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Embodied Cognition and Tangible User Interfaces: Alternatives for a reduction of Unmanned Aerial Vehicles Operators Workload

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Abstract

This article claims that the introduction of Tangible User Interfaces (TUIs) into the ground stations of Unmanned Aerial Vehicles (UAV) systems supported by the theoretical principles of embodied cognition will lead to improved interface efficiency and reduced operator workload. The increasing complexity of UAV missions has led to an increasing complexity control interface. This requires more and more cognitive treatment from the operators, leading to an increase in workload. The aim of this paper is therefore to demonstrate how the use of TUI and embodied cognition are leading to a reduction in the operator's workload. TUIs are a type of Human/Machine interface that will embed digital data or control into an object. Unlike graphical user interfaces, they allow the user to interact with the object by relying on the sensory-motor capabilities of the user. On the other hand,previous work on embodied cognition showed that perception, memory and spatial representations are rooted in the sensorimotor (*i.e.* perceptual and motor) system of the human being. There is therefore a possible match between the capabilities of the operators' sensorimotor system and the interface allowing the control of the UAV through TUI.

1. Introduction

In both the civilian and military domains, the field of application of Unmanned Aerial Vehicles (UAV) systems is opening up more and more every day as a result of technological advances in airborne vehicles (more durable, stealthier and smaller) and payloads (larger, varied and more accurate). Technological advances affect the spectrum of UAV's missions which, logically, are becoming more complex. For example, the concept of employment of the French Air and Space Force UAV system has quickly evolved from simple reconnaissance to area persistence in a highly collaborative context (*e.g.* C4ISR – Computerized Command, Control, Communications, Intelligence, Surveillance and Reconnaissance). More specifically, UAV systems are integrated into missions involving several command and control centers (*i.e.* C2), several vectors (aircraft, helicopters, UAVs, AWACS, *etc.*), several operational units deployed in the theater of operations (Special forces, Reconnaissance Squad). Thus, in addition to the information collected by the UAV system (provided by the various sensors), the operators have to process a significant number of tactical data resulting from their interactions with the other actors involved in an operation (*cf.* Figure 1).

Since the receiving of UAVs, the French forces, and ground station interfaces have continuously been developed according to the same design logic, *i.e.* visual presentation of information[1], cognitive processing of data[2], use of office computer peripherals (keyboard, mouse, joystick).

From a cognitive point of view, technological advances and the increasing complexity of drone missions are leading to a de facto increase in the workload of operators. The overall objective of the present research is to propose credible alternatives to both the purely cognitive and visual processing of operators and to the use of control devices that are too universal, *i.e.* devices that were not originally designed for these specific tasks. We argue that the introduction of Tangible User Interfaces (TUIs) in the ground stations of UAV systems, supported by the theoretical principles of embodied cognition, should improve the efficiency of the interfaces and thus reduce the workload of the operators.

The first part of this article is dedicated to the presentation of key concepts of TUI. Indeed, 'tangibility' cannot be defined in a binary way, 'to be or not to be tangible'. It results from the combination of several concepts presented

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[1] In concrete fact, for each new functionality of the drone system, operators see a new screen or new information on the existing screens.
[2] Operators have to deal with a lot of numerical data, text, etc.

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here. The concepts of metaphorical axis and affordance which are central notions in the field of the tangible underline the importance of designing a TUI by respecting a certain level of analogy between the real world and the digital world. Then, the notions of manipulation and proprioception are detailed. The aim here is to highlight the significant differences between TUIs and GUIs (Graphical User Interfaces). Next comes the introduction of an axis for classifying TUIs in relation to each other, called the embodiment axis, which is based on the concept of 'cognitive distance' between the input of the system, which allows the user to control the system, and the output, which informs the user of the result. The last paragraph is devoted to the functional links between TUIs and users' peripheral vision.

The second part deals with embodied cognition and the concepts behind it. First, the effects of action on perception will be explained. Indeed, the environment leaves cues that the sensorimotor system (perceptual and motor) can pick up. If perception is influenced by the sensorimotor system, it seems that memory is also influenced. This will be demonstrated in a second part. Finally, this chapter will discuss the importance of the sensorimotor system in the creation and use of spatial representations. Spatial representations are dynamic mental constructs that can, in some cases, account for executable actions in the present situation.

(a) EADS Harfang ground control station.
Picture from https://fr.topwar.ru

(b) Reaper Block-30 Ground Control Station.
Picture from General Atomics Aeronautical Website

Figure 1: The benefits inherent in the use of the Reaper compared to the Harfang are above all operational. From the point of view of interfaces, the regular increase in the functionalities of UAV systems leads above all to an increase in the number of screens.

