Electronic Partners That Diagnose, Guide and Mediate Space Crew's Social, Cognitive and Affective Processes

Jurriaan van Diggelen
jurriaan.vandiggelen@tno.nl
+31888662316

Mark Neerincx
mark.neerincx@tno.nl
+31 3463 56298

TNO Defense, Security, and Safety
Kampweg 5, 3769 DE Soesterberg, The Netherlands

ABSTRACT

Long-duration missions (e.g. to the Moon, asteroids, or Mars) require astronauts to collaborate and interact with complex computerized equipment and facilities under dynamic and hazardous conditions. The Mission Execution Crew Assistant (MECA) comprises crew support that acts as an "electronic partner" (ePartner), helping the crew to take care of their mental and social conditions and to schedule crew activities. We have developed a simple prototype of MECA which we use to test MECA's functionalities in analogue environments where test participants are placed in isolation for longer periods of time.

INTRODUCTION

Manned long-duration missions beyond low earth orbit (LEO), e.g. to Mars, set high operational, human factors and technical demands for a distributed crew operations support system. The mission execution crew assistance (MECA) is such a system that shall enhance human-machine teams' capabilities to cope autonomously with unexpected, complex and potentially hazardous situations. The MECA concept comprises distributed personal ePartners that help the team to assess the situation, to determine a suitable course of actions to solve a problem, to schedule on-the-job training, and to safeguard the astronauts/explorers from failures. One early prototype is being studied in the MARS500 mission, a unique opportunity to learn more about operations support required for long duration missions. Another experiment will be held in the Concordia base station, where twelve test participants will spend the winter season in Antarctica.

FRAMEWORK

Figure 1 illustrates the core high-level MECA functions that will be studied in the MARS500 and Concordia experiments. MECA's activity monitoring and scheduling support proceeds in four stages, starting in the upper left corner:

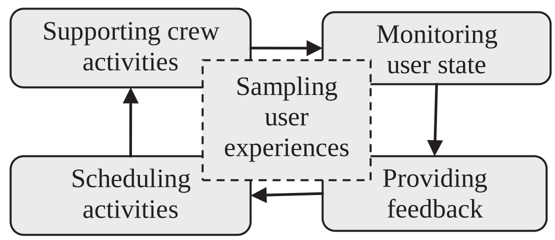

Figure 1. High-level MECA functions.

1. **Supporting crew activities:** MECA is always present. In this sense MECA provides continuous support. However, for some activities, MECA is latently present and only becomes active in off-nominal situations. For other activities, MECA plays a more prominent role and provides the framework itself within which these activities take place.
2. **Monitoring user state**: MECA monitors the crew members' performed activities. This includes assessing what the crew members are doing, measuring their performance, and assessing their cognitive state (i.e. their emotional state and task load).
3. **Providing feedback:** MECA provides feedback to their users by presenting the monitored data. This allows a user to better understand his current task behaviour in the context of his performance over time.
4. **Scheduling activities:** MECA supports activity scheduling by offering an electronic timeline tool, and by automatically scheduling (or suggesting scheduling) tasks, depending on its interpretation of the data on previous activities.
5. **Sampling user experiences:** MECA mediates the maintenance and appraisal of memorable experiences and events with a multimedia annotation tool. This function should support the astronauts to reflect on previous activities and happenings in a constructive way to improve resilience (cherishing of successes, coping with stressful events and learning).

Each of these high-level core functions can be implemented at different levels of sophistication. On the one hand, we can think of a full-fledged Artificial Intelligence (AI) implementation, where MECA automatically "reads" the user's mind to assess the user state, provides high level feedback by saying things like "take it easy", "come on", and "don't worry", and by acting as a smart secretary by appropriately (re-)scheduling the user's planning. On the other hand, we can think of a simple implementation, where the system monitors the user state by collecting questionnaire data, where the feedback consists of a statistical interpretation of this data, and where the system helps the user to reschedule the timeline by presenting relevant information.

