When problems arise that they cannot solve themselves, they currently use telephone and e-mail supplemented with photographs. Sometimes this is not enough to solve their problem and experts have to travel to the offshore installation. At times the travel by experts turns out to be for minor problems that could have been fixed by persons already on-site [1, 7].

2.2. Road construction

The Norwegian Public Roads Administration in County Nordland builds and maintains roads, bridges, ferry quays and tunnels in the North of Norway at places where there have not been roads before. The road workers are often in rural environments far away from a good infrastructure and their central office. When they need help they use their mobile telephones and sometimes e-mail. The road workers describe that this is not sufficient for all the help they need and experts travel to the construction area in order to "see and decide" [8].

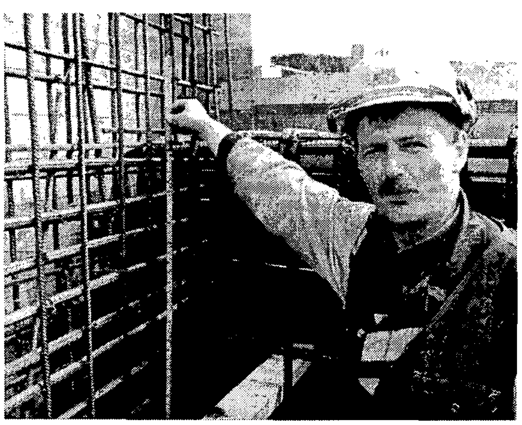

Figure 3: A bridge worker discusses a measure with a remote engineer. Viewpoint of remote engineer.

3. Methodology

3.1 Overview

An assumption for the studies performed was that audio and video with a high enough quality could be transmitted in real time from the remote expert location to the isolated field location.

Remote inspection situations were identified from which implementation considerations were derived. A qualitative case study approach was used based on interviews, observations, document reviews and role-play techniques.

A combination of 'top-down' and 'bottom-up' approaches was employed. The top-down approach had its focus on the end-user, for whom suitable technology was identified based on an assessment of the user's needs. This involved:

- identifying the real end-users,
- analysing their work,
- analysing their environment,
- identifying real remote inspection situations and
- deriving requirements for remote inspection terminals and networks.

Key elements are described further below.

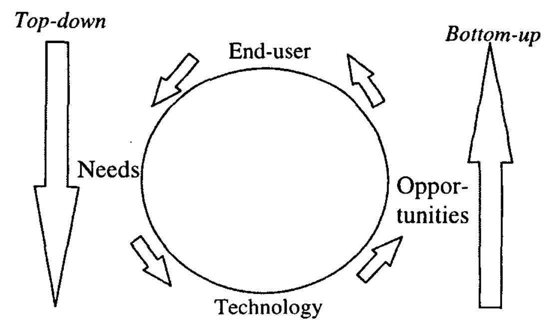

Figure 4: Top-down & bottom-up approaches were combined, 'top-down' was the priority.

An important requirement was that the case studies were based on the workers who would be influenced by remote inspection tools and not their representatives such as supervisors and managers, although such leaders wanted to describe the situations on behalf of the end-user.

In most cases of remote inspection there will be at least two persons, a person at the inspection site and a person at the remote site. Therefore, both, or all, involved were identified and the complete setting investigated.

Investigations of the working environment included both physical and social elements. In the physical environment it was necessary to understand, for example, how dark it could be, how wet, hot, dirty and explosive. It was necessary to study the social environment as the end-users seldom work alone and mostly in groups. Typically information is collected by the group and integrated for one purpose. The purpose of the task also therefore needed to be understood in order to comprehend the rationale for its initiation and successful completion. There may also be other companies at the field and remote site that are collecting the same information for other purposes and the methodology was intentionally broad to also study such occurrences.

The bottom-up approach supplemented the top-down data in recognition of the fact that new technology arrives constantly and gives opportunities for new applications. The bottom-up methodologies utilised included:

- analysing the market to identify interesting pieces of technology,
- brainstorming on new opportunities for the technology to support user situations,
- building mock-ups, demonstrators and prototypes to find out if the concept was understood (see for example figure 2 and section 3.4),
- demonstrating technologies and their potential uses,
- hosting over 15 workshops of 5 to 10 participants per workshop for specific user groups to generate new ideas and asses acceptance for the proposed new ways of working.