2. Tangible User Interfaces

In 1997, Ishii and Ullmer (CHI 97) presented a new concept of human-computer interface: Tangible User Interface (TUI). They defined them as interfaces that physically embody digital information and computation. TUI relies on the natural dexterity of human beings and embed digital information in physical space. Tangible interfaces make digital information directly graspable and manipulable [15]. Basically, a user manipulates one or more physical objects (called props) with his hands and a computer system detects his actions, modifies his internal state and gives feedback accordingly. Manipulating the props is equivalent to manipulating the data. Sometimes, in the case of a dynamic system with feedback, changing the data changes the state of the props (this is the 3rdloop in Figure 2).

2.1 Metaphorical axis and affordance

To determine whether an interface is tangible, Fishkin [9] introduced two kinds of metaphor. The first is to answer the question: is the effect of a user's action on a prop similar (from identical to totally different) to the effect of that same action in the real world? This is called a metaphor of *verb*, '*verb*' in the sense of action. If the action performed by the user within the tangible system is a faithful reproduction of the action that the user would perform in the real world, then the system can be said to offer a metaphor of *verb*. The designer of a tangible interface also chooses the shape, color, smell, weight and texture of its props. In this way, he generates sensory links between the user and the manipulated props, and thereby, between the user and the data embodied by the props. This is a metaphor of *noun*[3]. The system will be considered offering a *noun* metaphor if the appearance of the object strongly looks like the user knows. A tangible interface can propose both a metaphor of *verb* and a metaphor of *noun* . In this case, it makes

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[3] The authors chose these terminologies ' metaphor of *noun*' and ' metaphor of *verb*' because cognitive psychologists claim that nouns and verbs seem to be deeply embedded in our consciousness.

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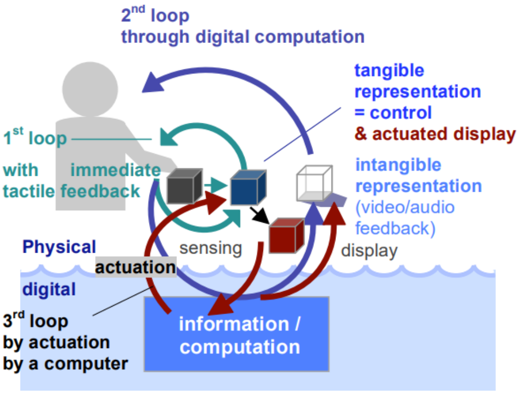

Figure 2: information loops according to Hiroshi Ishii [15]

strong use of analogies of both appearance and use, but the physical and virtual objects remain different. Finally, if no more analogies are needed, the metaphor is said to be *full*, the virtual system and the real system are one. Illuminating Clay [20] is an example of a *full* metaphor. Using clay, a landscape model is constructed, on which the curves of the terrain or the types of landscape (water, forest, snowy peaks) calculated by numerical simulations are projected. This clay landscape model has the shape and relief of the numerical model used to make the simulations. Transforming the clay props, transforms the digital model and triggers the simulation of the rendering that is projected. At this level of metaphor, the user does not need to make an analogy. In his mind, the virtual system is the physical system: he manipulates an object and its environment changes in the desired way. At the other end of the metaphorical axis, users can use props to control the system, but these manipulations are not linked to any analogy with the real world. We will say that there is no metaphor (*none*). The possibility of offering metaphors to the user gives TUIs a real advantage over GUI, which are reduced to their traditional input devices (keyboard, mouse, joystick).

These notions metaphors of *verb* and *noun* show that TUIs offer the opportunity to develop affordant props. Affordance is the characteristic of an object to ‘naturally’ suggest to its user how to use it [18]. Affordant props allow intuitive and rich manipulations. Indeed, the manipulation of the props in the tangible system relies on the perception user has on his/her environment and the manipulation of the props also exploits the dexterity of the user. Thus, affordant props must, at the same time, enable a digital effect analogous to a real effect (metaphor of *verb*) and, through its physical design, must suggest to the user all the possibilities of action (for example a cup handle whose invites us to grasp it) (metaphor of *noun*).

