COMMUNICATION-BASED MODELLING AND INSPECTION IN CRITICAL SYSTEMS

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Abstract: Safety-critical systems are systems whose failure would provoke injury or death to human beings. In avionic systems we have seen some significant evolution related to the aircraft cockpits. The Personal Air Vehicle (PAV) represents a new generation of small aircrafts being conceived to extend personal air travel to a much larger segment of the population proposing new concepts of interaction and communication in aviation. In this domain, communication is a critical factor especially among the users while running the system through its interfaces. This paper presents a technique for modelling and inspecting communication in the user interface of the avionics domain; a case study illustrates the proposal for artefacts of the PAV domain.

1 INTRODUCTION

Safety-critical systems are systems whose failure would provoke injury or death to human beings (Palanque, 1998). The term incident is defined as unexpected events that may or may not lead to accidents or deaths (Johnson, 2003). In aviation systems, many incidents have reasons originated from failures during communication mediated by the user interface artefacts as some statistics of the problems in the avionics domain show: from 34 total incidents, 1100 computer-related accidental deaths occurred from 1979 to 1982; 4% of the deaths due to physical causes; 3% of the deaths due to software error; 92% of the deaths due to problems related to human-computer interaction failures (Harrison, 2004). According to the Air Traffic Control (ATC), 90% of the air traffic incidents occur due to fault attributed to pilots or controllers. These reports show us the role a reliable user interface has in providing a better human-computer interaction enabling the correct use of critical artefacts and supporting decision making mainly during emergency situations.

Some significant evolution regarding the user interfaces in cockpits of aircrafts has happened recently. The flight decks (or cockpits) today utilize multifunction computer displays – where huge amounts of information are stored and the pilot navigates through layers and layers to find the required information (Carver and Turoff, 2007). He/she thus becomes more a system engineer than a pilot. This modern cockpit, named “glass cockpit”, represents information using graphical elements through diagrams and symbols. The automated systems may produce conflicting data from different sources and they will force decisions about which information to act upon (Carver and Turoff, 2007).

The concept behind the Personal Air Vehicle (PAV) represents a new generation of small aircraft that can extend personal air travel to a much larger segment of the population. PAV must provide simplified operation akin to driving a car. Although several tasks will be executed by the automation system because users are persons not supposed to be trained in pilot’s course, others will be allocated for humans. Within this scenario, the future of aviation is being discussed by the CAFE Foundation (Cafe, 2007) and the National Aeronautics and Space Administration (Young and Quon, 2006). There are several research sectors specialized in technologies related to PAV such as flight instructors systems (Allen, 2007), synthetic vision information system (Schnell et. al., 2002; Glaab et. al., 2003) and distributed decision-making (Rong et. al., 2005).

As cockpits have evolved technically, there are demands for new fundamentals, theoretical and methodological backgrounds that contribute on understanding the interaction and communication issues between human and machine.

We understand that the Human-Computer Interaction (HCI) field has a role to play and

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responsibilities to assume in this particular domain. HCI is a field of study concerned with human and machine in communication. It draws on knowledge on both the machine and the human sides. On the machine side, computer graphics, operating systems, programming languages, and development environments are relevant disciplines. For the human side, communication theory, graphic and industrial design, linguistics, social sciences, cognitive psychology, and ergonomics are important disciplines. Moreover, engineering and design methods are naturally relevant (Hewett et al. 2007).

The concepts of communication and interaction are sometimes blurred in the HCI context. Communication has been studied from different points of view, with associated models. The semiotic school understands communication as the production and sharing of meaning (Baranauskas et. al., 2002). Therefore, in the context of this work, we understand "communication" as implying code (anything that has a meaning for something or someone) sharing among systems. Regarding human and computer systems, they can communicate by interacting through icons, windows, progress bar, buttons and other user interface elements.

To our knowledge, literature on user interface analysis in the domain being considered has not paid special attention to communication issues. This work presents an exploratory approach for analysing the user interface of safety-critical systems regarding communication aspects. The proposed approach is applied to the analysis of the Synthetic Vision Systems (SVS) display that is one of the user interaction technologies required by PAV aircrafts.

The paper is organized as follows: Section 2 presents the theoretical background which serves as foundations for the proposed analysis. Section 3 applies the approach to an exploratory study of a PAV cockpit. Section 4 presents conclusions and points to further work.