3.2 Procedure

The procedure for data collection was similar but not identical for both the oil and road construction industries. This is because they were performed in sequence, with the oil industry studied first and improvements were made for the road construction investigation in terms of efficiency for both participants and the researchers. Also, different local demands for each field situation and organisation were met with flexibility of approach. However, in general, the procedural elements were:

- use of a general semi-structured interview guide by 3 different researchers, with more specific interview guides developed where necessary,
- individual interviews for the oil study, more group interviews for the road construction study,
- data collection sessions had three phases, with initially all interviewers present, followed by interviewers working individually and finishing with an interviewer-only group debrief session,
- all interviews were at least audio-recorded, with many also video-recorded, and the interviewer did not take notes during an interview,
- group workshops typically lasted for one day, beginning with a general presentation deliberately not having much detail, followed by questions about terminal requirements, then exposure to one of the prototype systems and finally a group discussion,
- role play techniques were initiated by the researchers when it was appropriate to explore further the nature of a participant's work; with the researcher taking the role of a co-worker to elicit information on types of interaction, situations and locations,
- document analysis was used when standard work procedures and regulations were identified,
- follow-up interviews with interviewees were conducted if necessary; sometimes at distance using telephone and e-mail.

3.3 Prototypes

The duration of prototype data collection was 4 years. During this period four systems were developed. All four were demonstrated to the oil industry participants. The road construction participants saw only the fourth prototype.

In the first prototype a Toshiba Libretto 100/ 166MMX was used with a WLAN and NetMeeting. Two-way audio and video were transmitted to a desktop PC. The field worker had a helmet where a small video camera, i-glasses HMD (Head Mounted Display) and a PC headset were mounted. The second prototype used a wired broadband two-way audio and video system with full duplex audio. The helmet was the same as for the first prototype, except for a Peltor headset for audio in/out. In the third prototype the helmet was changed with a better and smaller camera and Sony Glastron SVGA HMD (PLM-700). The forth system is the product described in section 5.3.

3.4 Analysis

A data analysis technique was adopted that was considered the most cost-effective in recognition of the time constraints operating within an industrially-oriented initiative. Formal content analysis of interview transcripts has not been undertaken to date. Rather, the main approach was to identify and document communication situations and technical considerations during the interviewer group debrief sessions that were held directly after each interview or workshop. This promoted a brainstorming and consensus-making approach to identifying and analysing results. It also addressed inter-interviewer reliability and shared understanding for next-stage data collection. Each main phase was documented as a written report and a presentation involving each interviewer.

For each communication situation identified a cost-benefit analysis was performed. These analyses were based on financial data provided during the interviews and as additional information obtained later by the researchers. For example, this included specific scenarios for the cost of lost time provided by the participating organisations. Relatively more financial information was available for the road construction study.

Initially the communication situations were very specific to particular work instances. Those with high cost-benefit outcome were grouped within a smaller set of more general situations through an interactive research team workshop.

4. Results

In accordance with the main question driving this research, the results on identified situations for remote inspection tools are presented first, followed by implementation considerations. In addition, findings for the importance of moving image (video) over still image are presented.

4.1 Situations

Three situations were identified and are described below: 'Decision support', 'Guidance and Demonstration' and 'Work planning'. These situations have been judged to have enough impact on the organisation to justify the cost of implementation.

4.1.1. Decision support. These situations involve a field worker having to make a difficult and time critical decision that may have great economic importance for the operation. This represents expert-expert communication between a field worker and a remote colleague who can help in a non-routine situation.

Examples:
1. When cracks or other irregularities are discovered in turbines on an offshore installation, there is a need to communicate with experts onshore to decide further actions. The turbines play an important role in the operations and are a limited resource. It is therefore crucial to repair them as soon as possible. If the turbines do not work, the production has to be suspended. In such situations it is desirable to reach a decision of the highest possible quality by including as many experts as feasible.
2. A road worker on an island off the coast needs to decide how to use explosives on a rock hindrance but there is an electrical transformer close to the intended explosion that supplies the island with power. The worker in the field would like to show the situation to other experts to be sure that the correct assessment has been made.
3. After an explosion has been carried out a telegraphic pole owned by another organisation requires attention which should be reported.

