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Annie Luciani

► **To cite this version:**

Annie Luciani. The instrumental paradigm in the framework of information technologies. Cognitive systems with Interactive Sensors 2009, Nov 2009, Paris, France. pp.74. hal-00479981

HAL Id: hal-00479981

<https://hal.science/hal-00479981>

Submitted on 22 Apr 2014

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The Instrumental Paradigm in the Framework of Information Technologies

Annie Luciani

Laboratoire ACROE-ICA, INPG, 46 avenue Félix Viallet, F-Grenoble

Abstract: In this paper, we focus on a type of instrument which allow the human to perform complex and subtle task, such as play violin or mould a paste. We examine the general properties that characterize such situations and we examine why and how they must be conserve in new instruments based on information technologies, under the scope of the fundamental mutations such technologies triggered. So doing, we aim at grounding this instrumental paradigm as a paradigm *per se*, not confused with other close approaches such as in Robotics or in Virtual Reality.

Keywords: Instrument, closed-loop dynamic systems, human-object interaction, force feedback transducers.

1. Introduction

In this paper, we do not want to trigger discussions about what is or what is not an instrument, such as: are formal representations, for example mathematics, instruments or not?, or is a hammer a tool or an instrument?. In other words, we do not want to debate about the word “instrument” itself. We want to examine the notion of instrument under the light of class of properties that are necessary to perform subtle and complex tasks, such as playing violin or moulding a paste, but not only, and that are not present in other types of tools. The word “instrument” can be here legally used as it is used for ages in such tasks, the oldest being the musical instrument, i.e. an object to do music. Conversely, we do not restrict the discussions to peculiar uses, such as music. We propose a functional analysis of such type of instruments in order to elicit what are their fundamental properties, physical as well cognitive, authorizing to consider them as an important and well-identifiable category of external tools humans are using to perform tasks. We examine too why they are necessary and how can we design information technologies in order to have at disposal these properties in that new technological context. To conclude, we want to launch discussions about their role in the structuring of the physical world as well in human cognitive processes.

2. Properties of instrumental human-world relationship

Since primary experiences such as those in which a human hits a tree with another piece of wood to alert his congeners by means of specific sounds and rythms, or, as staged by Stanley Kubrick in his movie « 2001 : the Space Odyssey », in which a femoral bone became a tool when received in hands by the monkey which threw it to the

space, while the parallelepipedic black box, fallen down from the sky, remained incomprehensible, the fundamentals of the instrumental paradigm were launched. In this paragraph, we enounce, in three points, the main properties of what is for us « an instrument », in order to examine further what is the epistemologic break introduced by the informations technologies and how it can be overcrossed.

1. The instrument as a physical object

In the instrumental relationship between humans and the world, an instrument is, at first, a part of the physical world, i.e. a physical object, chosen by humans and modelled or not by them. More, it is used to perform a task that humans cannot perform without it. So that, it operates morphological, physical and functional adaptations of the human morphology and the rest of the physical world. As example of morphological adaptation, a screwdriver allows to perform continuous rotation impossible to perform only by hand and fingers. As example of physical adaptation, the wax spread under the skis operates an optimization of the dynamic adherence in order to move faster. As example of functional adaptation, a musical instrument is a physical object that transforms gestures in sounds, in order to enlarge the capabilities of the human beings to produce sounds, because, except with his vocal cords, human is very poor acoustic vibrating structure. Thus, as the Janus figure, an instrument has two faces, and one can say, strictly speaking, that it is an interface. Alternately, it can be considered as a part of the physical environment, seen or heard by humans, or an extension of human body when near the body and taken in hands. As all the objects, when it is not in hands, its appraisal by human can be perceptual or formal. But when in hands and during the performance of the task, it is felt, and consequently known, through the human sensory-motor capabilities so that one cannot say who manipulate which and vice-versa (of the human and of the object). Human and object are constituting a single system, we can say a single instrumental system, mediating a human intention (implicit or explicit) to others human through the performed task. Consequently, we cannot speak of instrument or instrumentalist, separately, but only of the instrumental relationship between them, during which they constitutes a single instrumental system.