2 THEORETICAL AND METHODOLOGICAL BACKGROUND

The theoretical and methodological background considered in this work is Semiotics that consists on the study of the signs that are used for communication. The rules operating upon them and upon their use form the core of the communication study. As there is no communication without a system of signs, Semiotics as a discipline concerned with the analysis of signs or the study of the functioning of sign systems may offer an appropriate foundation.

Organisational Semiotics (OS) is one of the branches of Semiotics particularly related to business and organisations (Liu, 2000). OS understands that any organized behaviour is governed by a system of social norms which are communicated through signs. Methods for Eliciting, Analysing and Specifying Users' Requirements (MEASUR), resulted from a Stamper's research work in the late 70´s (Stamper, 1993), constitutes a set of methods to deal with all aspects of information system design: the use of signs, their function in communicating meanings and intentions, and their social consequences. The relevant methods for the specific scope of this work are described as follows:

- The Stakeholder Analysis allows all the interested parts (stakeholders) to be investigated that directly or indirectly have influences or interests in the information system under analysis. In the stakeholders analysis all interested parts are categorized in several groups whose context covers all the organization.
- The Evaluation Framing is an extension of the Stakeholder Analysis, which allows identifying, for each stakeholder category, their questions and problems, in order to discuss possible solutions.
- The Semiotic Ladder (SL) is an artefact primarily used to clarify some important Information System notions such as information, meaning and communication (Cordeiro and Filipe, 2004). Stamper (Stamper, 1973) extended the traditional semiotic divisions of syntactic, semantics and pragmatics by adding three other layers: social world, physical world and empirics as depicted in Figure 1, which, all together, form the SL.

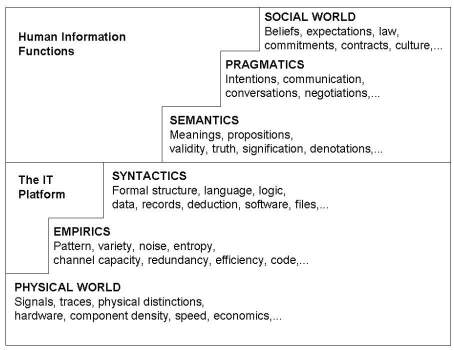

Figure 1: Semiotic Ladder, adapted from Stamper (1973).

A communication is considered successful only if all these six levels of the SL are successfully accomplished. The communication in upper levels depends on the result of the communication on lower levels. The Physical World deals with the physical aspects of signs such as cable or radio waves. The Empirics level deals with the statistical properties of signs such as channel capacity, patterns, efficiency. In the Syntactic level, there are signs and their relations to other signs forming a structure, language, data and records. The Semantics deals with signs and their relations to meaning that users perceive. In the Pragmatics level, the signs and their effect on users are identified. Finally, in the Social World, the signs and their relation to social implications are considered. If there is a failure in the Semantics level, it means that it is related to the human information function. Therefore, the SL may link human factors and social issues focusing on different levels of communication.

The Fractal Model of Communication (FMC) (Salles et al., 2001; Salles, 2000) captures the structure of the communication process involved in the application domain. The FMC models agents in communication through channels. A communicant agent shares information with other agents through channels. Figure 2 represents this concept of communication in which, in one level (or one fractal dimension), agents B and C communicate through channel A. In another level, A assumes the role of an agent in communication with C through channel AC.

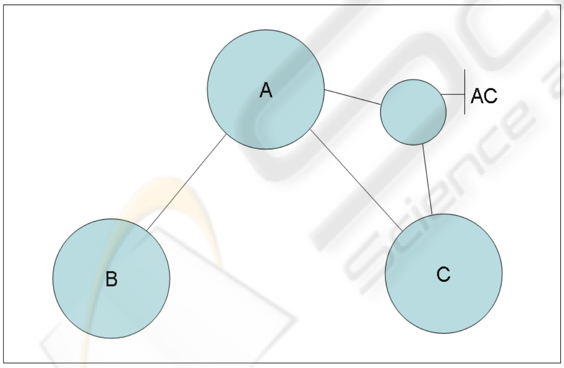

Figure 2: The Fractal Model of Communication (Salles, 2000).

The artefacts of Stakeholder Analysis and Evaluation Framing can be developed during the requirements analysis (Guimarães et. al., 2007). These artefacts can be reused for modelling and inspection using artefacts of Stakeholder Analysis and the Evaluation Framing for defining agents and channels for FMC. The communication inspection is accomplished by analysing all the six levels of the SL for each channel represented in FMC model.

