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Augmented Human Engineering: A Theoretical and Experimental Approach to Human Systems Integration

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1. Introduction

This chapter focuses on one of the main issues for augmented human engineering: integrating the *biological user's needs* in its methodology for designing human-artefact systems integration requirements and specifications. To take into account biological, anatomical and physiological requirements we need a validated theoretical framework. We explain how to ground augmented human engineering on the Chauvet mathematical theory of integrative physiology as a fundamental framework for human system integration and augmented human design. We propose to validate and assess augmented human domain engineering models and prototypes by experimental neurophysiology.

We present a synthesis of our fundamental and applied research on augmented human engineering, human system integration and human *in-the-loop* system design and engineering for enhancing human performance - especially for technical gestures, in safety critical systems operations such as surgery, astronauts' extra-vehicular activities and aeronautics. For fifteen years, our goal was to research and to understand fundamental theoretical and experimental scientific principles grounding human system integration, and to develop and validate rules and methodologies for augmented human engineering and reliability.

2. Concepts

2.1 Human being

A human being, by its biological nature – bearing in mind its socio-cultural dimensions, cannot be reduced to properties of mathematical or physical automaton. Thus, connecting up humans and artefacts is not only a question of technical interaction and interface; it is also a question of integration.

2.2 Human systems integration

As a technical and managerial concept (Haskins 2010), human systems integration (HIS) is an umbrella term for several areas of "human factors" research and systems engineering that include human performance, technology design, and human-interactive systems interaction

(Nasa 2011). Defining a system more broadly than hardware and software refer to human centred design (Ehrhart & Sage 2003). That issue requires thinking human as an element of the system and translating it qualitatively throughout design, development and testing process (Booher, 2003).

These are concerned with the integration of human capabilities and performances, from individual to social level into the design of complex human-machine systems supporting safe, efficient operations; there is also the question of reliability.

Human systems integration involves augmented human design with the objectives of increasing human capabilities and improving human performance[1] (Engelbart 1962) using behavioural technologies at the level of human-machine system and human machine symbiosis (Licklider 1960). By using wearable interactive systems, made up of virtual reality and augmented reality technologies or wearable robotics, many applications offer technical gesture assistance e.g. in aeronautics, human space activities or surgery.

2.3 Technical gesture assistance

Gesture is highly integrated neurocognitive behaviour, based on the dynamical organization of multiple physiological functions (Kelso, 2008)(de Sperati, 1997). Assisting gestures and enhancing human skill and performances requires coupling sensorimotor functions and organs with technical systems through artificially generated multimodal interactions. Thus, augmented human design has to integrate human factors - anatomy, neurophysiology, behaviour - and assistive cognitive and interactive technologies in a safe and coherent way for extending and enhancing the ecological domain of life and behaviour.

The goal of this type of human *in-the-loop* system design is to create entities that can achieve goals and actions (predetermined) beyond natural human behavioural, physical and intellectual abilities and skills – force, perception, action, awareness, decision…

2.4 Integrative design

Augmenting cognition and sensorimotor loops with automation and interactive artefacts enhances human capabilities and performance. It is extending both the anatomy of the body and the physiology of human behaviour. Designing augmented human beings by using virtual environment technologies requires integrating both artificial and structural elements and their structural interactions with the anatomy, and artificial multimodal functional interactions with the physiological functions (Fass, 2006). That needs a fitting organizational design (Nissen & Burton 2010).

Therefore, the scientific and pragmatic questions are: how to best couple and integrate in a coherent way, a biological system with physical and artifactual systems? How to integrate in a coherent way human and interactive artefact –more or less immersive and invasive, in a behaviourally coherent way by design? How augmented human engineering can anticipate and validate a technical and organizational design and its dynamics? How modelling and assessing such a design efficiency? How grounding HIS and augmenting human design on a validated theory? How assessing experimentally and measuring both performance and efficiency?

[1] Sensorimotor and cognitive

3. Augmented human domain engineering

Human-artefact systems are a special kind of *systems of systems*. They are made up of two main categories of systems. These two kinds of systems differ in their nature: their fundamental organization, complexity and behaviour. 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 is to couple and integrate in a behaviourally coherent way, a biological system (the human) with a technical and artifactual system. Augmented human engineering needs to model the human body and its behaviour to test and validate augmented human reliability and human systems integration (HSI).

3.1 Domain engineering

According to system engineering, taking into account user needs in the world of activities and tasks, designing system requirements is to find the system design, its three dimensional organizational dimensions of requirements - structural, geometrical and dynamical - and its three view plans of system design specifications –structure or architecture, behaviour –performance and efficiency, and evolution –adaptation, resilience capability…(Fig.1).

