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Integrated Multimodal Communications Management for Airborne Command and Control

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Increasing the communication efficiency and accuracy associated with Command and Control (C2) operations is crucial in many aerospace applications. This communication intensive environment imposes a high workload on Air Traffic Controllers and other C2 personnel who rely heavily on a variety of communication tools to efficiently plan, direct, coordinate, and control assets during missions. The C2 task is further complicated by the suboptimal integration of the various communication media utilized in the operational environment. The fielded communication tool suites have serious limitations and are not poised to meet the needs of advancing technology. A multidisciplinary research team in the Battlespace Acoustics Branch of the Air Force Research Laboratory has developed the Multi-Modal Communications (MMC) tool suite which is specifically designed to increase communication effectiveness, provide efficient voice communication retrieval, navigation of saved data as well as reducing the perceived mental workload of the operators.

Challenges in Command and Control Communications

Command and Control communications are challenging for many reasons. This time critical communication intensive environment imposes a high workload on the operators, who typically monitor and transmit on as many as eight or more simultaneous voice channels in addition to other forms of communication such as text chat, phone and email. Reducing the workload and increasing the communication efficiency associated with C2 operations is of extreme importance to achieve mission success.

Voice communications pose a unique problem due to the transient nature of verbal transmissions. The recipient has one chance to extract the crucial information or be forced to request a "repeat" which adds to the radio traffic. Additionally, multiple operators can speak at the same time thus reducing the intelligibility of essential messages. Not only is missed communication a problem during the mission, but the operators must take detailed notes to capture the information received. Later, they must rely on manually transcribed audio recordings of the mission for training and debriefing.

Currently, C2 centers are not required to standardize the collaboration tools available and used by the operators. Therefore, it is possible to have very different collaboration tools in various C2 facilities. Since multiple collaboration tools are needed to accomplish the mission, combinations of these collaboration tools are often kludged systems which are meant to assist the operator with the management of these individual systems. The incompatibility of these multiple modes of communication coupled with the variable combination of systems makes it difficult to combine them into a functioning collaborative tool suite suitable for all C2 environments. Presently, the integration of existing communication technologies has not yielded optimal results. The fielded communication tool suites have serious limitations and are not poised to meet the needs of advancing technology.

In addition to the lack of standardization and the incompatibility of the communications systems, there currently is very little capacity to capture, save and review these various communications. For instance, verbal radio communications are transient and perishable and reviewing verbal communications during a mission is impossible at the present time. A multidisciplinary research team in the Battlespace Acoustics Branch of the Air Force Research Laboratory has developed the Multi-Modal Communications (MMC) tool suite which is specifically designed to address these issues.

Current Collaborative Tools

Operators surveyed (Berry et al., 2006) in various C2 centers listed the collaborative tools most commonly used as phone, Chat/text messaging (mIRC), email, radio, secure telephone unit/secure terminal equipment (STU/STE), Voice over Internet Protocol (VoIP), Information Work Space (IWS), and video teleconference (VTC). Operators admitted there were too many different collaboration tools available yet each was limited in its own way. Operators stated that phone, text chat and VoIP were somewhat effective pending their availability. Of these collaborative tools, most operators preferred text chat. Perhaps this preference is due in part to the poor audio tools available making them an undesirable form of communication or it may be due to the convenience of a written record of communications that text chat provides coupled with the overall system stability of the chat functions which were less likely to crash.

Information Work Space

Information Work Space combines a few collaborative tools, but has limitations in sharing, posting, accessing, filing and attaching documents as well as data loss when IWS frequently crashes (Berry et al., 2006). The resulting work following a crash entails rebuilding chat rooms and regaining situation awareness (SA). Another drawback of IWS is its limited audio capability due to the simplex system similar to a walkie-talkie where one party speaks at a time. A simplex system limits the ability to communicate naturally by prohibiting interjections and not surprisingly is an unpopular form of communication. IWS chat functions were more often used than voice functions with operators using on average five chat windows at a time, while a few operators had as many as 14 chat windows open.

Text Messaging/Chat

Text Messaging/Chat was commonly used especially when IWS was unavailable (Berry et al., 2006). When this occurred the operators would switch to mIRC which is an Internet Relay Chat (IRC) client for Microsoft Windows. Despite mIRC's popularity, the operators noted it is difficult to reconfigure following a system crash. In this setting, mIRC was used only temporarily and once IWS was returned to functioning status, mIRC communications were duplicated and placed into IWS again. A common complaint about the chat tool was the inability to copy large amounts of data into a chat room. Brief departures from the chat room also caused a loss of SA since it was not possible to tag the last entry read. The operators would be forced to spend precious time re-reading text to ascertain where they previously left the stream of communication.

