Rationale for human modelling in human in the loop systems design

Didier Fass, Romain Lieber

Rationale for human modelling in human in the loop systems design

Didier FASS
LORIA INRIA UMR7503
ICN Business School
Nancy, FRANCE
didier.fass@loria.fr

Romain LIEBER
Centre de Recherche en Automatique de Nancy (CRAN)
University of Nancy, CNRS UMR 7039
Nancy, FRANCE
romain.lieber@cran.uhp-nancy.fr

Airbus France
Engineering
Toulouse, FRANCE
romain.lieber@airbus.com

***Abstract*—Human modelling in human-in-the-loop systems (HITLS) design can be a complex and dynamic endeavour. Thereby it needs a theoretical framework for grounding methods and models on verified principals and an integrative approach that takes into consideration the specificity of biological organization of living systems, according to the principles of physics, and a coherent way to organize and integrate structural and functional artificial elements. This paper focuses on the rationale of human modelling for HITLS design, in the context of a conceptual framework based on Chauvet's mathematical theory of integrative physiology (MTIP).**

Keywords- Modelling, Design, System of systems, Human-in-the-loop systems; Human System integration; Mathematical theory of integrative physiology.

I. Introduction

Human-in-the-loop systems (HITLS) [1] are a special kind of systems of systems (SoS). They are composed of two main categories of systems. These two kinds of systems differ from their nature: their fundamental organization, complexity and behavior. The first category, the traditional one, includes *technical* or *artifactual* systems that could be engineered. The second category includes *biological* systems: the human that could not be engineered. Thus, integrating human and complex technical systems in design [2] is to couple and integrate in a behaviourally coherent way, a biological system (the human) with a technical and artifactual system. HITLS engineering needs to model human body and its behavior to test and validate human reliability and human systems integration (HSI) by simulation using virtual environments, especially for safety critical systems.

Designers need reliable methods and models that can help them to test and modify HITLS architecture. Those methods and models are mainly numerical and intend to be predictive. The major benefit is to avoid late changes into the design life cycle that have cost and time impacts [3]. Thus, they need to take into account, at the earlier stage of the design, factors that influence system reliability, and develop the rationale of the modelling. Human is one of the major factors that influence this reliability [4]. As a biological system, we need to tackle human complexity and organization into the modelling, in order to certify a level of confidence. Current human modelling, due to a lack of theory, cannot provide designers with confident indicators. Such human modelling needs both a new epistemological approach (integrative) that takes into account the specificity of the biological organization of living systems and practical principles to organize and integrate structural and functional artificial elements of different nature. This paper focuses on the rationale of human modelling for HITLS design, in the context of a conceptual framework based on mathematical theory of integrative physiology.

II. VIRTUAL HUMAN MODELLING

Human modelling is mainly used for situations in which human acts with other humans and/or artifacts; in ergonomic activities: man-machine integration design and analysis (model of human activity in problem solving situation, adequacy of the task and human characteristics), in multi-agent simulations, and recently in systems engineering process.

Recent projects develop human model in the guise of virtual human model called digital or numerical manikin. Those projects mainly involve automotive, military, and medical industries. The aim is to develop either semi-autonomous or embodied digital manikin (virtual human model).

Current approaches found their modelling and simulation on anthropometrical and biomechanical data [5] for static (or aesthetic aspect) and dynamic modelling (motions capture and analysis); optimization algorithm [6] or motion database, for gesture and motion prediction; symbolic and computational approach, to model human cognition as a queuing network of information processing servers [7].

Furthermore, virtual human cognitive modelling integrates theories and methods of mathematical psychology, computational cognitive modelling and experimental psychology.

We propose to base human modelling and HSI for HITLS design on a scientific and theoretical framework: mathematical theory of integrative physiology (MTIP). Within this paradigm, human modelling involves taking into account human fundamental characteristics, such as anatomy (structure, dimensions, masses), and physiology (function, motion, gesture). It is to integrate into the same model data and knowledge of different nature and several domains.