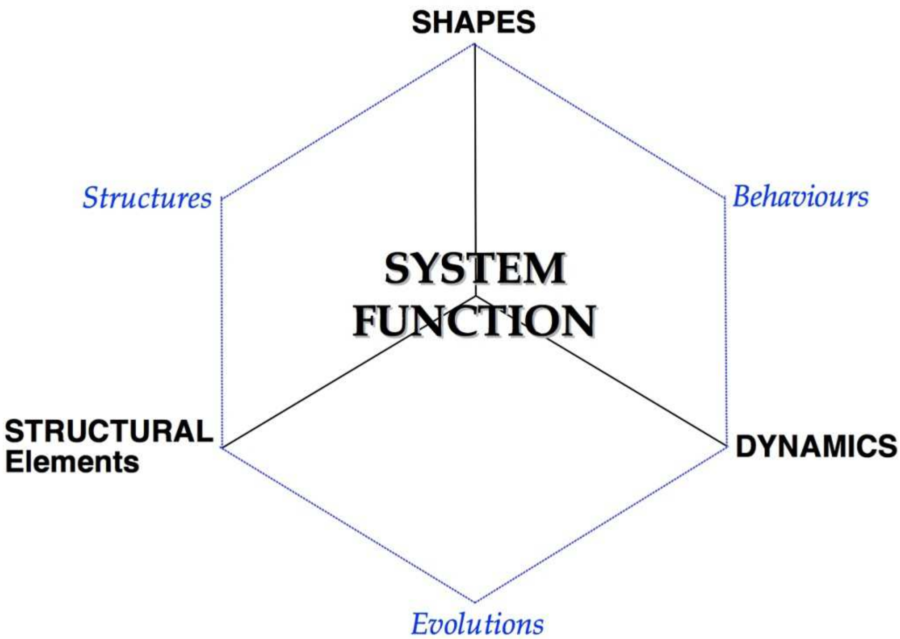

Fig. 1. Our overall system design general conceptual framework: System function results from the integrative organization of different structural elements, shapes and dynamics according there space and time scales relativity and specific qualitative and quantitative measurement units.

Thus, system engineering requires both expert skills and validated formal modelling methodologies. To some extent, the main difficulty is to build a system model from a collection of informal and sometimes imprecise, redundant and unstructured descriptions to the domain of expertise. A formal model could be relevant to highlight a hidden structure according to an intended function and its dynamics, or to apply operations or transformation on the system itself.

From domain engineering to requirements, our approach is situated inside Dines Bjoemer's framework (Bjoemer's 2006a, 2006b and 2009) based on the triptych: D, S -> R, where D is the domain of the problem and where requirements R are satisfied by the relation ->, which intends to mean *entailment*; so, S is a kind of model of our system built or expressed from D. If that triptych is able to express, in a synthetic manner, a situation related to the problem domain, a system model and the requirements, it remains at a global level and can thus be applied in different problem spaces and instances.

The domain provides a way to express properties and facts of the environment of the system under construction. The system model S is intended to summarize actions and properties of the system and it is a link between the requirements and the final resulting system. The relation -> is conceptualized as a deduction-based relation which can be defined in a formal logical system, and which helps to derive requirements from domain and model. This relation is sometimes called entailment and is used to ground the global framework. When one considers an application, one should define the application domain from the analysis and this may integrate elements of the world. The triptych helps for defining a global framework and offers the possibility to use tools that are useful for assessing the consistent relation between D, S and R; because we aim to use proof techniques for ensuring the soundness of the relation.

3.2 Human system integration

The major benefits of using augmented human modelling in design include reducing the need for physical development; reducing design costs by enabling the design team to more rapidly prototype and test a design; avoiding costly design 'fixes' later in the program by considering *human factors* requirements early in the design process; and improving customer communications at every step of product development by using compelling models and simulations. Thus, designing an artefact consists of organizing a coherent relation between structural elements and functions in a culture and context of usage. Modelling human beings consists of taking into account anatomical and physiological elements in the same model. It is to design functions by organizing a hierarchy of structural elements and their functions. 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. Therefore augmented human modelling in design requires an integrative approach according to the three necessities we defined for human systems integration (Fass 2007).

3.3 Human system integration domain

Since technical systems are mathematically grounded and based on physical principles, HITLS needs to be considered in mathematical terms. There are several necessities to make HIS and augmented human reliable (Fass & e: Lieber 2009).

- Necessity 1 – Designing a HITLS is to couple two systems from different domains organized and grounded on different principles theory and framework: biological, physical, numerical.
- Necessity 2 – HITLS design is a global and integrative model based method ground on Chauvet's Mathematical Theory of Integrative Physiology and domain system engineering.
- Necessity 3 – Modelling augmented human and HSI is to organize the required hierarchically structural elements, shapes and their interactional dynamics according an architectural principles, behavioural needs of performance and efficiency and evolutionary needs.

Consequently, designing augmented human following human system integration is to organize hierarchically and dynamically human and artefact coupling. This requires a new domain engineering approach for requirements and specification based on biological user's needs and functions.

3.4 Augmented human engineering

Dealing with augmented human engineering is being able to situate and limit its domain for specifying the whole system – biological and artifactual integrated system- in accordance with the high-level and global requirements:

- ***D:*** The ecology of the augmented human: scientific validated principles of augmented human needs and functions*;*
- ***R:*** Augmented human teleonomy, augmented human economy and ethics***;***
- ***S:*** Biological, technical and organizational specifications of the human-artefact system – performance, efficiency, reliability, security, safety, stability**.**

4. Augmented human's needs

Who would even think about separating a living goldfish from its water and its fishbowl?