2. The instrumental system as a dynamic system

Such instrumental system exhibits specific and rich properties. The relation between the human and the physical object is more than a sensory-motor relation like hand-vision sensory-motor relationship when showing an object by pointing it with the finger. When in hands, human body and the physical object are not only like two things in contact. They constitute an inseparable closed loop dynamic system (Figure 1), really as a single object.

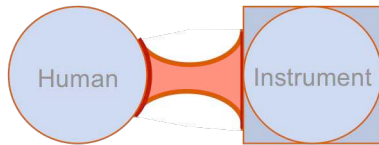


Figure 1 : The intimate instrumental relationship
(by the courtesy of J.L Florens¹)

This single object is a complex dynamic system composed of an active part and of passive part as shown in the figure 2. We intend here “active”, not in the sense of the humans are subjects able to have intentions, but in the sense of that a system embeds an internal source of energy able to modify internally its internal states. Indeed, the human bodies have the capability to modify the tonicity of their muscles during a jump. It is not necessary that the instrument is also active² to have at disposal the minimal functionalities able to characterise the instrumental system as a dynamic system.

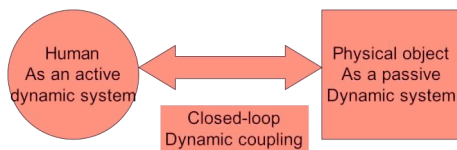


Figure 2 : The basic instrumental system as a dynamic closed-loop system

Considering the instrumental system as a dynamic complex system allows to understand better why it is able to exhibit features that cannot be found in other types of human-world relationships, for example in hand-vision relationship. Indeed, the instrumental system composed of the closed-loop coupling between a human and a physical object exhibits dynamic properties such as energetic exchanges consistency, reactivity or dynamic adaptation. Such properties are not necessary to perform types of tasks such as those that can be performed through formal communication by signs and languages or by open-loop command systems. But they are necessary to perform tasks that, either by principle or until new technologies will provide new proves, cannot be performed by the first types of tools. The distinction between both is well represented by the concept of ergotic and non-ergotic

¹ Thanks to Jean-Loup Florens for his particularly expressive representation of the coupling human - physical object.

² As it is aimed when introducing autonomous processes in objects (real or virtual). In such last cases, we obtain a system that is of course more complex, but not fundamentally of a different type.

tasks proposed by C. Cadoz [1]. Let us illustrate that with emblematic cases as those shown in Figure 3: playing a cello, rubbing a surface and moulding a paste. During such instrumental performances, the physical body of the instrumentalist and the instrument are closely dynamically coupled, being then able to produce non-predictable emergent effects: timbre changing, sticking, cracking, breaking, transients, bifurcations, stability regions, etc.. In the finger-glass system, the sound can appear or not; timbre can change or not. And all of these effects cannot relate simply to only parameters control processes: the intensity of the sound is not directly correlated only to the pressure force or to the finger velocity. When the sound is started, the pressure and the velocity can be relaxed to maintain it. It is the same in the bowed string playing during which human gestures are able to manage very complex dynamic patterns: relaxing the pressure, increasing or decreasing the velocity of the bow, at the right state of this complex dynamic system, etc. When success, the expression used is: “it is one with his instrument”.



Figure 3. Three emblematic cases of the instrumental situation

3. The complexity of the transformation from an object to an instrument

The intimate relation between human and object during the performance of an instrumental task (i.e. a task performed by means of an instrumental human-world relationship as defined before) leads to the emergence of cognitive features such as those of the embodiment process or of considering the instrument as a *second nature* [2]. Indeed, the process articulates the following stages: (1) seeing or hearing an object, distant in space and thus constituting a part of the environment, (2) choosing it, (3) touching it and grasping it, (4) manipulating it and (5) using and playing it in the performance of the task, and this process is everything but trivial. In that process, the object is progressively transformed in an instrument, so being a part of the human body (his second nature) and the human is progressively transformed in an instrumentalist, so being a part of the instrument (its human nature) (Figure 4). All along the playing of the instrument by *his* instrumentalist, the instrument became *his* own. We will see further that in the context of tools based on information technologies, this trade-off remains a non-solved bottleneck. Vice-versa, and because the instrument is intrinsically a physical external object, and not (only) a knowledge or a formal tool for example, able to being in mind according to the functionalities of the memory processes (whatever