III. MATHEMATICAL THEORY OF INTEGRATIVE PHYSIOLOGY

The mathematical theory of integrative physiology, developed by Gilbert Chauvet [8] [9] [10], examines the hierarchical organization of structures (i.e., anatomy) and functions (i.e., physiology) of a living system as well as its behavior. MTIP introduces the principles of a functional hierarchy based on structural organization within space scales, functional organization within time scales and structural units that are the anatomical elements in the physical space. This abstract description of a biological system is represented on *figure* 1. It copes with the problem of structural discontinuity by introducing functional interaction ψ from structure-source *s* into structure-sink *S*, as a coupling between the physiological functions supported by these structures.

Unlike interactions in physics, at each level of organization functional interactions are non-symmetrical, leading to directed graph, non local, leading to non local fields, and increase the functional stability of a living system by coupling two hierarchical structural elements. As said G. Chauvet : "we have chosen a possible representation related to hierarchical structural constraints, and which involves specific biological concepts. We also made the important hypothesis that a biological system may be mathematically represented as a set of functional interactions of the type: $s \xrightarrow{\psi} S$. However, the main issue now is to determine whether there exists a cause to the existence of functional interactions, i.e. to the set of triplets $s \xrightarrow{\psi} S$? What is the origin of the existence (the identification) of *s*, *S* and ψ that together make a component $s \xrightarrow{\psi} S$ of the system? The answer to this issue is the existence of a mathematical principle, the stabilizing auto-association principle or PAAS, a principle that makes of a framework, the MTIP, a veritable theory. *The PAAS may be enounced as follows*: For any triplet ($s\psi S$), denoted as $s \xrightarrow{\psi} S$, where *s* is the system-source, *S* the system-sink, and ψ the functional interaction, the area of stability of the system $s \xrightarrow{\psi} S$ is larger than the areas of stability of *s* and *S* considered separately. In other words, the increase in complexity of the system $s \xrightarrow{\psi} S$ corresponds to an increase in stability. MTIP consists in a representation (set of non-local interactions $s \xrightarrow{\psi} S$), an organizing principle (the PAAS), and a hypothesis (any biological system may be described as a set of functional interactions) that gives rise to two faces of the biological system, the (O-FBS) and the (D-FBS). The first one may be studied using the potential of organization, the second one using the S-Propagator formalism, that describes the dynamics in the structural organization, making an n-level field theory. Both are based on geometrical/topological parameters, and coupled via geometry/topology that may vary with time and space (state variables of the system) during development and adult phases. The structures are defined by the space scale κ; hence the structural hierarchy, the functions are defined by the time scale *T*, hence the functional hierarchy. Any model built in this theoretical framework will use the same representation, the same basic principle and hypothesis, and consequently will be comparable and able to be coupled with any other on" [10].

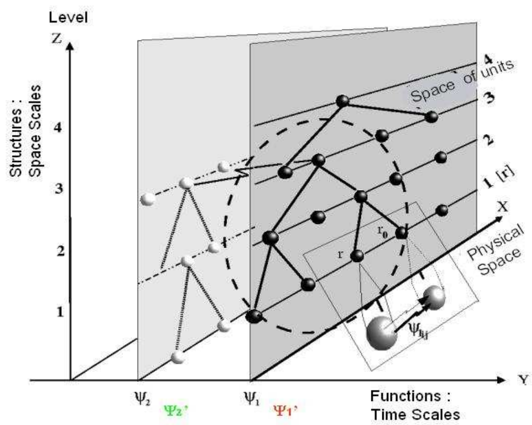

Figure 1: *Ω - 3D representation of a biological system based on the Chauvet's MTIP [11]*

What we propose in this paper is to couple the biological system with an engineered system. This is a new theoretical paradigm for knowledge-based systems and augmented human design: "For the biological system, the PAAS represents a principle of organization in which it is difficult to doubt. Although the true challenge is to mathematically identify these functional interactions, practically, the theoretical framework using *observed* functional interactions allows rigorous integration of coupled processes, and thus useful to provide explanations for many phenomena." [10].

Thus MTIP will be applied on different space-time levels of the body -the physiological system- and the engineered system. It defines a theoretical framework of integrative physiological design for human systems integration, for augmented human and thus for modelling human-in-the-loop systems design.