Other Collaborative Tools

Email offered a limited capacity in such a dynamic and high tempo environment (Berry & Lindberg, 2009). Phone and STU/STE communication was inconvenient since it required operators to remove their headset in order to hold the phone to the ear. VoIP functioned similarly to telephone use but heard through the headset. VTC was available in certain facilities in the building and not at individual terminals. Radio was often used; however, the operators rarely wore both ear cups in order to hear conversation around them.

Purpose of Multi-Modal Communications Tool Suite

The Multi-Modal Communications (MMC) tool suite was designed to offer C2 operators a combined versatile and intuitive interface which would alleviate the workload and errors associated with an intensive communication environment. This integrated Communications Management tool will improve communications by streamlining the cumbersome and varied forms of communications and give the C2 operator access to the complete spectrum of communications in a single tool. Voice and chat communications will be seamlessly integrated into a single digital communication system over one headset (phone, chat, voice, radio) for internal and external communications.

MMC is an integrated net-centric architecture which will distribute, monitor, archive, and retrieve analog voice transmissions (radio communications), VoIP communications, and text messages across distributed operators on the GIG.

MMC records, archives and displays the verbal and text communications to the operator for real-time playback during the missions reducing workload while enabling the C2 operator to be more effective and efficient. This eliminates the perishable nature of radio communication and allows the operator to focus on the task instead of remembering and writing down information. The MMC tool also employs virtual audio display technology to spatialize the multiple audio signals to aid in the intelligibility of the radio communication. The combination of these technologies has led to the design of a communication interface that will improve the performance of operators confronted with monitoring a high volume of radio communication.

Features of Multi-Modal Communications Tool Suite

Audio Recording

The MMC tool captures the radio communication as text and records each transmission as an audio file. Operators have the ability to play back the original radio transmission by clicking on the desired line of transcribed text. Each audio file or radio transmission is time stamped for easy reference and documentation.

Speech-to-Text Transcription

The speech-to-text transcription feature captures incoming speech and transcribes it into text. This allows all voice traffic to be captured and recorded as a text log. The operator now has the ability to read what was spoken and review previous voice transmissions. Since all radio communications are logged, the operator is easily able to search for keywords during the mission or use the text for debriefing or training purposes.

Spatial Audio

The spatial audio feature (also called 3D Audio) allows users to spatialize each of their monitored radio channels such that the audio signals appear to originate from different azimuth locations. MMC allows the operator to place the radio channels in one of nine spatial locations and to change that location anytime during the mission. This flexibility of configuration allows the operator to organize and more efficiently monitor multiple radio channels. Several studies have shown that the spatialization of speech can improve the intelligibility of communication, lower the perceived mental workload associated with monitoring simultaneous streams of communication, and decrease the negative effects of noise during communication (Bolia, 2003; McAnally, Bolia, Martin, Eberle, & Brungart, 2002; Nelson, Bolia, Ericson, & McKinley, 1998; Nelson, et al.1999; Ricard & Meirs, 1994).

Instant Replay

The instant replay feature provides immediate access to the last message transmitted. By pressing the 'replay' button, the last fifteen seconds of the radio transmission will be replayed, allowing the operator to instantly review or clarify the last transmission. Additionally, the replay feature isolates that particular channel by temporarily muting all other channels.

Isolate

The isolate feature mutes all other radio channels and only plays the specified channel, allowing the operator to focus their attention solely on that channel. The operator may now more effectively direct their attention to critical situations by muting less critical radio transmissions.

Transmit

The push-to-talk feature allows the operator to speak and be heard by other operators monitoring the specified channel. The push-to-talk is activated by mouse clicking the 'Talk' button and holding it down while speaking. Other operators listening to that channel, hear the communication in real-time while the spoken communication is transcribed into the display window.