The FMC models communication in any fractal dimension: from the organizational context (business) to a small pixel in the screen (user interface elements). For example, if the context of requirements is relative to the user interface, then the FMC should have a channel representing the user interface. If the requirements refer to a specific interaction object, the channel regarding the user interface should be *exploded* reaching to lower fractal dimension to have specific channel regarding this interaction object. Therefore, the FMC should be adjusted according to the requirements contexts.

The presented artefacts can be articulated for modelling and inspecting the communication as proposed in this work. Figure 3 illustrates it.

The inspection is conducted by verifying all levels of the SL in all FMC channels. Examples of questions defined for each SL level are listed in Table 1.

Table 1: Questions for the six levels of the Semiotic Ladder.

Layer	Question
Physical world	How is communication being accomplished regarding physical aspects (signals, traces, physical distinctions, hardware component, etc)?
Empirics	What are the empirical characteristics (pattern, capacity, speed, noise) of this communication?
Syntactic	How is communication being accomplished in syntactic terms (language, formal structure, files, software)?
Semantics	How is communication being accomplished regarding semantics (Meanings, propositions, validity, truth, signification, denotations)?
Pragmatics	How is communication being accomplished regarding pragmatics aspects (Intentions, communication, conversations, and negotiations)?
Social world	How is communication being accomplished in social terms (Beliefs, expectations, law, commitments, contracts, culture)?

The SL allows exploring each communication channel with a wide coverage. The physical, empirics and syntactic levels focus on information technology and the levels of semantics, pragmatics and social world focus on the human context.

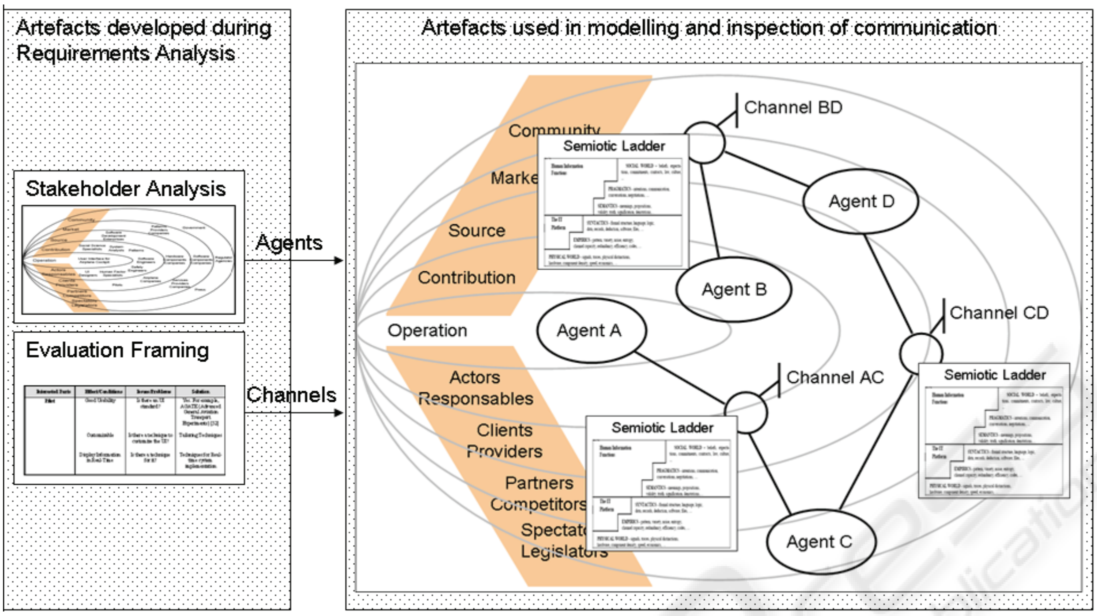

Figure 3: Modelling and inspecting communication.

In the next section, these modelling and inspection techniques will be applied in a case study related to the PAV context.

3 MODELLING AND INSPECTING A PAV DISPLAY

This section presents the modelling and inspection for the SVS display, one of the technologies proposed for human-vehicle interaction for PAV, based on outcomes from the analysis of the problem domain carried out using the OS methods (Guimarães et. al., 2007). Due to the specificity for SVS Display, in this section the FMC is adapted for the context of this display.