4.1.2. Guidance and demonstration. These situations involve a field worker requiring assistance from a remote expert to carry out a special task. Unlike the symmetric role of expertise for the Decision Support situations above, these situations involve asymmetric communication between someone 'more expert' and someone 'less expert'.

Examples:
1. When a field worker needs guidance on how to handle a new and not fully understood task.
2. When an operator needs guidance on how to assemble new equipment.
3. When medical guidance can be given from a hospital in an accident or rescue operation involving personal injury.

4.1.3. Work planning. These situations involve a field worker assisting an expert in a remote office.

Examples:
1. An engineer in charge of a new job inspects a remote working area from an office location with the help of a person in the job area.
2. Inspection of mechanical structures at an almost inaccessible place using professional climbers. The equipment should facilitate the remote inspection technician to see what the climber can see.
3. Commissioning prefabricated structures at a remote factory.
4. Inspecting prefabricated elements for quality control in order to accept them before they are shipped to the installation site.

4.2. Asymmetry in situations

Billinghurst et al. (1999) discuss symmetry and asymmetry in functional-, implementation-, social-, task- and information types when a person uses a wearable computer and communicates with a desktop user [9]. In the three situations identified in the current study, asymmetry is a key factor, although 'Decision support' tends to involve symmetric task performance. Expert-expert communication takes place between experts, but they are experts in different domains.

Another aspect of asymmetry is the distinction of who is initiating the call, as summarised in Table 1.

In 'Decision support', there is a general expert in the job that is performed communicating with another expert in the topic of concern. For both 'Guidance and Demonstration' and 'Work planning' non-experts communicate with experts, but the initiating site is different for the two situations.

Decision support	Guidance and demonstration	Work planning
Expert (field), expert (remote)	Non-expert (field), expert (remote)	Non-expert (field), expert (remote)
Initiated from field	Initiated from field	Initiated from remote

Table 1: Initiation of call and relative expertise in three communication situations

In all three situations, there is a need for two-way audio and one-way video (from the field site to the remote site). There may be more than one remote site involved simultaneously in a multiparty-session.

4.3 Requirements for moving image as video

For all three situations a need was identified for moving images. Still images as 'snapshots' would not work. Though the required quality varied between specific situations there was a periodic need for high resolution in both the space (number of pixels) and time (frame-rate) domains. For example:

- For decision support on an oil platform where a non electronic load-meter needed to be seen, both the time and space resolution needed to be high for the onshore experts to find what they were looking for.
- For guidance and training a field worker needed to show what he was doing to get the needed trust to be allowed to repair a complicated electric system, an engine or a seismic dragging device. Otherwise, the expert would be unable to verify that new faults was not introduced.
- For work planning an important facility was that continuous transmission could take place while the camera was panned; for example enabling the expert to communicate the necessary field of view (e.g., by saying "stop, go nearer").

Video that was always switched on was identified as a a critical. Both of the abilities to see how the camera was moving and to see moving objects were identified as a mandatory properties.

It may be argued that the space resolution of a high-quality moving image is too low and that instead a higher resolution still image could be taken when a perspective has been found. However, the current studies did not provide data to support this.

5. Implementation considerations

First general considerations are summarised, followed by terminal and the network considerations. Each consideration is presented here as an issue to be addressed in order to maximise the potential for successful implementation.

5.1. General considerations

Enable multiparty communication. The field worker sometimes needs to discuss problems with people at more than one site at a time. This means that there is a need for multiparty conferencing and it is possible that each party has different videoconference equipment.

Consider potential threats to privacy. The remote inspection tool will open 'the private room' so that users cannot be sure who is watching or listening. For example, a private conversation may be broadcast because a field worker with a remote inspection tool is working nearby.