4.1 Epistemological needs

Converging technologies for improving human performances (Rocco & Brainbridge 2002), *augmented human*, need a *new epistemological and theoretical* approach to the nature of knowledge and cognition considered as an integrated biological, anatomical, and physiological process, based on a hierarchical structural and functional organization (Fass 2007). Current models for human-machine interaction or human-machine integration are based on symbolic or computational cognitive sciences and related disciplines. Even though they use experimental and clinical data, they are yet based on logical, linguistic and computational interpretative conceptual frameworks of human nature, where postulate or axiomatic replace predictive theory. It is essential for the robust modelling and the design of future rules of engineering for HIS, to enhance human capabilities and performance. *Augmented human* design needs an integrative theory that takes into account the specificity of the biological organization of living systems, according to the principles of physics, and a coherent way to organize and integrate structural and functional artificial elements (structural elements and functional interactions). Consequently, virtual environments design for *augmented human* involves a shift from a metaphorical, and scenario based design, grounded on *metaphysical* models and rules of interaction and cognition, to a predictive science and engineering of interaction and integration. We propose to ground HSI and *augmented human* design on an integrative theory of the human being and its principles.

4.2 Chauvet's mathematical theory of mathematical physiolgy (MTIP) needs

The mathematical theory of integrative physiology, developed by Gilbert Chauvet (Chauvet 1993a; Chauvet 1993b; Chauvet 1993c) examines the hierarchical organization of structures (i.e., anatomy) and functions (i.e., physiology) of a living system as well as its behaviour. MTIP introduces the principles of a functional hierarchy based on structural organization within spaces limits, functional organization within time limits and structural units that are the anatomical elements in the physical space. This abstract description of a biological system is represented in (fig. 2). MTIP copes with the problem of structural discontinuity by introducing functional interaction, for physiological function coupling, and structural interaction Ψ from structure-source s into structure-sink S, as a coupling between the physiological functions supported by these structures.

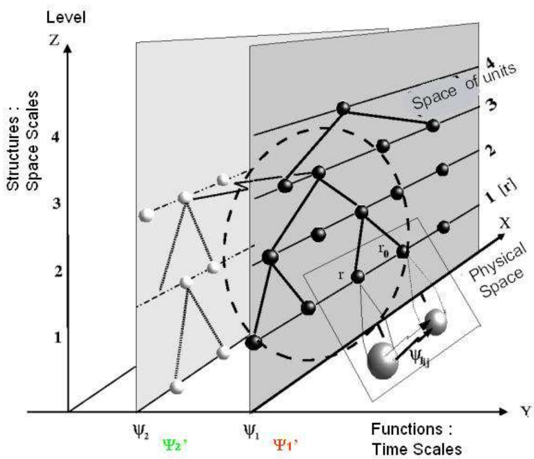

Fig. 2. Ω - 3D representation of a biological system based on the Chauvet's MTIP.

Chauvet had chosen a possible representation related to hierarchical structural constraints, and which involves specific biological concepts. MTIP consists in a representation: set of non-local interactions, an organizing principle: stabilizing auto-association principle (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 potential of organization (O-FBS) and the dynamics in the structural organization, making an n-level field theory (D-FBS). 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 Z, hence the structural hierarchy, the functions are defined by the time scale Y, hence the functional hierarchy.

MTIP shows three relevant concepts for grounding human system integration:

- Functional interaction: The first important hypothesis of the MTIP is that a biological system may be mathematically represented as a set of functional interactions of the type $s \overset{\psi}{\rightarrow} S$. Unlike interactions in physics, who are local and symmetric at each level of organization, biological or 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. 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' $s \overset{\psi}{\rightarrow} S$? What is the origin of the existence (the identification) of s, S and ψ that together make a component $s \overset{\psi}{\rightarrow} S$ of the system?
- PAAS: is a mathematical principle that makes of a framework, the MTIP, a veritable theory. The PAAS may be stated as follows: For any triple (s ψ S), denoted as $s \overset{\psi}{\rightarrow} S$, where s is the system-source, S the system-sink, and ψ the functional interaction, the area of stability of the system $s \overset{\psi}{\rightarrow} S$ is larger than the areas of stability of s and S considered separately. In other words, increasing in complexity the system $s \overset{\psi}{\rightarrow} S$, corresponds to increase in stability.
- Potential of functional organization: describes the ability of the system to combine functional interaction in a coherent way, in such a dynamic state of a maximum of stability and reorganization.

Therefore augmented human engineering needs designing artificial functional interactions – short sensorimotor artificial functions, which generate a maximum of stability for human-artefact systems in operational conditions. Thereby MTIP provide for us an abstract framework for designing human-artefact system and designing organizations for dynamic fit (Nissen & Burton 2011). These are the reasons why MTIP is a relevant candidate theory for grounding augmented human design.

5. Rational for a model of *augmented human*

As claims by Fass (Fass2006), since artifactual systems are mathematically founded and based on physical principles, HSI needs to be thought of in mathematical terms. In addition, there are several main requirements categories to make HIS and augmented human design safe and efficient. They address the technology - virtual environment-, sensorimotor integration and coherency.

Requirement 1: Virtual environment is an artifactual knowledge based environment

As an environment, which is partially or totally based on computer-generated sensory inputs, a virtual environment is an artificial multimodal knowledge-based environment. Virtual reality and augmented reality, which are the most well known technologies of virtual environments, are obviously the tools for the augmented human design and the development of human in-the-loop systems. Knowledge is gathered from interactions and dynamics of the individual-environment complex. It is an evolutionary, adaptive and integrative physiological process, which is fundamentally linked to the physiological functions with respect to emotions, memory, perception and action. Thus, designing an artifactual or a virtual environment, a sensorimotor knowledge based environment, consists of making biological individual and artifactual physical system consistent. This requires a neurophysiological approach, both for knowledge modelling and human in-the-loop design.