Because the full-fledged AI implementation is currently still science fiction, MECA's current implementation is closer to the simple implementation than to the AI implementation. Nevertheless, we believe that also the principles behind more advanced support systems can be explored by evaluating more simple prototypes.

SEMI-AUTOMATIC MONITORING

A major focus of MECA is to support team resilience by monitoring team member's performance, and condition. Performance monitoring looks at effectiveness and efficiency of the member's operations and his/her related refresher trainings status, whereas condition monitoring assess the appropriateness of his / her social, cognitive and affective responses to a task or situation. In our approach, monitoring is a joint astronaut-ePartner activity. The ePartner anticipates on (near) future developments of robust sensing technology for monitoring the emotional states of the astronauts. In the current prototype versions, the majority of the "monitoring" data is provided by the human actors.

MECA combines a Cognitive Task Load (CTL) model with a model of the Emotional State (ES) to assess human responses in high-demand task domains. The CTL model distinguishes three load dimensions: the time occupied, the level of information processing (skill-, rule- or knowledge-based behaviour), and number of task-set switches. The ES-model distinguishes two dimensions: the arousal level—low versus high—and the valence level—positive versus negative. ES and CTL are related: for specific load conditions a specific emotional state ("response") can be expected. For example, when task load increases, an adequate response is to invest extra effort (i.e., arousal increases) in order to maintain good performance.

In a first experiment, we used a Bayesian Network to train the Performance, ES and CTL models with their interrelationships. A "Naïve Bayesian Network" algorithm provided performance predictions with 86% and 74% accuracy for two data-sets, respectively: a data-set from a 'clean' lab-setting and in a dynamic field test environment. Both experiments used the SOWAT as a monitoring tool.

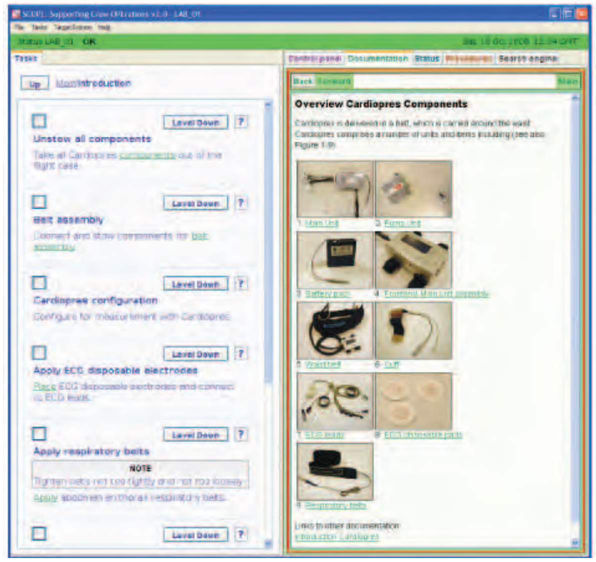

Figure 2. Example screen of the "Collaborative Training" environment for refreshment training of procedures.

MARS 500 EXPERIMENT

In the MARS500 experiment carried out in Russia, a 6-person crew is isolated for 520 days to simulate a manned Mars mission (3 Russian, 2 European and 1 Chinese "astronaut"). In this setting, a prolonged and repeated interaction with ePartners' functions will be tested. First, via "Collaborative Training" with rotating trainer/trainee roles, the ePartner guides the joint training of procedures, assessing the interpersonal communication and mediating knowledge transfer from the "expert" to the "novice" crewmember (see Figure 2).

Second, via entertainment gaming the ePartner can be an "affecter" which improves the crewmember's mood. Figure 3 shows a simple entertainment that is integrated into the MECA system.

Third, via a timeline tool the ePartner motivates the crew members to perform certain activities and to maintain a personal (episodic) memory (see Figure 4).

