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How do Tigre pilots build a coherent situation awareness (SA) of the night world through their multiple sensors (IR and I^2)? These bring numerous opportunities for pilots to misunderstand each other because of field of view (FOV), wavelength spectrum and point of view differences. After a brief review of the literature on how operators build an SA of the world, we present the field project developed to analyze the impact of sensor commonality and diversity. Realistic situations are recorded to witness how Tigre pilots "create" a mental model of the situation and develop a collaborative strategy. Crew co-construction of sense is considered through verbal and Human Machine Interface (HMI) mediated exchanges.

Introduction

From Gazelle to Tigre

In a previous study the French aerospace medicine institute (IMASSA) was appointed for the evaluation of the workload induced by the progressive update of an in service helicopter including a new thermal imaging display. Subsystems devoted to night vision (Night vision goggles (NVGs), Infrared Images (IR)) or to navigation purposes were asymmetrically distributed among the crew drastically increasing demand. Such asymmetry implied an overload of communication to achieve manageable SA and impacted flight safety. [1]

Figure 1. Left Viviane Gazelle, Right Tigre front (top) and back seat (bottom). The technological leap between former and later helicopter HMI is tremendous. Notice the numerous multiple function display (MFD) in the Tigre cockpit.

Enter the Tigre: Franco-German newest military rotorcraft. As can be seen on figure 1, there is a tremendous technology leap between the Tigre and its predecessor the Gazelle. Yet the study we performed on this older helicopter gave us insights of what was going to happen with the Tigre. The Gazelle is a side-by-side two pilot crew, but during night missions with NVGs the benefice for SA due to direct visual cross checking disappears because NVGs have small FOV.

So basically in the night use configuration, it is a fairly good model of the tandem two pilot crew that can be found on the Tigre. Neither one sees the other, and they can have different cockpit configuration.

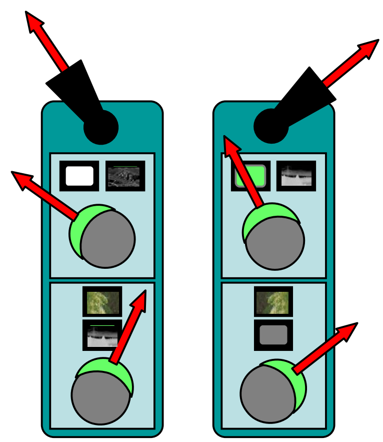

Figure 2. Multiple possible images and points of view between two Tigre crew that could be a challenge to "share" in a coherent SA.

Specifically the Tigre has multiple MFDs for each crewmember that can display various sensor outputs. It is the same problem of multiple figurations of the environment we had with the older helicopter only multiplied by the number of sensors and pilots using them (figure 2):
- Two displays per pilot
- Two crewmember per Tigre
- Plus, at night, each pilot has a Type 2 night vision device (figure 3) adding another figuration of the world.

Hence, the mental load that was responsible for severe discomfort and navigation errors in the older helicopter of the previous study is going to be multiplied (if no restriction is applied) and could have an impact on flight safety.

Achieving a proper SA between the 2 crewmembers can then become a challenge and must be evaluated.

Figure 3. Topowl® Helmet used in the Tigre has side sensors thus qualifying as a Type II night vision device.

The current research project

We try to tackle this challenge by analyzing (i) how crewmembers extract information from multiple raw sensor images, (ii) how they use them to build a coherent representation of the outside word and last (iii) how they "share" it with other crew members that use the same or different set of images.

To address this we designed a two level research program. The first part undertakes the analysis and comparison of the physical content of cues in various sensor images that lies under the reconnaissance strategy carried out by pilots [2]. The second part focuses on how crewmembers elaborate their own interpretation of their multiple sensor images and how each one manages to build with the others a consensus on the visual information distributed among them.

Review

After positioning our work, with regards to its specifics, at the intersection of multiple research fields, we review proposed technological solutions and focus on the concept of Situation Awareness (SA) and its latest development for collective and distributed work.

The specificity of the Tigre

Flying the Tigre using at night its multiple sensors and MFDs puts our study issues at the intersection of multiple research fields:
- Complex dynamic situation: Tigre crews are in flight, at night with a novel HMI,
- Interpretation of sensor images: Multiple sensors relaying various figuration of the environment on MFDs,
- Mental model of space: the information presented needs to be put in coherence with some sort of "fusion",
- Distributed co-operative work: the physical separation of Tigre crewmembers is new for our Army Aviation,
- Sharing of representation: the coordination of crewmembers is mandatory.