Literature proposes several elements for the user interface of SVS displays including symbolic, textual and graphical representations. Not all SVS displays are designed for PAV. Although Domino (2006) proposed a user interface layout for a SVS display without mentioning whether it was designed for PAV or not, it provides a SVS display layout. The horizon (composed by sky and terrain) is presented as 3D objects; all obstacles (fog, clouds and darkness) are removed as this display provides a synthetic view, i.e. data related to visualization is obtained from a database and not from the real world. It provides information (represented as Indicator) regarding current altitude (represented as Tape), current speed (as Tape), pathway display elements and other information that can help the user to get a situational awareness. This SVS display will be analysed regarding communication aspects considering the PAV context. Figure 4 depicts the FMC in a fractal dimension representing display SVS proposed by Domino with more specific agents and channels. There is no limit for the number of fractal dimensions allowing any detail degree when necessary.

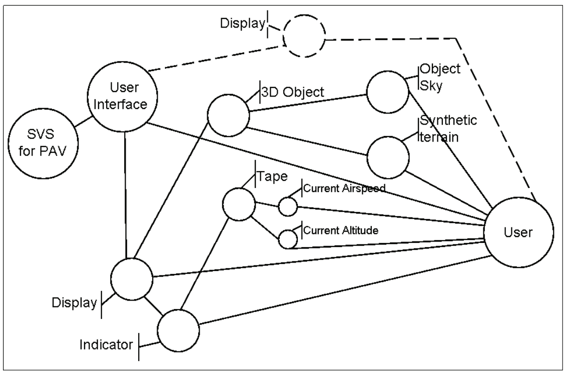

Figure 4: Modelling SVS display using FMC.

In interactive systems, the FMC represents the communication between two agents (the display and the user) through a channel called user interface acting as communication media. One important concept related to modelling in safety-critical systems is redundancy. For example, aircraft with redundant displays is a typical configuration. We model redundancy in FMC by using dashed connections and dashed circles as Figure 4 depicts.

This communication related inspection technique consists on answering questions listed in Table 1 for all channels represented in FMC and in all fractal dimensions for obtaining a complete view. The answers should be easy to understand explaining how the communication is accomplished in each layer of SL. In this case study, we have the answers regarding the channel *Tape* presented in the Table 2.

Table 2: Answers of SL for channel *Tape*.

Layer	Answer
Physical world	Tape consists on several colored pixels
Empirics	The tape may show any range of values depending on the context (altitude, speed).
Syntactic	The rectangle is presented with scale of values and a current value pointed by a triangle.
Semantics	This object is well known by pilots which means that there is a current value with specific range and scale.
Pragmatic s	This object represents for pilots the current value with scale information.
Social world	Providing better situation awareness, the pilots feel safe during the flight.

The analysis of the SVS Display proposed by Domino based on the Table 2, shows that the communication channels through tapes seem adequate for pilots. In the case of PAV, the users are not only the pilots but people without intensive training. Therefore, this artefact may not be sufficient for PAV.

The artefacts (Stakeholders Analysis, FMC and SL) allow rich information related to communication with wide coverage. The organization can be prepared for most of communication failures studying alternative ways if a communication fails. The alternative ways can be obtained focusing on the FMC to identify the redundant communication channels supposing situations of each specific channel or agent is unavailable. The SL provides a more specific focus on context directed to the cause of communication failure for each channel. This list of possible communication failures and respective ways for treating failures also contribute to improvements in communication. Consequently, it leads to improvements in the quality of the technical product.

4 CONCLUSIONS

Communication is a critical factor to be addressed in safety-critical systems, especially in the avionics and aviation domain. Semiotics as a discipline focused on communication may provide a good foundation to inform the modelling and inspection of communication in these systems. This paper proposed using artefacts of Organizational Semiotics allied to a framework for modelling communication: the Fractal Model of Communication (FMC). The approach was illustrated with the modelling and inspection of communication regarding a SVS display of Personal Air Vehicles.

The FMC represents agents and channels of communication with unlimited fractal dimensions. In this way, the communication model can be presented in overview and with detailed information of each channel, with the six layers of communication of the Semiotic Ladder. FMC and Semiotic Ladder provide support for inspecting a communication system (e.g. the user interface) helping to detect problems related to communication. This technique allows seeing the connection between the organizational view and the user interface contexts. The overall communication quality depends on the quality of communication in each channel. Nevertheless, the FMC may grow in complexity presenting many agents and channels making the reading difficult. Some visualization tools may allow the presentation of the FMC model with a configurable filter to allow visualizing each fractal dimension separately, zooming in and out to show only the agents and channels needed for a specific consideration.

As an extension of the communication-based modelling, some adjustments of this technique could inform the system development for improving the quality of the communication among agents in the organization. Moreover, part of this communication based modelling upon FMC may be automated by a tool. This tool would be valuable for defining redundancy points, obtaining alternative ways (channels and agents) to maintain communication.

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