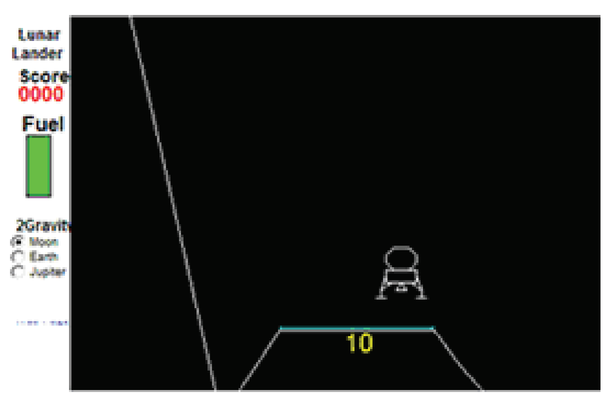

Figure 3. Example screen of Lunar Lander.

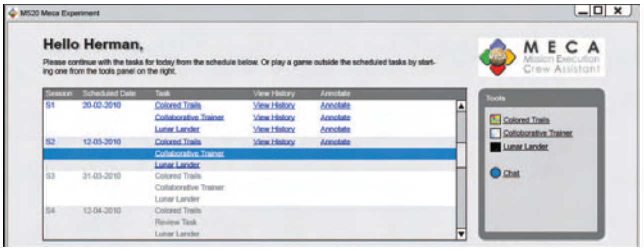

Figure 4. The timeline and user experience tool.

The MECA experiment setting for MARS500 is as follows:

- two groups of three astronauts who train and game once a week for half an hour (incl. procedure training and an entertainment game)
- the astronauts communicate via text chat only
- MECA collects information on crew condition (social, cognitive, affective) and performance (effectiveness and efficiency of operations during the training and gaming
- MECA provides (simple) feedback on crew condition and performance
- MECA provides a task scheduling and multimedia annotation tool

A first experiment with the ePartners provided data to train Bayesian Network models on Cognitive Task Load (CTL) and Emotional State (ES), and their effects on performance with Bayesian Networks. CTL specifies the task demands in terms of time occupied, task complexity and task switches; ES specifies the emotional responses in terms of valence and arousal.

The screen in Figure 5 shows MECA's feedback mechanism for performance, emotional state (arousal, valence, and dominance), cognitive task load (time occupied, level of information processing, and task-set switches). On the upper part of the window, the user can see all values of previous sessions. The data is presented in such a way that correspondences between these three aspects can easily be recognized (e.g. the combination of high cognitive task load and poor performance). This could give the user a better insight in his (or her) own functioning.

On the lower left part of the window, the user can see the scores of the current session in comparison with the average score of the previous session. On the lower right part of the window, the user can add annotations to the current session, using text, audio, video, or photos. This could also help to improve the user's memory, and awareness of his (or her) functioning over time.

Figure 5. The tool for giving feedback on crew condition and previous performance.

CONCORDIA EXPERIMENT

Concordia station is a permanent international research facility high on the Antarctic ice cap. The objective of Concordia station is to operate as an international research facility to conduct scientific programmes. Concordia provides a unique test platform for MECA, because of its setting in an isolated extreme environment for long duration experiments with high demands for crew autonomy. In this setting, more prolonged or repeated usage of MECA services can be tested. We are performing another design iteration of the MECA core support elements for nominal and off-nominal situations and corresponding conditions (i.e., the appropriateness of his or her cognitive and affective responses), which need this type of prolonged evaluation in extreme and isolated environments. Based on our findings in previous projects we have identified the following issues as promising to be included in this refinement:

- **Goal-based timeline tool**: We plan to enhance the MECA timeline functionality by using persuasive technology. This allows the timeline tool to motivate the crew members to perform certain activities. This improves mental health, and satisfaction. For example, physical exercise trainings are known to have a positive effect on mental health of astronauts. However, when the astronaut feels obliged to do these trainings, this positive effect disappears. We believe that, by allowing users to specify their goals when they schedule their activities, they become more motivated to perform these activities. In the scheduling phase, MECA and the users set up their goals collaboratively. In the feedback phase, MECA relates the user's performance to his or her goals.
- **Social games:** To maintain a healthy social atmosphere among a small group of isolated crewmembers, we plan to develop new tools for monitoring and (if needed) repairing social relations. We start from social interaction games, where multiple players have mixed objectives and must collaborate with each other to achieve their goals. We will add new gaming concepts, such as joint resource supervision, and tit-for-tat collaboration, to allow better monitoring of social relations, and to improve potential conflicts between crewmembers.

- **Personalization:** MECA will adapt itself to the personal characteristics of its users. During the activity monitoring phase, much information is gained about how the crewmembers behave under which circumstances. During the scheduling phase, we plan to use this information for offering personalized support. For example, MECA advises changes on the planned schedule, optimizing the users' performance and resources usage by to postponing, cancelling reassigning or scheduling new activities.
- **First aid COLT:** In previous MECA projects, we have gained positive experiences with procedure-training functionality. In Concordia, we plan to extend this functionality to the first aid domain. This allows the non-medical crew members to learn medical procedures from the medical crew members.

CONCLUSION

This paper presented ongoing research on electronic partners that diagnose, guide and mediate space crew's social, cognitive and affective processes. We follow a situated Cognitive Engineering methodology in which ePartner's functions are being developed incrementally. In collaboration with their human counterparts, these ePartners sense and affect crew's performance, task load and emotional responses. First prototypes are being tested at MARS500 and Concordia, evaluating the support functions and providing data to train our models. First results show that cognitive task load and emotion have additional value for performance assessment, and that Bayesian Networks can be used to train the models (e.g., it is possible to deal with missing data, and easy to extend and refine).

ACKNOWLEDGEMENTS

MECA is a development funded by the European Space Agency (contract numbers 19149/05/NL/JA and 21947/08/NL/ST). Project partners are TNO Human Factors (NL; coordinator), Science & Technology BV (NL), OK-Systems (E) and EADS-Astrium (D).

REFERENCES

1. Fogg, B.J., (2002). ***Persuasive Technology: Using Computers to Change What We Think and Do***. Morgan Kaufmann, SanFrancisco, CA.
2. Grootjen, M., Neerincx, M.A., Stolk, K.D., Weert, J.C.M. van & Bierman, E.P.B. Design and user evaluation of an interface prototype that adapts to the operator's cognitive task load. In: D.D. Schmorrow, D.M. Nicholson, J.M. Drexler & L.M. Reeves (Eds), Proc. 4th Intern. Augmented Cognition. Arlington, Virginia: Strategic Analysis, Inc (2007), 97-106.
3. http://www.crewassistant.com
4. Neerincx, M.A., Kennedie, S., Grootjen, F., and Grootjen, M. Modelling Cognitive Task Load and Emotion for Adaptive Maritime Interfaces. In: Lecture Notes in Artificial Intelligence. Schmorrow, D.D.; Estabrooke, I.V.; Grootjen, M. (Eds.), Foundations of Augmented Cognition: Neuroergonomics and Operational Neuroscience. Proceedings of the 5th International Conference of the Augmented Cognition, Berlin/Heidelberg: Springer (2009), 260 – 269.
5. Neerincx, M.A. Bos, A., Olmedo-Soler, A. Brauer, U. Breebaart, L., Smets, N., Lindenberg, J., Grant, T., Wolff, M. The Mission Execution Crew Assistant: Improving Human-Machine Team Resilience for Long Duration Missions. Proceedings of the 59th International Astronautical Congress (IAC2008), Paris, France: IAF. DVD: ISSN 1995-6258.
6. Picard, R.W. ***Affective Computing***. MIT Press, Cambridge, MA, 1997.