Because it covers most of all these aspects, we decided to use SA as our guideline, for a *tentative exploration of how pilots can, at first, deal with sensor images, and ultimately share and use them as a collective.*

SA to the rescue of performance

Situation awareness was the big thing in the nineties; finally one knew where to look for individual performance improvement. It so appeared technology had already been improved and the pilot remained the sole (at 80%) responsible for all ill deeds in the cockpit. So the Holy Grail was found. A clear message was sent: understand SA in the first place, train to get a better SA, design to enable a better SA.

Alas, at the turn of the century, inputs proliferated in cockpits through multiplied sensors and networks, and there was trouble again with performance. Naturally the next effort is to circumvent this new overflow of information… with more technology. First advances are frustrating at best.

Technical solutions with suboptimal results

Fusion is the leading scheme for multiple sensor imagery. When images are fused by technology, only "significant" information in each image would be relayed to the pilot, reducing the sense making workload (sense is made of all the information *before* it reaches the pilot).

This bulk of information needs to be processed and enhanced before it reaches the pilot. Sensor fusion is needed but proves to be tricky already on still images [3], color enhancement is not *the* solution [4], I^2 and

IR can be superimposed with some processing but only with images from the same point of view (POV) and same scale [4]: hardly what awaits the common operator that will face images of multiple origins, sensors, points of view and scales.

In fact, multiplicity of images is not the problem; pilots are used to deal with extreme demands: but multiplicity of scale, POV and figurations of the outside world is another issue. What the pilot needs is a better way to localize cues of heading, scale and POV in each sensor with regards to the task at hand (navigation, detection, localization…). What are those cues in I^2 or in IR images, and how do pilots exchange on them? Those are the real questions, not only for today's helicopter crew but also for all those who exchange on the battle network.

Yet the Tigre is not completely bereft of specific technology for information sharing. Both equipped with the Topowl Type II Night vision System (NVS) with head tracking, Tigre pilots can acquire the other's POV when needed at a mere push of a button. Another option is to have the helicopter heading to rejoin the (backseat) pilot's line of sight automatically. Such rotation can be very fast and most surprising for the pilot flying (front seat) who will temporarily be overridden. Those specific systems can somewhat reduce "endless parley" between pilots in emergency situations but cannot cover the whole collective sense making processes. Electronic transfer of data between aircraft is expected to facilitate sharing of intel but is still under development.

As of now, while waiting for yet another miraculous breakthrough in image fusion, the pilot is left alone to deal with the raw material. Actually the pilot cannot be alone. Tanks to the growing complexity of (poorly) integrated systems, cockpit workload is nearly impossible to tackle with a crew of one, especially while there is a network centric warfare at hand relaying multiple demands from far away. Moreover, as mentioned before, like many other military aircraft, Tigre helicopters go by two on operational missions. That is a four person collective with a minimum of two POVs, and a potential distribution of four representations of the world. This is where SA meets the collective.

Pilot's SA in the Tigre: Perception and cues

SA matured essentially from pilot studies. It represents "[his] internal model of the world around him at any point in time" Endsley [5] (p97). In 1995, beyond "Knowing what's going on" [6] (p36), the SA model is finalized as a triptych.

> "Situation Awareness is the **perception** of the elements in the environment within a volume of time and space, the **comprehension** of their meaning, and the **projection** of their status in the near future."

As we see it, it relies first on getting the inputs (Perception), second on coherence making with current representation of the world (Comprehension) and last on enablement of anticipation (Projection), which is the best way to spare resources. Flying the Tigre is definitely about making sense of multiple inputs and enabling anticipation.

Visual perception is 80% of incoming Information to the brain and the Tigre's HMI is loaded with visual inputs, either symbolic or analogical, some of which represent a "view" on the environment (i.e. Infra Red and I^2). Extracting information from these implies hours of practice and putting them to coherence is yet another layer of expertise. Ensley [6] insists on the importance of expertise for perception: "advance knowledge of the characteristics, form, and location of information can significantly facilitate the perception of information". Such expectations (a subtype of anticipation) are ready-made models of the future that only need to be validated at lesser cognitive expenses. As she said, "with higher level of expertise, operators develop knowledge of critical cues in the environment that allows them to make very fine classification". Those classifications enable easier matches between a minimal number of cues and a previously encountered situation.

But for an identical situation, cues are not identical through various sensors. Each System (IR or I^2) has specific rendering of the environment that challenges natural perception cues. For example the monocular cues that usually enable depth perception are completely disrupted with both IR and I^2. Through training, one needs to build a "library" of prototypical cues with regards to the sensor involved to overcome this. In our multi sensor situation, only repetitive interactions can lead to the building of a usable SA.