Allow for sensitive management of technology introduction. Wearable computers are possibly the most difficult technology to introduce. The user must understand the positive as well as the negative implications and see it as a 'friend', not an 'enemy'. This consideration has been identified previously [10].

5.2 Terminal considerations

Determine if wearable computers should be personal. Users sweat in wearable equipment, they need different sizes and the tools should fit the personal images which users have. At least parts worn close to the body should be for individual use.

Never allow loss of context. Faulty decision making can occur if the remote expert views another direction than believed to be the case. One solution is to have a second camera that shows the context or a location identifier that informs of the first camera position.

Keep the camera steady. If the field worker wears the camera the remote expert can suffer effects similar to being 'seasick'. Mayol et al. (2000) found that the highest score for the combination of steadiness and FOW (field of view) is gained by wearing the camera on the shoulder in stead of the head, hand or chest [11]. In addition, the camera may have a built-in steadying function or the remote expert may steer the view using a far-end camera control mechanism, as with the "gesturecam" [12].

Keep use as simple as possible. The terminal should be simple for making calls, with the functionality restricted only to features that really support the field worker. The camera should have auto-iris and auto-focus.

Consider the directory mechanism. A telephone directory mechanism should be supported. Directory mechanisms are often forgotten by manufacturers and service providers but are fundamental to enabling ease of use.

Support asymmetric working practice. The design should encourage the remote expert to perform all necessary system control via the stationary terminal (e.g., typewriting, mouse clicking and initiation of other applications).

Make the terminal easy to configure. It should be easy to take components from one terminal and use it on another if a terminal breaks down, as new parts may take a long time to transport to the remote site.

Provide options for high enough quality on video. The resolution of a video camera is relatively low. The resolution for videoconferences and compressed video is usually 352x288 pixels or less whereas some frame-grabbers are able to extract frames with 640x480 pixels. .

Consider the readability of the screen. In bright sun, an LCD (Liquid Crystal Display) or HMD (Head Mounted Display) may have too little contrast to be used. The number of pixels should also be considered.

Consider feasibility of hands- and eye-free operations. Whereas 'hands-free' is typically thought of as speech recognition for sending commands by users that need to have both hands free, 'eyes-free' means that the users need to see with no obstacle in front of their eyes. Thus for eyes-free tasks users cannot wear a head-mounted display and cannot look at a display in the vicinity. However, they can listen to text generated speech. This therefore raises the question to what extent the terminal must be hands- or eyes-free. An extreme situation occurs for climbers that need hands- and eyes-free equipment when they climb to almost inaccessible places in a construction. When they get to their destination, they may secure themselves and no longer need hands- and eyes-free facilities.

Provide robustness. In inhospitable environments the terminal may be exposed to salty humid air, cold, dirty surroundings, splashing liquids and working situations where the terminal may be dropped.

Provide predictable reliability. Users can cope with equipment that stops functioning if they are aware of it. The critical aspects are that users know both when and why there can be equipment failure. For example, a warning of a low battery level gives predictable reliability.

Comply with EX requirements. Electronic equipment used in explosive atmospheres (such as Zone 0 and Zone 1 of the European standardised zones by Cenelec) should be EX approved. The equipment should not emit heat or sparks to its surroundings (figure 5).

5.3. Implementation of a wearable computer for industry

Figure 5: Using EX-certified wearable computer in area where there is a danger of explosion.

The wearable computer that has been implemented is a vest made of watertight flame-retardant textiles. It is built to survive in harsh conditions. The components are enclosed in watertight housings ensuring proper protection in hazardous areas. The computer is a Pentium II 400 Mhz processor with up to 256 MB RAM and 20 Gbyte hard-drive. It supports H.323, H.263, MPEG-1 and MPEG-2. The operational time is up to 8 hours running time with extra battery. The display is a touch-display with 800 x 600 resolution and with 32 bit colours. A headset with microphone is used for audio input and output. A high quality video camera is mounted on the shoulder or head with 480 lines of resolution and with an auto-iris, auto-focus and zoom. The vest can be used with wireless LAN (802.11b), multiple GSM lines, satellite links, wired Ethernet and UMTS. The battery capacity is 3:15 hours. An EX version will be produced with the ability to be used in areas where there is a danger of explosion (figure 5).