Requirement 2: Sensorimotor integration and motor control ground behaviour and skills

Humans use multimodal sensorimotor stimuli and synergies for interacting with their environment, either natural or artificial (vision, vestibular stimulus, proprioception, hearing, touch, taste…) (Sporn & Edelman 1998). When an individual is in a situation of immersive interaction, wearing head-mounted display and looking at a three-dimensional computer-generated environment, his or her sensorial system is submitted to an unusual pattern of stimuli. This dynamical pattern may largely influence the balance, the posture control (Malnoy & al. 1998), the spatial cognition and the spatial motor control of the individual. Moreover, the coherence between artificial stimulation and natural perceptual input is essential for the perception of the space and the action within. Only when artificial interaction affords physiological processes is coherence achieved.

Requirement 3: Coherence and HIS insure the human-artefact system performance, efficiency and domain of stability

If this coherence is absent, perceptual and motor disturbances appear, as well as illusions, vection or vagal reflex. These illusions are solutions built by the brain in response to the inconsistency between outer sensorial stimuli and physiological processes. Therefore, the cognitive and sensorimotor abilities of the person may be disturbed if the design of the artificial environment does not take into account the constraints imposed by human sensory and motor integrative physiology. The complexity of physiological phenomena arises from the fact that, unlike ordinary physiological systems, the functioning of a biological system depends on the coordinated action of each of the constitutive elements (Chauvet 2002). This is why the designing of a artificial environment as an augmented biotic system, calls for an integrative approach.

Integrative design strictly assumes that each function is a part of a continuum of integrated hierarchical levels of structural organization and functional organization as described above within MTIP. Thus, the geometrical organization of the virtual environment structure, the physical structure of interfaces and the generated patterns of artificial stimulations, condition the dynamics of hierarchical and functional integration. Functional interactions, which are products or signals emanating from a structural unit acting at a distance on another structural unit, are the fundamental elements of this dynamic.

As a consequence, the proposed model inside Chauvet's MTIP assumes the existence of functional interactions between the artificial and the physiological sensorimotor systems. This hypothesis has been tested through experiments described in the following section. This model in the framework of MTIP is formally described in figure 3, that is the 3D representation of the integrated augmented human design. The human (Ω) (fig.2.) is represented as the combination of the hierarchical structural (z) and functional (Y) organizations. X-Axis corresponds to the ordinary physical or Cartesian space. Each physiological function ψ is represented in the $x\psi y$ plane by a set of structural units hierarchically organized according 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-symmetric functional interaction.

Units at the upper levels of the physiological system represent the whole or a part of sensorial and motor organs. Augmented human (Ω') (fig.3.) design consists of creating an artificially extended sensorimotor loop by coupling two artifactual structural units *I'* and *J'*. Their integration into the physiological system is achieved by the functional interactions (i.e. sensorimotor) they generate. From sensors' outputs to effectors' inputs, the synchronized designed artificial system or process *S'* controls and adapts the integration of the functional interactions artificially created into the dynamics of the global and coherent system.

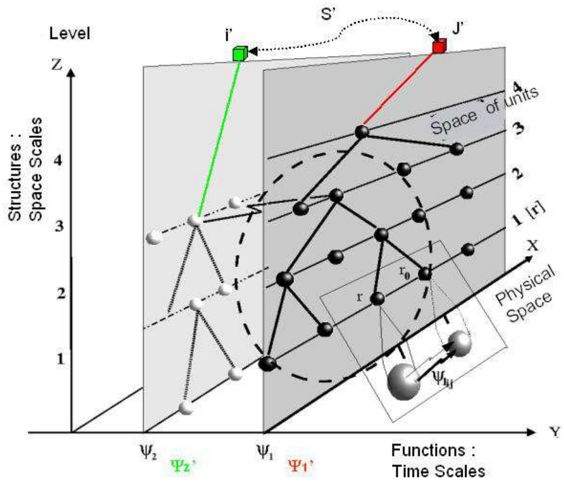

Fig. 3. Ω' – a representation of *augmented human*: artifactual loop coupling the biological system with an artifactual system to an artificial sensorimotor loop (Fass 2007).

This is our theoretical paradigm for augmented human modelling.

According MTIP we highlight three grounding principles for augmented human engineering and human-artefact system design[2]:

- Principle 1: functional interaction is an affordance, a sensorimotor and emotional coupling function depending on geometrical structure of the artifactual design, its architecture;
- Principal 2: the hierarchical structural and functional organization of the human-artefact system must allow behavioural performance and effectiveness inside the boundaries of an operation domain of stability.
- Principle 3: the degree of organization of a human-artefact design, its degree of functional complexity, must be compliant with the evolution of the human-artefact system situated in its operational environment, context, and domain of stability (safety, security and reliability).

[2] These theoretical principles of human system integration are consistent with the ten organizational HSI principles define by Harold Booher (Booher 2003) or the three HSI design principles defined by Hobbs et al. (Hobbs et al. 2008).

6. Experiments

The goals of this research are to search for the technical and sensorimotor primitives of augmented human design for gesture assistance by a wearable virtual environment, using virtual reality and augmented reality technologies, for human space activities, aeronautical maintenance and surgery. We have chosen as behavioural assessment adapts to a virtual environment, a neurophysiological method used in motor control researches to study the role of the body in human spatial orientation (Gurfinkel et al. 1993), and the representation of the peri-personnal space in humans (Ghafouri & Lestienne 2006).