they are³), the human being has always and at each time the capability to leave instantaneously the instrumental state and to render the instrument to its status of a trivial physical object of the environment. Alternately, the instrument plays as a temporary extension of the human organology and as a part of the external environment and thus, it is a locus on which some complex cognitive processes can take place. The symmetric process, strictly correlative to the embodiment process here, and permitted by principle by the status of external object, is the disembodiment process.

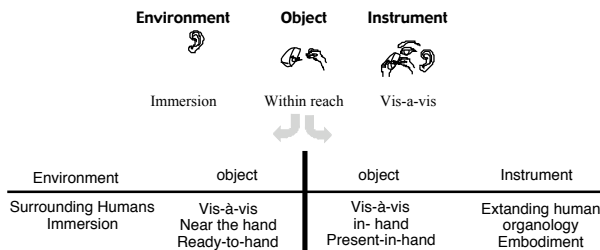


Figure 4. From Immersive to the embodied instrument : a bilateral complex cognitive process.

So, the mutation process of an object in instrument (and of the human in an instrumentalist) is the support – as well as the material representation – of the dual cognitive processes of embodiment and disembodiment, the first one stressing his integration within the world and the second one, maintaining his individuality. Notice that the concept presented here is fundamentally different of that «Immersive Virtual Reality» which seeks at disconnecting totally the human from his natural environment. The precise point and instant during which the object becomes in physical contact with the human body is then of a existentialistic critical point. First, it is no less than the point in which the human create cognitively the notion of the sense of matter. That consists not only in the notion of the object in the sense of non simultaneous space occupation, such one being also supported by visual or tactile experiences. It consists else in the experience of something that is, at the first, resistant [3] and more, of something that opposes and proposes complex behaviours to humans sensory-motor acts: from elasticity and viscosity to dry friction and other more complex ones. Such behaviours are precisely learned and intimately used by humans during the instrumental playing: playing violin, skiing, maintaining an object more or less grasped all along a complex manual task such as screwing a screw with a screwdriver, etc.

3. The instrument and instrumental relation in the context of Information Technologies

In the previous paragraph, we detailed basic functional, technical and cognitive properties of the instrumental relationship. We do not pretend to have exhausted all the questions around it. But, we hope, at first, the reader

convinced from now of the necessity of such relation. Nevertheless, all the topics discussed above are necessary for examining why and how the instrumental relationship can be implemented in information technologies.

One can consider that mechanical instruments serve perfectly all the instrumental tasks and that electrical, and/or computer technologies, have been designed to develop other types of tools for other types of tasks. Let us notice that the constraints imposed by mechanics in the optimal design of such instruments is a critical limitation for the three types of adaptivity we spoke above: morphological, physical and functional. No doubt that electromechanical teleoperated master-slave systems designed to extend the space, to improve the accuracy of the manipulation, and to secure humans who manipulate were necessary. No doubt neither that synthesis process enlarge considerably the variety of the sounds and images the humans are able to produce. But what is the main and fundamental difference between purer mechanical instrument, such as a violin or a puppet, and electrical or information – based ones? A first and obvious answer is: in such implementation of the relationship between the human and the system which perform the task, the coupling, as described before, as well as the sensation of the matter which naturally exist in mechanical interaction, are lost. They are not naturally supported by electrical technologies, and thus, if necessary, we have to (re) construct them.

Such very simple observation leads to, first one remark, and second, one new concept. First, the mediated relation between humans and the physical world by means of electrical and computer technologies cannot be an instrumental relationship. And second the electrical-based instrumental relationship which could exhibit the main properties of the mechanical relationship, cannot be anything else than a *representation of the instrumental situation*, as introduced by C. Cadoz [4] and developed in [5][6]. Such representation has not to be understood as a representation of specific instrumental cases, such as playing violin or piano, as it could be understood at the first glance, but the representation of the principles of the instrumental situation. Consequently, we ask, and try to solve, what are the main technological and conceptual bottlenecks for the implementation of a representation of the instrumental relationship within electrical and computer technologies.