The human (Ω) [figure 1] is represented as the combination of the hierarchical structural (z) and functional (y) organizations. The (x) axis corresponds to the ordinary physical space. Each physiological function ψ is represented in the xψy plane by a set of structural units hierarchically organised according to space scales. Two organizational levels are shown: ψ_1 and ψ_2. The different time scales are on the (y) axis, while space scales, which characterize the structure of the system, are on the (z) axis. The role of space and time clearly appears. Ψ_{1ij} is the non-local and non-symmetrical functional interaction.

Units at the upper levels of the physiological system represent the whole or a part of sensorial and motor organs. HSI (Ω') [figure 2] consists in creating an artificially extended sensorimotor loop by coupling two artifactual structural units I' and J' [11].

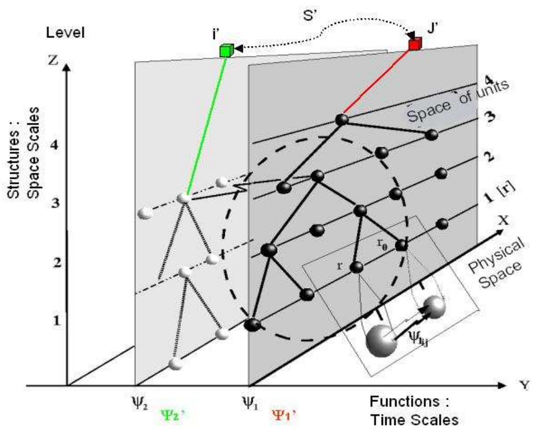

Figure 2: *Ω' - representation of a human in the loop system coupling the biological system with an artifactual system on the left to an artificial sensorimotor loop [11].*

Their integration into the physiological system is achieved by the functional interactions they generate. From sensors outputs to effectors inputs, the synchronized computerized process S' controls and adapts the integration of the functional interactions artificially created into the dynamic of the global and coherent system.

It is a new theoretical paradigm for human systems integration modelling.

IV. RATIONALE FOR HUMAN MODELLING AND HITLS DESIGN

Since technical systems are mathematically thought and based on physical principles, HITLS needs to be thought in mathematical terms. There are several necessities to make HIS reliable.

A. Necessity 1 – Designing a HITLS is to couple an artifactual system to a biological system

Human modelling, as a scientific way to consider human characteristics and his coupling with his environment, needs an epistemological approach that enables to question the representativeness and validity of models and related concepts. Thus, a new conceptual framework that questions the nature of the interaction between human and environment (social or technical) as an integrated biological, anatomical, and physiological process, has to be developed.

If physical and mathematical theories permit to describe the matter, it should be the same concerning living systems - human. It seems necessary that a rational explanation could make us understanding harmonious complexity and effective working of a living organism, and its integration in its living or working environment, toward the considerable mechanisms which constitute it.

Thereof, we suggest general principles, methods and related tools to design HITLS and anticipate their reliability by simulation.

B. Necessity 2 – HITLS design is a global and integrative model based method

Model based system engineering (MBSE) is an important part of systems engineering. It uses computer aided design tools that enable to drive system simulations and validate technical studies or design decisions. MBSE is developed to design technical systems or systems of systems. It is a necessary but not sufficient way for HITLS design.

Contrary to current approaches that are data or goal oriented, human modelling needs a predictive approach. Those modelling process are not integrated, and therefore, not sufficient to model human. Such models should be used to create models of individuals rather than using aggregated summaries of isolated functional or anthropometric variables that are more difficult for designers to use. Human and technical models are developed independently. There are no scientific principles to organize and assess the functional coherence of the HSI for HITLS performance and reliability.

Designing an artefact consists in organizing a coherent relation between structures and functions in a culture and a context of usage [design=structure/function]. Modelling human consists in taking into account anatomical and physiological elements in the same model [human modelling = functions (physiology) / structures (anatomy)].

The underlying question of human modelling in HITLS design is to know how to organize and integrate a hierarchy of structural elements and their functions [12].