On an ecological point of view, Smith & Hanckock [7] (p138) push the idea that SA is "adaptive externally directed consciousness". Through an air traffic control (ATC) example they show that the salient cues controller search are not what one would normally gather on the controller's screen (e.g. locations of aircraft) but their interactions as potential conflicts. This underlines the tricky part of using perception cues for the "comprehension" part of SA: Cues are not only sensor specific, they are also task oriented.

Last but not least, when building one's representation one has no knowledge of the respective participation of symbolic and analogical information. If "A picture is worth a thousand words", yet some times, a single symbolic word can efficiently convey crucial intel. But explaining the fullness of a picture (even more a video) with chosen words could demand an endless discourse with tremendous vocabulary precision and richness. Hopefully this is rarely the case as pilots' use of sensor is task oriented and thus operatively adapted. One does not describe all, only what is necessary for the course of action. Because they have little time, they have developed efficient strategies: Pilots rely on implicit knowledge. There lies the crucial component between single person SA and collective SA: implicit knowledge.

SA in the Collective

We are interested in how a crew shares information on their perception: the outcome of this sharing being a better SA. In the founding paper of 1995, Endsley [6] already anticipates on what is an efficient collective SA: “overall team SA can be conceived as the degree to which every team member possesses the SA *required* for his or her responsibilities.” There is no mention of a good SA being necessarily one and the same for everyone in the collective. SA is adapted to one's goals and local environment demands. These can be identical when there is a commonality of location and tasks, but not mandatory. One can argue on the necessity of overlaps in SA, but to what extent and on what grounds?

In our situation, because of the tandem configuration of the Tigre cockpit, most of the overlap present in the older helicopter is gone. If you consider that collocation or proximity allows for observation of another’s activities and the gathering of information about other’s capabilities, tasks, and situation [8, 9], a shared perspective will be harder to establish and maintain. Graham & al [10] even noted that physical collocation is twice as likely to produce a shared mental model. Early in the development process of the Tigre, this was taken into account and crew resource management (CRM) courses were developed concurrently to counter balance this physical separation. Once physical proximity is lost, communication is the only medium left enabling cross-training [11] and we already witnessed an increase in communication time in the Tigre up to 75% of the time.

In a recent paper, Stanton et al [12] feel that a shared SA approach (appropriate for a shared workspace, resources and goal situation) could misdirect attention to inappropriate aspects of the task in a distributed situation with partial overlap of resources and goals. They propose the Distributed SA (DSA) as another approach that we find interesting for a team such as the Tigre's. Salas [13] considered a team:

> “[A] distinguishable set of two or more people who interact dynamically, interdependently and adaptively toward a valued goal/objective/mission, who have each been assigned specific roles or function to perform, and who have a limited lifespan membership.”

Team SA is about "a sharing of a common perspective [ ] regarding current environmental events, their meaning and projected future" [14]. This points to the fact that consensus is needed on the "valued" goal/objective/mission, not on the SA. Sallas & al [15] (p131) specify team SA as the "shared understanding of a situation among team members at one point in time". Chronology is brought up as an important factor. Team SA will vary in time for each participant in the collective with regards to the goal at hand.

In a distributed team, there are points in tasks where SA may overlap from time to time, but constant shared unique SA is not mandatory. Moreover, compulsory "rendezvous" for sharing may not be such a good idea when imposed upon otherwise involved operators. The interruption of whatever task they are implicated in might be at best counterproductive.

Artman [16, 17] completes this view by introducing the notion of agents (either human or artifacts) that can contain a part of SA in a distributed situation. SA is part shared, part distributed. Emphasis is put on the fact that a universal complete unique SA for a distributed collective is not necessary. The strength of collaboration resides in the ability for crewmembers to monitor non completely overlapping parts of the environment while sharing enough so all can perform their task in the distributed collective. If everyone must know everything, there is no economy of resources. And economy of resources is what the collective is all about.

One can view SA as knowledge (on the situation) dynamically changing from unique, complete and shared among the collective (but demanding to maintain), to multiple, smaller, more-or-less-overlapping and distributed (but cost effective for the individual). All possible stages in-between could be witnessed, but Tigre crew's model of SA might tip more often towards a more shared than distributed

SA because of the numerous overlapping functions between crewmembers (global security, detection, system management, radios, …).