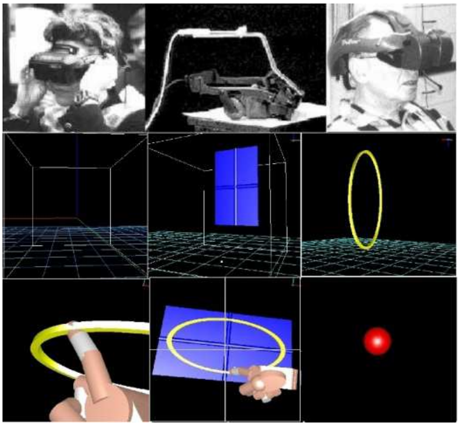

Fig. 4. Examples of different structural and functional primitives for virtual environment design.

6.1 Paradigm

The following method was developed for expert system engineering (knowledge based system) and to explore the knowledge nature as a behavioural property of coupling generated in the dynamics of the individual-environment interaction, either natural or artificial. We use gestures as a sensorimotor maieutic.

The gesture based method for virtual environment design and human system integration assessment is a behavioural tool inspired by Chauvet's theoretical framework, i.e.:

i. an integrated marker for the dynamical approach of augmented human design, and the search for interaction primitives and validation of organization principles; and
ii. an integrated marker for a dynamical organization of virtual environment integrative design.

By designing a artificial environment, a human *in-the-loop* system consists of organizing the linkage of multimodal biological structures, sensorimotor elements at the hierarchical level of the living body, with the artificial interactive elements of the system, devices and patterns of stimulation. There exists a "transport" of functional interaction in the augmented space of both physiological and artifactual units, and thus a *function* may be viewed as the final result of a set of functional interactions that are hierarchically and functionally organized between the artificial and biological systems.

6.2 Material and method

To find the main classes of virtual environments and highlight the dynamical principles of hierarchical organization of human systems integration and virtual environment design for assisting gesture, we set up a protocol according to a complex and incremental design (fig.4.). The experiments were performed in laboratory and a prototype was tested during a French National Space Centre (CNES) parabolic flight campaign.

Devices: Head mounted display I-Glasses® immersive or see-trough, Frastrack Pohlemus® electromagnetic motion tracking system, workstation with a specific software design for managing and generating the visual virtual environment in real-time.

Protocol: Our protocol is based on graphical gesture analysis, more specifically of the drawing of ellipses within 3D-spaces. It's inspired by neurophysiology of movement [20]. By selecting this experimental paradigm, the movement was considered as the expression of a cognitive process *per se*: the integrated expression of the sensorimotor three-dimensional space.

In laboratory, ellipses drawn without virtual environment are the control experiment. It consists of two main situations: open and closed eyes, touch or guided by a real wooden ellipse, and memorized without a model. To highlight the dynamical principles of organization for assisting gestures, we set up a protocol according to a complex and incremental VE design, allowing intuitive learning of both task and use of virtual environment. Ten volunteers (7 men and 3 women, 25 to 35 years old) were asked to performed graphical gestures (drawing of ellipses: eccentricity 0.87 – major axis 40cm and minor axis 20cm) in the three anatomical planes of reference for each step of incremental design (Fig. 5).

The first step of the protocol consisted of drawing ellipses wearing a turned off HMD to study the influence of HMD design and intrusiveness on sensorimotor integration and motor control. The last step of the virtual reality artefact combined allocentric and egocentric prototypic structural elements of artificial visual space, model of ellipses and their planes of movement, and a visual feedback of movement.

Parabolic Flights – hypergravity and weightlessness: to test our prototype (Fig. 6, 7 and 8), three right-handed trained volunteers were asked to draw ellipses (major axis 30 cm and minor axis 15cm) in two orientations of the three anatomical reference planes: vertical sagittal (VS) and transversal horizontal (TH). These drawing of ellipses were performed continuously and recorded during both the 1.8g ascents and the 0g parabola itself, feet in foot-strap (F) or in free-floating (FF), in two main situations: free gesture and assisted gesture wearing a visual virtual environment. Visual virtual environment was generated in immersion (RV) or in augmented reality (RA).

Data analysis: sixteen gesture-related variables are calculated from data produced during the parabola and recorded from the sensor worn on the tip of the index finger of the working hand: kinematics (Number of ellipses), Average velocity, Covariation Vt/Rt, Amplitude), position (Global position, Position / x axis, Position / y axis, Position / z axis), orientation (Global orientation, Orientation / sagittal plane, Orientation / frontal plane, Orientation / horizontal plane) and shape (Mean area, Eccentricity, Major axis variation, Minor axis variation) – indexes in Annex 1.