C. Necessity 3 – Modelling human and HSI is to organize hierarchically structures and functions and their functional interactions

MTIP principles seem to be the best way to deal with HITLS scientific and industrial issues.

By integrating structures and functions of both human and technical elements, integrative physiological organization intends to model the basis of human behavior and its functional interactions with artefacts and environment. The HITLS global function is the response to environment stimulations and the result of an integrated process (perception, decision, action). Each function is dynamically generated by a specific organization of structures and functional interactions. Thus, human modelling in HITLS comes down to design structural architecture and functional interactions. It is to design the coherent and relevant structural and functional organization and parameters that lead to the behavioral expression.

The behavioral modelling intends to model human and the properties of the human system interaction, based on the idea that the global system organization constrains the human behavior and vice versa.

V. CONCLUSION AND PERSPECTIVES

"Integrative theoretical physiology based behavior modelling" seems to be a better way to ensure the reliability of HITLS and manage human modelling than traditional computational and symbolic approach. Fass assessed the pertinence of human systems integration modelling based on the MTIP principles by using virtual environments for gesture assistance in weightlessness and hypergravity experiments [11] [13].

In fact, MTIP introduces a paradigm shift from interface system design to interaction and integration system of systems design. Thereof designing an artefact system consists of making biological individual and artifactual physical system consistent and coherent.

These scientific paradigm and method find a lot of applications for safety critical systems design and engineering, notably for the mitigation of human risks in aeronautic or nuclear power plant monitoring or augmented human design. It's also an interesting area for enhancing and improving human dimension in recent engineering systems interoperability issues.

REFERENCES

[1] Bittner, AC, Jr.. Requirements testing and evaluation: Human-in-the-loop systems. Ergonomics in Design, October 1993, pp29-32.

[2] Booher, H.R. Handbook of Human Systems Integration. Wiley, Hoboken. 2003.

[3] Green, Rush F., and Charland, Julie. Human modeling in the Product Lifecycle Management of the Boeing 787 Dreamliner. SAE International. 2006.

[4] Axelsson, J. Towards an improved understanding of humans as the Components that Implement Systems Engineering. Volvo Car Corporation, Dept. 94100 PV 32. 2002.

[5] Reynolds, Herbert M., and Hubbard, Robert P. Anatomical frames of reference and biomechanics. The Human Factors Society, 22(2), p. 171-176. 1980.

[6] Horn, E.N. Optimization-based dynamic human motion prediction (MS Thesis), Universty of Iowa, College of engineering, 2005.

[7] Liu, Y., Feyen, R., and Tsimhoni, O. "Queueing Network-Model Human Processor (QN-MHP): A computational architecture for multitask performance in human-machine systems," ACM Transactions on Computer-Human Interaction, vol. 13, no. 1, 2006, pp. 37-70.

[8] Chauvet, G. A. Hierarhical functional organization of formal biological systems: a dynamical approach. I. to III. Philosophical Transaction of the Royal Society London B, 339, 1993, 425-481.

[9] Chauvet, G. A. Theoretical systems in biology: hierarchical and functional integration. Volume III. Organisation and Regulation. Oxford, Pergamon,1996.

[10] Chauvet, G. A. A new paradigm for theory in Integrative Biology: the principle of auto-associative Stabilization. Biochemical networks and the Selection of Neuronal Groups. Journal of Integrative Neuroscience, 5, 3, 2006, 381-416.

[11] D. Fass. Rationale for a model of human systems integration: The need of a theoretical framework. Journal of Integrative Neurosciences 5(3), 2006, pp 333-354.

[12] D. Fass. Integrative physiological design: A theoretical and Experimental Approach of Human Systems Integration. Engin. Psychol. And Cog. Ergonomics, HCII 2007, in D.Harris (Ed.) LNAI 4562, 2007, pp. 52-61.

[13] D. Fass, Virtual environment a behavioral and countermeasure tool for assisted gesture in weightlessness : experiments during parabolic flights *Journal of Gravitational Physiology*, Volume 12, Number 1; July 2005, pp. P19-P20, (ref 20060054310, in *Scientific and Technical Aerospace Reports* (*STAR*), NASA, vol 44, 26, p 125.)