The information technologies started from the notions of electrical transducers and signals. Indeed, electrical transducers and signals, and thus, all the electrical sciences including computer sciences, operate the fundamental historical shift from mechanically coupled systems to input-output systems [7], breaking the mechanical-based closed loop and thus having to represent it as well in the formal representations as in the electrical and information systems. The input-output representation formalism introduces a causality between what is the input and what is the output, that does not exist in the mechanical systems. Consequently, in the

³ Here, there is no necessary for us to assume any hypothesis on the memory processes.

representation of coupled systems, it obliges to separate the two intimately stuck parts, for example the cellist and the cello, each of them being then represented by an input-output block as shown in the figure 5 and to represent their coupling by connecting the output of the one onto the input of the other. So the representation of the instrumental system introduces a cascade of two causal relations: the cellist is considered as an input of the cello and the cello as an input of the cellist.

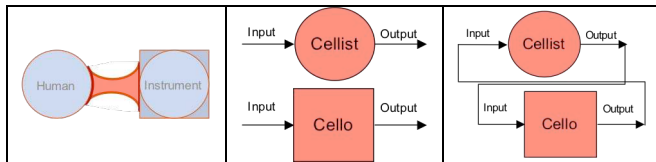


Figure 5. The shifts in the representation of the instrumental system

Left: the instrumental system; middle: its splitting in two input – output systems; Right: the input-output representation of their coupling

The input-output representations ground the sensors-actuators (more generally transducers) and signals technologies and information systems, and vice-versa. The outputs of a system are then sensors that acquire their behaviours and transform them in signals and the inputs are actuators that receive these signals. We do not discuss about the reduction due to the fact that the sensors, the actuators and the signals so produced represent only some parts of the physical behaviours⁴. But, we will focus on the fact that the coupling is not totally representable in electrical and in computers systems. Then, the questions are: Is it possible to restore the sensation of the matter? How can we implement the input-output correlations to preserve the representation of the coupling? In the following, we propose three aspects, one conceptual, two technological, which can help to progress in the answers of such questions.

1. “Transparency of the system or new representation of the instrumental universe”

The approach we present here differs conceptually and pragmatically of that which is usual in robotics and the differences have a great incidence for the philosophy and technology of instrumental paradigm in information systems. In the robotics domain, the approach is to tend to replicate at the best a real situation. The concept is that of “the transparency” of the new electromechanical system, i.e. how can we render the behaviours caused by the new electromechanical system as transparent as possible? This concept derives from the electrical teleoperation in which one tried to render the new components added from the mechanical teleoperation as fonctionnally “transparent”. Although the answer is that it is not absolutely possible [8][9], the main stream in robotics worked to solve the question of transparency so risen.

⁴ that is of course a true critical question, widely examined in electrical engineering and transducers theories and systems.

Our approach is near from anthropological point of view. It do not consists in reproducing existing instrumental situations by rendering as inexistent as possible the specificities brought by novel technologies, but in developing new instruments under specific conditions and assumptions. These conditions are to take care of the fundamentals of human-world couplings, in order to develop not only new systems, but those that will be able to preserve such fundamentals and experiment their role in human cognition as well in the performance of the tasks. Our approach is then tasks independent, and can be expressed as: how do we specify the scheme represented on the right of the figure 5 and implement it in information technologies to obtain, *at the best for the human*, the instrumental situation represented on the left of the same figure? A temptation could be to consider that the answer could be only on the human side and that the question can be solved by human-based design of robotic systems after having performed psychophysical and cognitive preliminary experiments. We outline here that it will be not sufficient: first because the instrumental problem is not the same than risen by transparency in the teleoperation chain [10]; second, because the instrumental paradigm for ages do not consist in copying previous instruments and previous situations, but in creating new instruments for new tasks for new instrumentalists, and third, because the human-mechanical object system is not observable and needs new experimental workbenches to be better known. The basic technical schema which represents the instrumental situation within the domain of information technology is given in figure 6.