As Stanton et al [12] (p1308) noted, individual's SA comprises also a "meta-SA" of others' SA. When I know what the others know, I can rely on implicit knowledge and communicate most efficiently. What we are describing here is a mental model of the collective; the concept for SA is the shared mental model [18]. It covers dependencies and interrelationships between team objectives, team mechanisms, temporal patterns of activities, individual roles, individual functions, and relationships among individuals. Shared mental models allow team members to implicitly and more effectively coordinate their behaviors, monitor others to anticipate needs, identify deficiencies and provide support [19].

The challenge is to understand how collaborative exchanges build this metaknowledge of the collective. For instance, Wellens [14] found, in a simulated work group, that group SA did not increase with the size of the channel of communication but with the quality of the information conveyed.

When communicating on sensor images, what is the best and most concise information an operator must convey to be grasped most efficiently by another crewmember using (maybe) another sensor?

Specific work analysis methods had to be developed to take into account these highly constrained night flight conditions and have proved their efficiency [1]. We adapted laboratory level methodologies and transferred them to operational situations. The monitoring system consisted of simultaneous recording of MFDs showing sensor images selected by the two pilots, plus the recopy of the pilots' head mounted Night Vision System (NVS) and ongoing communications (figure 4).

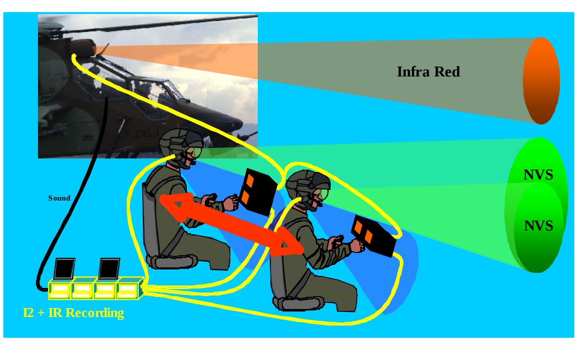

Figure 4. Experimental recording system designed to be fitted in an operational Tigre.

Simultaneous replay of the recordings will use CAPTIV® visualization and task coding system (www.teaergo.com). Cognitive walkthrough [20] will be performed with involved pilots having various levels of expertise in the use of IR and I^2. At first, individual strategies will be analyzed on dynamic recordings of both IR and I^2 images gathered on a test helicopter with both sensors. Once the individual strategies will be collected, one Tigre and its crew will be used for the collective assessment. In final runs, two Tigre helicopters will be recorded for the assessment of specific issues dealing with a greater distributed collective.

As of today, the experiment is in progress; the first image collecting flights have been performed with the initial validation of the recording system in the Tigre flight test centre in Valence (France). Such a certification process is always a challenge when using laboratory equipments in operational helicopters to ensure valid and representative recordings.

Expected results

SA review enables us to focus on selected aspects of our Tigre crew situation. Because of the loss of implicitly shared information due to the distributed cockpit and sensor displays, Tigre crews obviously need a "cooperative perception": a management of resources for perception and its sharing. Though this cooperation will be based mostly on verbal exchanges, some of the technical opportunities imbedded already in the Tigre, will be involved (i.e., access to a recopy of the pilot's IR, access to the current line of sight of the other pilot…).

To assess how this cooperative perception is built, we designed a study of real night flights, first to evaluate the individual strategies for making sense out of multiple sensor images, and then to review the collaborative strategies for building a shared mental model of the distributed perception.

On the individual level, we expect to find:
(i) How pilots shape each space reference (scale, heading) in each sensor?
(ii) How they extract salient cues in each sensor with regards to the use of these cues (transfer in another sensor or to the other pilot)?
(iii) How they spatially relate sensors to synthesize own perception and create a situated model and last
(iv) when the situation gets dynamic, how they increment this model at lower cost (if they monitor only changes)?

Our next step is to assess on the collective level:
(i) If there is a cycle of collective perception sharing (building of a shared model) to inquire for or answer to others' situated representation or if there is a shared model in continuous construction? This relates to the co-existence of situated models and shared models having different contents, hence validating Artman's view that "there can exist a collective state of mind, which is not represented in any single locus" [16].
(ii) The difference between receiving or sending information to build the shared model of the situation. How do pilots yield to change their own model to account for inputs from others? How do they convince others with their own model? In the end, what is most expected is a co-construction of sense through exchanges of optimized models with efficient strategies of description using space references, active sensors identification and critical cue exchanges.

Conclusion

Co-operative perception may well be the key to the improvement of training procedures in the Tigre, while waiting for efficient sensor fusion technology.

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