In the context of workload reduction, the implementation of affordant props should allow the learning time of a new functionality to be reduced by offering the user an intuitive use. The reduction in learning time is important in view of the complexity of operator training. Intuitive use is naturally less costly in terms of cognitive resources, all the more so if this intuitiveness of the interface is also achieved through manipulation. The use of an affordant prop incites a necessary and sufficient action, best responding to a problem observed during a mission. This implicit incentive can support stimulus-response compatibility (presented later).

2.2 Manipulation and proprioception

On the specific point of data manipulation, tangible interfaces are also an interesting alternative to the GUI. In a graphical interface, the information is modified by the user using a keyboard and mouse, or with the finger, in the case of tactile interfaces. A tangible interface, on the other hand, proposes the use of a prop, as we have seen previously, capable of embodying digital data or control over this data. The notion of embodiment will be explored further in the following paragraph. The manipulation of tangible props offers the opportunity of a direct modification of the digital data, whereas the classic peripherals often require a series of operations that are not very intuitive and quite distant from the desired action. For Ishii *et al.* [16], tangible interfaces therefore have the ability to both transport digital information into the physical world and to modify it directly through the manipulation of props.

The manipulation of props instead of a mouse and keyboard is a central point in the process of reducing the cognitive load that runs through the research work presented here. Indeed, the manipulation of props solicits (almost by definition) the user’s sensorimotor system, whereas traditional interfaces systematically involve visual processing of information (which is known to be overloaded in the case of drone systems). The physical manipulation of props facilitates the user’s mental simulation of the action they wish to perform [23]. By simplifying the task through the use of props, the action becomes more precise, complete and intuitive than that elaborated through the manipulation of classical digital devices (mouse/keyboards).

The manipulation of tangible props allows the mobilization of ’proprioception’ for the user. Proprioception is the perception that a person has on the position of his or her body in space. It ensures balance, movement control and provides information on even the most discreet body activity (*e.g.* hand and finger movements). According to Ghez [12][page 846], proprioception is also a projective mechanism that ‘updates an internal representation, or model of the mechanical properties of the limb that is used to specify both the general kinematics plan and the adjustment that are necessary to adapt this plan for movements in different directions’. At the same line, Berthoz [4] defends the hypothesis of a cognitive system which acts as a biological anticipator and makes predictions about future events. For this author, the anticipatory nature of the cognitive system is based on recent experiments combining motor and sensory signals (or representing the appropriate procedure for adjusting a gesture or achieving a goal). Finally, information about limb position is not consciously processed since an individual does not need to devote controlled activity to tasks such as postural maintenance or joint stability [2].

Work linking proprioception and tangible user interfaces for cockpits has already been proposed [1, 6, 17, 26]. Although touch screens have many advantages (direct interaction with digital information, flexibility, *etc.*), they have one major disadvantage: they provide mainly visual feedback[4]. This required precise and sustained visual attention from the user during use. In order to overcome this, the authors propose to make a part of the screen ‘physically prominent’. This prominence serves both to highlight information and to provide access to a physical element on a digital screen. This prominence of the screen makes it possible to dispense with visual contact by bringing the user’s proprioceptive capacities into play. By freeing up eye contact, this type of interface reduces the user’s workload.

To conclude, unlike the keyboard/mouse combination for which manipulation and representation are in two dimensions, tangible interfaces offer the user manipulation and perception in three dimensions. These characteristics are in line with the natural capacities of the human being (touch, depth perception) and allow an embodiment (see next paragraph) of the digital data that is very meaningful for the user. The development of interfaces dedicated to the control of a UAV system integrates all the functionalities inherent to tangible interfaces (*i.e.* sensorimotor processing, direct data manipulation and facilitated 3D representation) and will significantly reduce the workload of operators.

2.3 Embodiment axis

In a tangible interface, digital information and/or control over that information is embodied in a physical prop. Fishkin [9] suggests a categorization of the ‘cognitive distance’ between the input and output of the tangible system. In this taxonomy, as embodiment increases, the ‘cognitive distance’ between the input mechanism and the output of that mechanism decreases. Fishkin [9] proposes four stages:

Distant: In a system where the embodiment is distant, the input and output are physically distant. The user’s attention and focus are constantly shifting from input to output. This is the case, for example, with a television remote control or a screen system with a keyboard.

Environmental: With an environmental embodiment, the output surrounds the user and remains linked to the input. Fishkin [9] uses the example of a sound mixer where the user perceives the adjustments he makes directly around him.