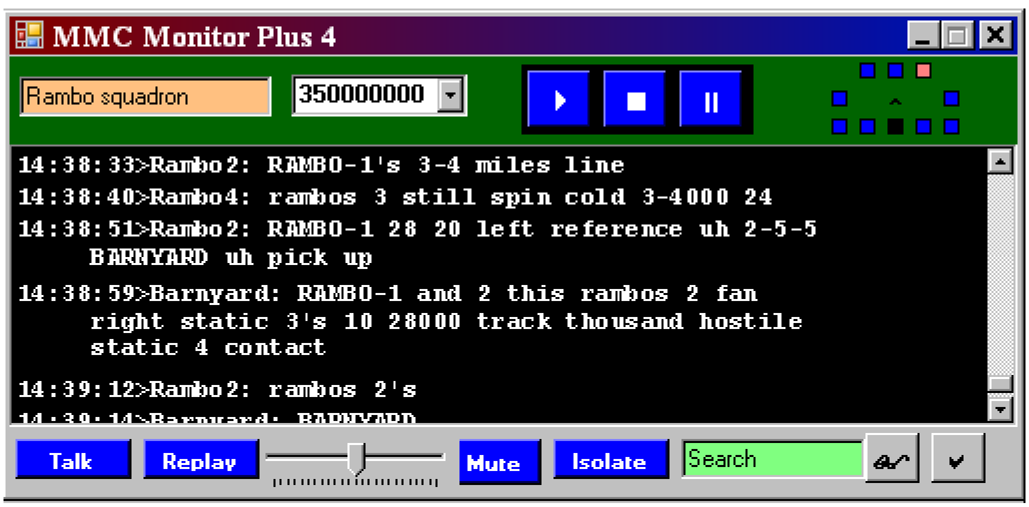

Figure 1. Multi-Modal Communications tool suite display of a single radio communications window.

Future Capabilities

Since the operators prefer the use of chat messaging while communicating; chat capabilities are currently being implemented into the MMC. This chat feature will be similar to current chat clients in that users will sign into secured chat rooms to monitor and transmit text messages. This chat function will have the capacity to convert text to speech. Operators will have the option to speak their messages to be transcribed in the chat window as well as hear text messages in a synthesized voice. Additional features will enable the operator to review logged communications in faster than real-time to be able to review large chucks of past communication in a speeded form in order to be brought up-to-date.

Research and Survey Data

Throughout the development of the MMC tool, 11 subject matter experts (SME) were shown MMC and asked to participate in a usability questionnaire and interview. The SMEs had diverse C2 operations experience ranging from 1 to 27 years ($M = 11.57$), thus providing comprehensive feedback on the features and design of MMC. This feedback led to the redesign of the interface making it more operator-friendly and congruent with the operator's needs. The SMEs indicated that MMC would improve job performance by allowing them to accomplish tasks more quickly and efficiently. MMC was unanimously supported by all of the SMEs involved as an essential tool in the field and a valuable tool for training and debriefing. Feedback also included comments indicating the spatial audio feature would enhance talker identification and speech intelligibility while the transcription and playback features would help reduce miscommunications and the need for call backs. Overall the SMEs signified that MMC was intuitive and easy to use.

In addition to collecting questionnaire data, performance measures were also collected to compare operators' ability to detect and respond to critical messages via standard radio communication alone (no 3D audio, no voice-to-text and no replay) and with the MMC (3D audio, voice-to-text, and replay). Operators monitored six radio channels for ten minutes for the presence of a critical message which identified a hostile entity along with information pertaining to their location (Viper 1, Hostile-North Lead Group, 55 miles). Their task was to repeat that information back on the correct radio channel. There were six radio transmissions per min with the occurrence of one critical message per min on each of the channels. Nine paid participants from the General Dynamics research pool at Wright-Patterson Air Force Base in the Battlespace Acoustics Branch served as participants in this study. Three separate 2 (Condition) × 2 (Trails) Within-Analysis of Variance was performed for measures of Correct Detection, Response Accuracy, and Response Time. The data revealed that participants were better at detecting critical messages in the MMC condition (M_{CD} = 72. 31%) then in the radio condition (M_{CD} = 50.18%), $F(1, 8) = 23.23$, $p < .01$. The ANOVA on the response accuracy also showed that MMC condition (M_A = 94.27%) was greater than the radio condition (M_A = 82.56%), $F(1, 8) = 7.20$, $p < .05$. Analysis of response time revealed that it took longer to reply when using MMC (M_T = 11.59 s) then the standard radio (M_T = 7.65 s), $F(1, 8) = 5.39$, $p < .05$. Thus it seems the addition of the voice-to-text capability in the MMC algorithm improves overall performance in detection and response accuracy but may increase response time, presumable because listeners who are uncertain were waiting for the transcribed text before making a response. It is important to note that there was on average a 5 to 8 sec delay in the voice-to-text transcription thus inherently increasing the time it took participants relying on the text to reply. The transcription latency has since been decreased to less than a second thus continuing investigation of the performance of the MMC is in progress. None of the other main effect of interactions in these analyses reached significance, $p > .05$ in all cases.

Conclusions

MMC has integrated several stand-alone features known to improve communications in order to create a network-centric communication management suite. The data collection and feedback from subject matter experts (SME) indicates that MMC has the potential to improve the communication effectiveness of operators in intense communication environments. Although MMC currently does not meet all of the needs of an operator we fully expect the empirical tests, both in the lab and field studies, to show that MMC does in fact improve performance during communication monitoring tasks. We also expect these tests to highlight other features to further develop in the MMC thus creating a fully functional multi-modal communication suite.

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