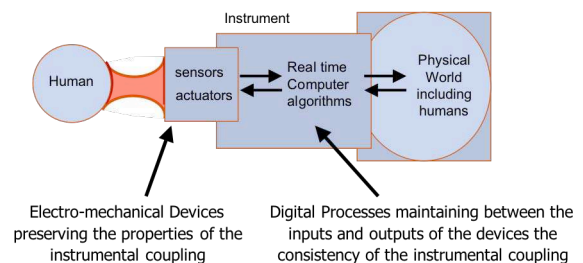


Figure 6. The representation if instrumental situation in the framework of Information Technology

Thus, the question becomes : what are the necessary and minimal conditions we must preserve, to have at disposal the instrumental properties from the human side, when shifting the technologies: we can say, what could be the “task-independent *axioms*” of the instrumental situation. We now sketch two minimal of these basic properties, and their correlated technological needs.

2. A first minimal dynamic property: rigidity and hard collisions

First of all, when used in computer technologies, i.e. when the system that receives the inputs from sensors and produces the outputs to actuators, is based on or includes computers, the causality introduced between inputs and outputs is transformed in a temporal causality. Indeed, a non instantaneous computation process is inserted between the inputs and the outputs. In the

electromechanical coupling between human and such systems by force feedback transducers, this question is related to that of the bandwidth of the system device / computer algorithms. This bandwidth depends obviously on the dynamical properties of the device itself but also on the computer algorithms and the communications systems between both. These two last can be expressed by the temporal latency between the outputs of the device (resp. inputs of the computer) and its inputs (resp. outputs of the computer). More this bandwidth is, and less the latency is, more the restitution of coupling between rigid systems will be. That is a critical point in force feedback transducers design, known under the terms “Stability” or “Bandwidth problem” [11].

Having in mind the previous discussions [3] about the fact that the contact situation conveys the sense of resistance of the external matter and further of the matter itself, the rendering of contacts is also a critical point for a perceptual, cognitive, and further existentialistic point of view on the side of the human being. Consequently, all the technical components (force feedback transducers including sensors, actuators, mechanical embedding of them and electronic regulation processes) must be used coherently and consistently to render, at the best - the interaction during collisions and contacts between a human and a simulated resistant matter in the computer. It will be in the same time a workbench in order to experiment (1) what is the cognitive role of the contact situation in the trade-off from “environment” to “instrument” via the intermediate stages of “object - near the hand” and the “object – in – hand”; and (2) How it could be a necessary component for considering the instrument as a “second nature” of the instrumentalist. Couroussé and colleagues, in [12] tackled these questions in a specific research on the haptic-audio tapping. Using the high quality TELLURIS platform, in which all the systems and processes are running at 44 kHz⁵, they show that, when hitting an acoustical surface, the properties of the matter (its non-linear elasticity and viscosity), are influencing the maximum of the frequency of the hits. To sum up, according to the critical role played by the existence of the matter, revealed during the contact and collision situation, in the instrumental situation, the rigidity during contact is the first axiom of the instrumental relationship to be rendered at the best in the framework on information technologies.

We saw that our approach is different for conceptual reasons of that of robotics, based on transparency concept. It is technically different than the main stream of researches in Virtual Realities. In Virtual environments and virtual reality systems, most of the works are dedicated to the immersion of humans within virtual environments. This immersion is simultaneously physical by means of systems such as Caves in which 3D images and sounds are surrounding the human beings, and virtual by means of avatars of the human beings representing

them in the virtual environment. The core problem here is the wideness of the represented spatial environments and systems put the emphasis on the navigation and the exploration of large spatial and geometrical 3D scenes. The collisions problem is processed from a geometrically-based point of view, the critical problem being that of the geometrical computation of the intersection between two complex geometrical shapes to prevent interpenetration. There are lot of works developed in computer graphics and applied in robotics when complex manufactured objects. The related scientific questions are summarized in [13]. In this framework, the dynamic of the contact remains a secondary problem, while it is one of the first generic property systems have to render in the instrumental paradigm.