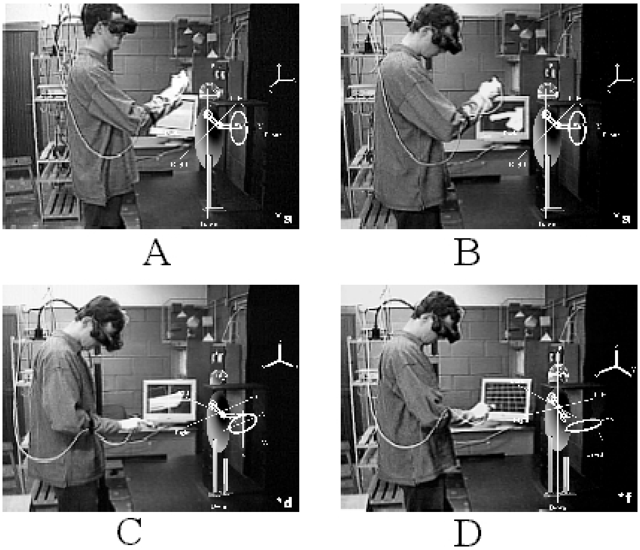

Fig. 5. Graphical gesture of ellipse drawing in the 3D space is performed and analysed in different configurations, more or less complex, of immersive virtual environment assisted drawing ellipses: A- SV ellipses and neutral and coloured background, B- SV ellipses and anthropomorphic visual feedback of movement (artificial hand), C- TF and model of ellipse insert in its plan of movement without visual feedback of movement, D- TH ellipses and abstract representation visual feedback of movement (ball).

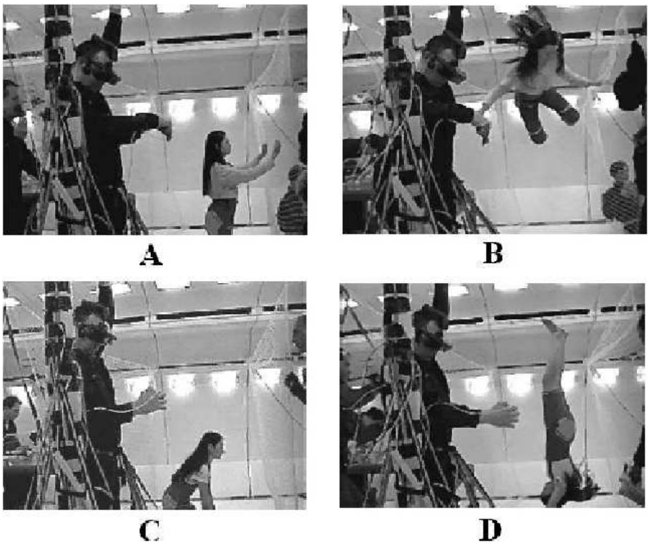

Fig. 6. Drawing of SV (A,B) and HT (C, B) ellipses with gesture assistance in hypergravity (1,8g – A, C) and microgravity (0g – B,D)

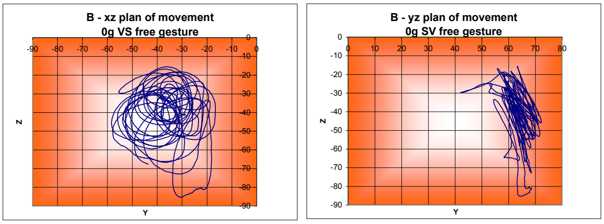

Fig. 7. Weightlessness (0g), example of ellipse drawing in vertical sagital orientation without assistance. We observe a total lost of shape and orientation accuracy.

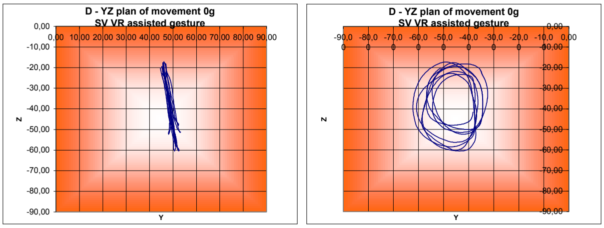

Fig. 8. Weightlessness (0g), example of ellipse drawing in vertical sagital orientation with assistance in vertical sagittal orientation. Even if the shape is not precise, orientation of movement is very accurate and stable (tacking into account the magnetic field distorsion) despite that loss of the gravitational referential and vestibular perturbations. Artificial visuomotor functional interaction coupling by virtual environment enhance stability according the Chauvet's MTIP theory and its principles of auto-associative stabilization.

Statistical analysis: We use a method of multidimensional statistical analysis. Principal component analysis and hierarchical classification are calculated with SPAD 4.0® to show the differential effects of hypergravity and microgravity on graphical gestures for each subject wearing or not the system. A second goal of this exploratory statistics is to assess the design of our prototype and the dynamics of the human virtual environment integration in weightlessness and on earth.

*Results***:** The variable correlation circle (Fig. 9.) shows the first principal (F1) component is correlated in a negative manner with the position, kinematics and shape variables; especially with the global position F, the average velocity B and the mean area E. The second principal component (F2) is correlated in a negative manner with the variables of orientation M, J and K. Whereas K orientation variation in relation to the sagittal plane is fairly correlated with F1. Thereof, the more the average person is placed downward and on the left on the F1-F2 plane, the more their global orientation and orientation in relation to both the frontal and horizontal planes will be important (Annex 1).

Principal component analysis F1-F2 factorial plans (Fig. 10.): Axis 1 (42.70%) shows two sets of experimental status. The first set contains control status head free, touched ellipse, opened or closed eyes, visual guidance, and the virtual reality assisted gesture with visual feedback, ball or hand, and referential frames of action: plane of movement or ellipse model. The second set contains individuals without ellipse model; head free, opened or closed eyes and memorized, HMD off, no gesture feedback and no allocentric or egocentric referential frames. These positions of individuals on the axis 1 reveal the importance of visuo-haptic interactions for gesture in real or virtual environment. Inside that set, they are differences between real touched ellipses situations and " virtually touched". The visuo-haptic class contains two sub-classes (visuo-tactile and visuo-proprioceptive).