Nearby: In a system where the embodiment is nearby, the user perceives the output while simultaneously acting on the input of a system so the cognitive distance is low. Fishkin [9] takes the example, which is not a TUI, of seat controls where the user feels the changes they make directly. In the area of tangible interfaces, Ryokai’s [22] I/O Brush system is an example of a close embodiment. In this system, the user selects colors from digital ink in the physical world with a brush and applies them directly to their virtual canvas. The application of the color to the canvas is a close embodiment, as the user directly perceives the effect of the brush. See Figure 3.

Complete: In the case of a complete embodiment, the input system is also the output system. In other words, a complete embodiment allows the information to be perceived and acted upon through the same props. In a system with full embodiment, the cognitive distance is zero.

In order to reduce the workload, it seems worthwhile to avoid the distant embodiment that forces one to focus on input and output separately. Indeed, reducing the cognitive distance can lighten the workload by reducing the time of the action/perception process. In the context of UAV cockpits, the use of a close and/or environmental embodiment seems most appropriate as a full embodiment merging input and output does not seem a priori feasible.

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[4] For most of them, despite the innovations proposed by Apple on the Iphone 13

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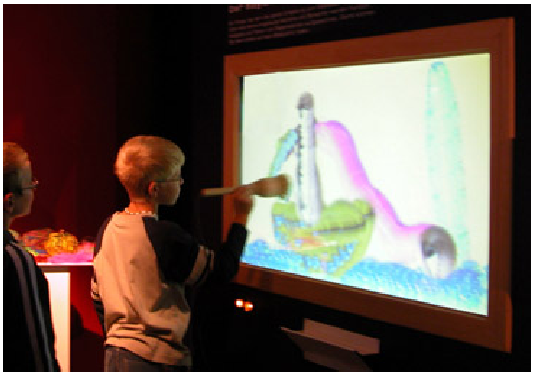

Figure 3: I/ O Brush [22]. In this tangible interface, the user applies paint to a screen with a physical brush that can 'catch' color in the real world.

2.4 Use of the peripheral vision

As mentioned above, one of the characteristics of tangible interfaces is the embodiment of digital data. In the case of shape-changing tangible interfaces (3rd feedback loop implemented in Figure 2) this embodiment allows, on the one hand, a meaningful display of digital data and, on the other hand, to account for the evolution of digital data. Thus, a shape-changing tangible interface presents a physical embodiment of digital information in three dimensions, and its evolution over time. The figurative power of a tangible interface makes it possible to access the meaning of the digital data through the user's peripheral vision. This is not the case if the representation is provided only by a graphic interface through a screen. Peripheral vision is the external part of human vision that is distinguished from the central vision provided by the fovea. The second one provides the visual system with a detailed image through the eye fixations and allows the cognitive system to recognize precisely the processed information. As its name indicates, peripheral vision is dedicated to the processing of elements located in the periphery of the visual field. Contrary to central vision, peripheral vision does not allow precise recognition of perceived elements, it distinguishes more than it sees. However, peripheral vision detects movements and changes of state very quickly, even in the dark (scotopic vision). Peripheral vision therefore gives a general impression of a visual situation as quickly as possible and allows foveal vision for a more detailed and slower analysis. It should be noted here that peripheral vision covers more than 99% of the field of vision, whereas it only requires 50% of the visual cortex.

For that reason, it would be very interesting to carry out a detailed analysis of digital data within a ground station of a UAV system that does not need to be processed very precisely and regularly. The idea here is to relieve the operators of central visual processing in favor of peripheral processing of certain digital data. This would involve embodying digital data that requires *ad hoc* monitoring, to report, for example, on the exceeding of operational limits set upstream. The rapid variation of the fuel level of the vector, in case of damage, is a 'good candidate' for the embodiment. Another example is the management of the chain of command, which is information shared by all drone operators common time management among others. A tangible shape-changing interface dedicated to this information should capture the pilot's visual attention as soon as possible and allow him to react as quickly as possible. Furthermore, the benefits in terms of visual and cognitive costs of the embodiment of a digital data shared between two operators, *e.g.* the remote pilot and the sensor operator, also deserve to be precisely evaluated.

This first part of the tangible has shown the role that TUI could play when it comes to exploiting the proprioceptive capacities of users and more precisely of UAV pilots.

3. Embodied Cognition

Embodied cognition is a movement of ideas that has developed in opposition to traditional cognitivism. This movement, which is a minority today, opposes the analogy between the functioning of the human brain and that of a computer, the founding comparison of cognitivism. The crux of the disagreement between cognitivism and embodied cognition lies in the format in which knowledge is represented. According to embodied cognition, the mind cannot be reduced to the amodal processing of symbolic information. On the contrary, cognition would be rooted in sensory and motor systems. Cognition would therefore no longer be abstract and amodal, but rather essentially sensorimotor. To summarize, embodied cognition considers that the mind must be understood in the context of its body (the 'sensorimotor context'), and of its interaction with the environment [3]. Therefore, human knowledge should be sensorimotor in nature.