The weight is 5 kg for the non-EX-version and 7 kg for the EX-version.

5.4 Network considerations

The network should be reachable everywhere. None of the existing or upcoming networks can meet this requirement today. If the requirement is relaxed to where there will be access to any 3G- or newer mobile network it is possible to cover a major proportion of the European population. However, it is often outside these areas that field workers are located. Also, it should be possible to include rural areas where remote inspectors will be temporarily located for work or pleasure when away from their more typical office location. Contact 'everywhere' should mean 'all around the world', not only in a local community or in one country.

The network should not introduce characteristics that hinder person-to-person communication. Currently there are many characteristics that cause concern. For example, too long delays, too much noise or distortion and dropouts will not be tolerated and will hinder the introduction of these services. Speech may be difficult or impossible to understand because of too much noise, and the delay of the speech may be too long to support natural human interaction. Video may be delayed even longer than audio due to burst distortion and resynchronisation of the protocols. The effects on human communication need to be understood [e.g., 13].

Provide for multiparty conferencing. Multiparty conferences require network mechanisms that manage various protocols, the MCU (multiparty control unit) mechanisms, different bitrates between users and, in some cases, floor control. These network mechanisms should be enabled.

Provide broadband capacity. 'Broadband' capacity for a fixed network usually means more than 1.5 Mbps in the USA and more than 2 Mbps in Europe. UMTS is setting the standard for mobile communication, with 384 kbps upwards considered as broadband capacity. On the basis of the subjective user responses in the current study it does seem possible that media quality should be good enough from UMTS with 384 kbps. However, further work is currently being performed to objectively assess this [13].

6. Conclusion

Ranked in order of importance the three main situation categories where the end-users stated that there is a real need for remote inspection are 'Decision support', 'Guidance and demonstration', and 'Work planning'. These situations are identified as having a high perceived cost-benefit factor because problems can be solved faster with less travel and interruptions and because a remote expert can handle a greater number of sites [1, 8].

A key feature that distinguishes the two main situation categories is the role of the participants in terms of the relative symmetry or asymmetry in expertise. Decision support involves the communication of experts, whilst Guidance and demonstration involves communication between an expert and relative novice.

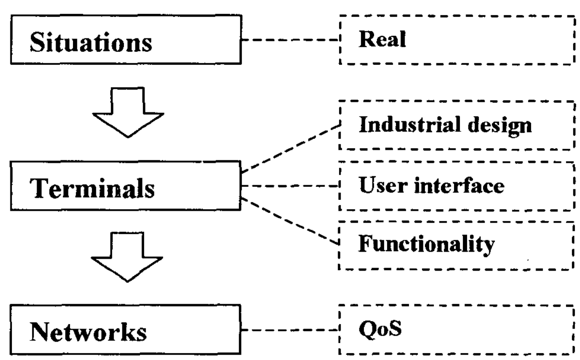

Figure 6: Graphical problem-solving structure.

From understanding these situations knowledge has been gained about how the terminal should be designed, how it should be operated and what its functionality should be. The problem-solving structure that has been identified is summarised in Figure 6.

It has been found that the terminal should typically be personal, support video context and a steady camera, be simple to use, easy to configure and support high enough media quality to be general purpose for multiple users within a particular target user domain. It should have a hands- and eye-free mode, be robust and reliable and, when applicable, comply with EX requirements in potentially explosive environments. A terminal has been built for the purpose of commercialisation.

It was found that still images could not support remote inspection, but may give additional help. Moving images as video was essential. Furthermore, the critical nature of this video is not to provide classical "Talking Head" video as typically expected from videoconferencing, but "video-as-data" as defined by Egido [14].

For the underlying network, it was found that the network QoS (quality of service) is the most important characteristic.

7. Further work

The case studies outlined here are being followed up by field studies that are providing additional data on work patterns and usage requirements.

The identified issues of user-based QoS and network QoS and how they affect the network are being studied in both laboratory and field conditions [13].

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