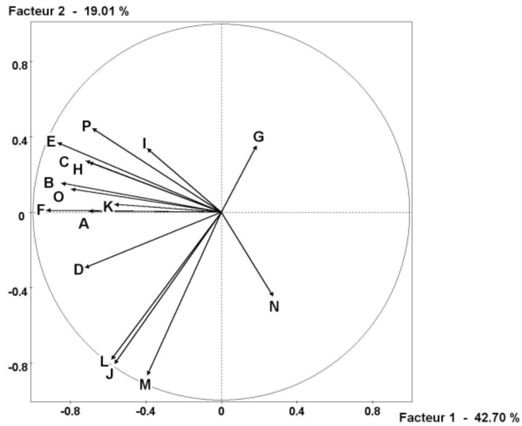

Fig. 9. Variables correlation circle.

Axis 2 (19.01%) shows difference functions of the orientation plane of movement. The distortion of the gesture spatial orientation is greater without visuo-haptic inputs, even with spatial frames of reference and models of action (ellipse model and plan of movement). These positions of individuals on the axis 2 reveal the importance of the gesture spatial orientation. Without visuo-haptic elements, situation of sagittal plane drawing ellipses are nearest to the gravity center of the factorial plane. Frontal and horizontal orientations influence motor behavior with contrary effect. The gesture distortion is greater in the horizontal plane. It also shows significant influence of HMD configurations and of gesture feedback representation. There are functional semiotic differences between ball and virtual hand with enhanced functional differences in absence of visuo-haptic elements. There are four noticeable statuses: 88A, 172a and 175a, without gesture feedback, induce similar behavior to situations with visuo-haptic interactions; 39f, drawing ellipses in the horizontal plane wearing HMD off immersive I-Glasses, induce the greatest distortion in motor control.

The multidimensional statistical analysis (Fig. 9 and 10) confirms the existence of structural and dynamical primitives of human system integration and virtual environment design, for assisting gestures the *a priori* main classes of virtual environment organizational elements. Their organizational and functional properties - the way to couple real and artificial sensori-motor functions - have a significant influence on the human *in-the-loop* system behavior. By enhancing and interacting with the sensorimotor loops, they are able to modify (disturbing or improving) the motor control, the gesture and, as a consequence, the global quality of human behavior. According to these experimental results, the interactions generated by the artefacts may be identified as functional interactions.

Thus we are able to show differential effects for each element of the incremental design of VE, and to assess the global design and dynamics of the human system integration. These experimental results will ground VE design modelling according to the hierarchical organization of theoretical integrative physiology.

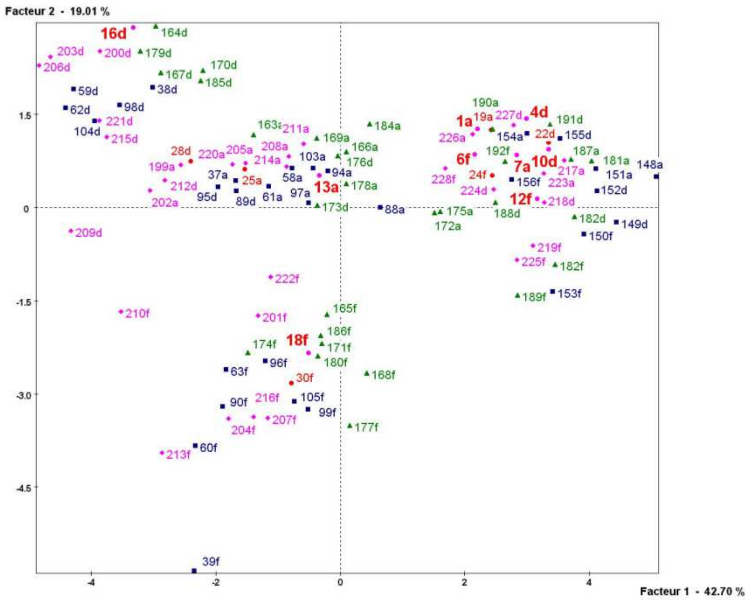

Fig. 10. Principal component analysis, F1-F2 factorial plans: outcome analysis of the virtual environment elements organization is done by observing statistical individuals (indexes Annex 2 and 3) position on the F1-F2 plan (representing 67.71% of the total inertia).

7. Conclusion and perspective

Designing a human-artefact system consists of organizing the linkage of multimodal biological structures, sensorimotor elements at the hierarchical level of the living body, with the artificial interactive elements of the system, devices and patterns of stimulation. There exists a "transport" of functional interaction in the augmented space of both physiological and artifactual units, and thus a *function* may be viewed as the final result of a set of functional interactions that are hierarchically and functionally organized between the artificial and biological system elements.

Structures or Architecture: spatial organization of the structural elements, natural and artificial, coupled by non-local and non-symmetric functional interactions according to PAAS. It is specifying the function(s) of the integrated system. Different organizations specify different architecture and their specific functions:

Behaviour: temporal organisation of the patterns of artificial functional interactions condition and specify the dynamics fit of augmented sensorimotor loops. It is determining augmented human behaviour.

Evolution: the spatiotemporal organization of the structural elements and the functional interactions they produce and processes specify functional stability of human-artefact system according to the *potential of functional organization* principle during the *life of augmented human.*

Contingent on ecology and economy, architecture, behaviour and evolution as specified, define and limit the *life domain of augmented human*.