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If the cognitive system is by essence sensorimotor, then the spatial representations, elaborated by the human brain to guide action, must also integrate sensory and motor information. It should be noted here that the notion of 'spatial representation' refers to the way in which an individual represents the elements of an environment as well as their absolute and relative positions. According to the theoretical principles of embodied cognition, a spatial representation is constructed from two sources, an external source, perception, and an internal source, memory. The idea being that if the information at the source of spatial representations is embodied (in the sense that it is rooted in the body), then it is reasonable to think that spatial representations are also embodied [7].

3.1 Perception structure space as a function of possible actions

Phillips & Ward [19] argues that humans perceive the world in the form of affordances, *i.e.* that the environment incorporates cues that univocally suggest actions to humans. This hypothesis assumes the existence of a rapid and systematic link between perception and action that optimizes the guidance of action in the environment. In other words, affordances are visual cues that incorporate information about action possibilities in the environment and are automatically 'caught' by the human sensorimotor system. For example, the handle of a cup placed near an individual is an affordance, because it calls for the grasping of the cup. Note that if this cup is outside the individual's zone of possible action, the motor cortex of the person does not activate. The possibility of action is therefore the boundary between peripersonal space (where action is possible directly) and extrapersonal space (where action is possible as a result of movement). For Coello and Bartolo [5] the organization of the space of perception into two distinct zones depending on whether action is possible directly (peripersonal space) or after a displacement (extrapersonal) supports the idea of a functional link between perception and possible actions. To summarize and in accordance with an embodied vision of cognition, perception would have the function of guiding action.

The paradigm of stimulus-response compatibility [10, 11] has for long suggested the existence of a functional link between perception and action. The authors have shown that the response time to pick up an object is proportional to the number of actions it takes for the position of the object to be compatible with that of the hand that is going to pick it up (see Figure 4). Therefore, for embodied cognition, perception does not only have a passive role of representing information from the environment (as argued by the supporters of a radical traditional cognitivism), but perception guides action through the processing of affordances. In other words, perception structures space according to possible actions.

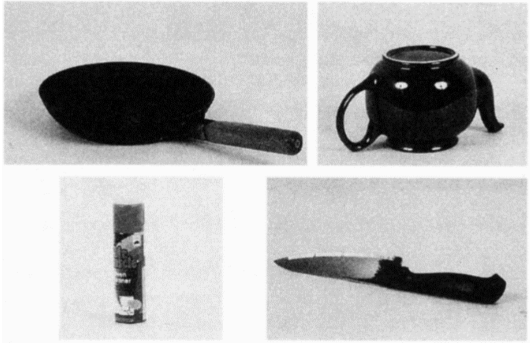

Figure 4: In this series of experiments, subjects were asked to determine the hand they would use to pick up the object based on the image presented [24]

While graphical user interfaces rely less or none on the sensory-motor abilities of operators, tangible user interfaces by their physical existence allow for a more intuitive integration of the digital world into the users' environment. In other words, the 'tangibility' of the props makes it possible to provide affordances that will be perceptible by the sensorimotor system. The fact that the props can be manipulated makes it easier to use the user's proprioceptive abilities, which is impossible with graphical interfaces.

In addition, tangible user interfaces contain a subcategory called 'shape-changing tangible interface'. A shape-changing tangible interface deforms and evolves according to the values taken by the digital data it embodies. Unlike a graphical interface placed in the visual field of an operator, the physical existence of the props of a tangible interface allows for the rapid activation of users' sensorimotor abilities [21]. Perceiving the physical evolution of an object (in the case of shape-changing TUI) without dedicating high attentional resources is a major advantage of TUI over GUI. It is possible to imagine an interface for which the monitoring of data (and its evolution) does not involve its precise identification. With TUI, it is sufficient to place in the operator's peripersonal space (and in his peripheral vision, see point 2.4 of this article), an evolutive prop which represents the variation of the data. Thus the reaching of a critical

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threshold, embodied by a physical evolution of the props, will become an affordance indicating to the operator that action must be taken as a matter of priority, even urgently. In the specific case of UAV cockpits, the integration of a tangible user interface would therefore allow a better perception of the digital data and their variations throughout a mission (however long it might be). The implementation, for example, of a shape-shifting interface embodying a data item that needs to be monitored (such as altitude, remaining fuel or consumption) would allow operators to quickly and without effort represent the state of the system.