3. A second minimal dynamic property : accurate dynamic friction

Having created the minimal conditions to restore the sense of the matter through its physical resistance within information-based technological systems, and reminding, as explained above, that humans uses the others properties of the matter (other than and in addition with its resistance) in the instrumental tasks, a second stage consists in restoring at the best such behaviours. Some others behaviours of the matter such as all the viscoelastic effects able to render all types of deformability are easily derived from the rigidity effects discussed above. The second critical dynamic feature for most of complex instrumental tasks is then the friction effect. Differently than the collision processing that led to lot of works in robotics and in virtual reality, even if their developments do not tackle with the instrumental paradigm, there is a very few number of works that tackle with the friction effect. Hereto, the technological developments are at the front of the state of the art. Florens and coworkers[14] [15] demonstrate that when the friction between a bow and a string is simulated by computer and feedback to the force feedback transducer manipulated by the instrumentalist at a high frequency, typically 1500 Hz in [14] and 44 kHz in [15], the sensation of the presence of the vibrating bowed string increased significantly. The instrument became more and more playable and new gestures and exploratory manipulations happened due to the fact of wide possibilities of dynamic gestural adaptations and learning, by allowing the instrumentalist to play with non predictable effects as those occurring in the finger-glass interaction we told in the first paragraph of this paper. Here too, the rendering, at the best, of the usual properties of the matter when instrument are in hand, such as friction, will allow to know better what is its role in the cognitive appraisal of the instrumental situation and in different criteria characterizing the performed task: efficiency, playability, handleability, creativity.

4. Conclusion and further questions

We have not examined here others questions such as the morphological ones (number of sensors and actuators and morphological arrangements). They play undoubtedly an important role in human manipulation of physical objects. Indeed, some drastic limitations of the existing force

⁵ Virtual Reality systems implement sampling rate for force feedback processes at maximum of 1 kHz and robotics systems do not currently overcome 10 kHz.

feedback devices are related to the fact that they allow only punctual contacts. However, we demonstrated that dynamic properties of the close-loop coupling between human and a physical object, is a necessary condition, (even if it is not a sufficient one), to have access to behaviours that are the specificities of the instrumental system and that cannot emerge otherwise. Based on primary functions of the instrumental paradigm, we showed how the central concept of robotics, i.e. the transparency of the electrical and information parts of the system, despite the huge development of interactive teleoperators including haptics, does not match with the instrumental paradigm. We showed also that Virtual Reality, despite too the huge uses of the haptic devices, does not fit longer within such instrumental paradigm. So, the field of instrumental situation in computerized environment remains to be developed and is still a subject for future. We have to know more, to build more, to experiment more around the non trivial concept of instrument and instrumental relationship, from an anthropological point of view, within the scope of information technologies.

The instrumental paradigm as posed here is the inspirational principle for the technologies developed in the laboratory [15, 16, 17], ERGOS and TELLURIS respectively for force feedback devices and for highly reactive real time computer algorithms. They have been designed and implemented in order to be able to render both of the primary and generic physical behaviours of the dynamic coupling between human and a physical object, hard contact and dynamic friction, and thus, in a sufficiently accurate way in order to be able to experiment the cognitive aspects related to them.

Several other fundamental issues remain pending. Taking the examples of Arts, such as Musical Arts, Visual Dynamic Arts, Choreographic Arts, no doubt that the instrumental relation, in the meanings developed in this paper, is fundamental to produce subtle sensory effects. But further, if we include the very long process to design an instrument, process in which the physical matter is also pointed out, we could see that the instrument is not only a way to adapt the human and the world to perform tasks that humans cannot do, but more a way to organize and structure, in the same movement, the physical world and the human gestures. The best example is that of the musical instruments, of which their physical registration correspond intimately to the musical notations systems and to the education of the hearing.

5. Acknowledgement

This work has been performed with the support of the French ministry of Culture and the French Research Agency Project ANR-08-CREA-031. Thanks to my colleagues Claude Cadoz and Jean-Loup Florens, who enlightened my thoughts and my feelings around the notions discussed in this paper, all along inestimable hours of discussions.

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