MTIP is thus applicable to different space and time level of integration in the physical space of the body and the natural or artificial behavioural environment; from molecular level to socio-technical level; from drug design to wearable robotics, and to life and safety critical systems design.

Future work should address questions related to the development of formal models (Cansell & Méry 2008; Méry & Singh 2010) related to augmented human engineering. New questions arise when dealing with deontic or ethical questions that might be handled by an augmented human together with classical formal modelling languages based on deontic or modal languages.

Industrial scientific and pragmatic challenges rely on designing intelligent and interactive artifactual systems relating machines and human beings. This relationship must be aware of its human nature and its body: it is anatomy and physiology. The man-machine interface becomes an integrated continuation of the body between perception-action and sensory and motion organs. By integrating human body and behaviours, the automaton is embodied but this embodiment grounds on the user's body; it enhances capabilities and performances. Efficiency and reliability depend on respecting these fundamental necessities.

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9. Annexes

9.1 Annex 1: Calculated variables

Index	Variables
A	Number of ellipse
B	Average velocity (cm/s)
C	Covariation Vt/Rt
D	Amplitude (cm)
E	Mean area (cm^2)
F	Global position
G	Position / x axis (cm)
H	Position / y axis (cm)
I	Position / z axis (cm)
J	Global orientation
K	Orientation / sagittal plane(d°)
L	Orientation / frontal plane(d°)
M	Orientation / horizontal plane(d°)
N	Eccentricity
O	Major axis variation
P	Minor axis variation

Table 1.

9.2 Annex 2: Training and control experimental status indexation

Control	**INDEX**		
	Situation		Gesture Orientation
Opened Eyes	touched ellipse	**1a**	VS
		4d	TF
		6f	TH
	visual guidance	**7a**	VS
		10d	TF
		12f	TH
	memorised	**13a**	VS
		16d	TF
		18f	TH
Closed Eyes	touched ellipse	**19a**	VS
		22d	TF
		24f	TH
	memorised	**25a**	SV
		28d	FT
		30f	HT

Table 2.

9.3 Annex 3: Assisted graphical gesture experimental status

Virtual Environment		**INDEX**			
	Visual environment	**I/O Immers**	**I/O N Immers.**	**Proview 60**	**Gesture orientation**
HMD off	no	**37a**	**163a**	**199a**	VS
	no	**38d**	**164d**	**200d**	TF
	no	**39f**	**165f**	**201f**	TH
No gesture feedback					
	Allocentric frames	**58a**	**166a**	**202a**	VS
	"	**59d**	**167d**	**203d**	TF
	"	**60f**	**168f**	**204f**	TH
	Egocentric frame	**61a**	**169a**	**205a**	VS
	"	**62d**	**170d**	**206d**	TF
	"	**63f**	**171f**	**207f**	TH
	Ellipse + Allo frames	**88a**	**172a**	**208a**	VS
	"	**89d**	**173d**	**209d**	TF
	"	**90f**	**174f**	**210f**	TH

	Ellipse + Allo+ Ego	**94a**	**175a**	**211a**	VS
	"	**95d**	**176d**	**212d**	TF
	"	**96f**	**177f**	**213f**	TH
Gesture Feedback					
Ball	simple	**97a**	**178a**	**214a**	VS
	"	**98d**	**179d**	**215d**	TF
	"	**99f**	**180f**	**216f**	TH
	Ellipse + all references	**148a**	**181a**	**217a**	VS
	"	**149d**	**182d**	**218d**	TF
	"	**150f**	**183f**	**219f**	TH
Hand	simple	**103a**	**184a**	**220a**	VS
	"	**104d**	**185d**	**221d**	TF
	"	**105f**	**186f**	**222f**	TH
	Ellipse + all references	**151a**	**187a**	**223a**	VS
	"	**152d**	**188d**	**224d**	TF
	"	**153f**	**189f**	**225f**	TH
	"				
Vision and touch	Ellipse and hand	**154a**	**190a**	**226a**	VS
	"	**155d**	**191d**	**227d**	TF
	"	156f	192f	228f	TH

Table 3.

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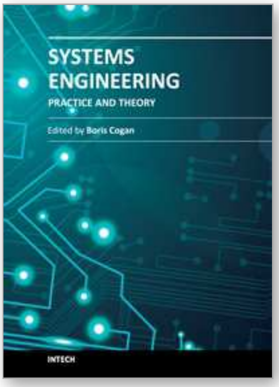

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The book "Systems Engineering: Practice and Theory" is a collection of articles written by developers and researches from all around the globe. Mostly they present methodologies for separate Systems Engineering processes; others consider issues of adjacent knowledge areas and sub-areas that significantly contribute to systems development, operation, and maintenance. Case studies include aircraft, spacecrafts, and space systems development, post-analysis of data collected during operation of large systems etc. Important issues related to "bottlenecks" of Systems Engineering, such as complexity, reliability, and safety of different kinds of systems, creation, operation and maintenance of services, system-human communication, and management tasks done during system projects are addressed in the collection. This book is for people who are interested in the modern state of the Systems Engineering knowledge area and for systems engineers involved in different activities of the area. Some articles may be a valuable source for university lecturers and students; most of case studies can be directly used in Systems Engineering courses as illustrative materials.

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