In summary, unlike graphical interfaces, which are overloaded with digital information that requires costly 'translation' to move from a symbol to action, a tangible interface presents digital data in the form of manipulable and affordant objects to optimize processing. In other words, tangible interfaces modify the nature of the information to be processed so that it 'matches' the sensorimotor nature of the knowledge stored in the operators' memory.

3.2 The sensorimotor nature of procedural memory

According to the principles of embodied cognition, perception encodes environmental information according to the possibilities of action, *i.e.* according to the different senses and motor actions solicited by the environment (sometimes in the form of affordances). Considering that perception is based on the sensorimotor system, it seems logical that memory is also based on the sensorimotor system, since one of its functions is to store the information provided by perception (*i.e.* sensorimotor information). It is the procedural memory (a subdivision of human memory) which groups together the perceptual, motor and cognitive representations stored in long-term memory and likely to be processed in working memory. These are dynamic representations that allow the acquisition and realization of various sensorimotor skills. Access to this memory is automatic (particularly in the presence of affordances).

The principle of encoding specificity [25] explains that memory is more efficient when the same information is present during encoding and retrieval. This is demonstrated in the experiment by Godden and Baddeley [14]. In this experiment, participants had to memorize a list of words either underwater or on land, depending on the experimental condition. Afterwards, they were asked to recall them either in the environment in which they memorized them or in the other. The results show that the lists were best recalled when the recall environment matched the memorization environment. Similarly, a study by Engelkamp [8] shows that subjects who learns a list of action sentences perform better on a recall task when they are required to mime the words rather than after simply listening to them. Taken together, the results of these two experiments show that the sensorimotor system plays a central role, both in the encoding of information and its environment and in the storage of memorized information and its recall. For Barsalou [3], there is a sensorimotor reactivation during memory reactivation.

According to Tucker and Ellis [24], the perception of an object that has already been manipulated reactivates the possibilities of actions performed on that object. When an object is perceived, direct processing is done. This direct processing (called *on-line* processing) is an immediate perception of the possibilities of action in the environment as it is presented to the observer. This perceptual process is supported by a 'deferred' process (called *off-line* processing) which is of a mnemonic nature. The observer's prior sensorimotor knowledge is activated to refine action possibilities, not on the basis of environmental information but on the basis of the observer's prior sensorimotor experiences. In other words, *off-line* processing is a sensorimotor reactivation of previous experiences with the perceived object. Glenberg [13] considers that affordances are not only perceptible information in the environment through possible actions, but that they are complemented by the observer's prior knowledge of the object's functions or experiences with the object.

Since the vast majority of GUIs present only symbolic, 2D visual information on screens, their processing only calls upon the visual memory and semantic memory (for memorizing meaning) of the operator. In other words, GUI cannot call upon the operator's sensorimotor capacities, nor his procedural memory (place of expert knowledge), and they cannot generate affordances which would guide the operator's action.

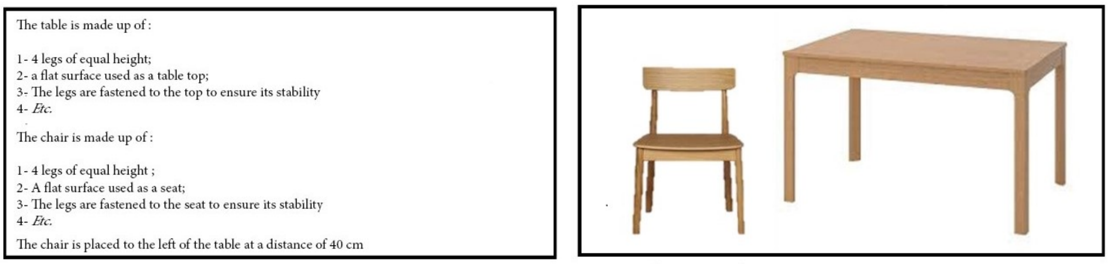
In the very restrictive case of remote control of a UAV system, the human/machine interactions inherent in GUI are totally inadequate to the sensorimotor capacities of the operators, capacities which are nevertheless central to the elaboration of a spatial representation of the remote situation. With TUI, a tangible prop allows the operator to use his perceptive, cognitive and memory capacities. TUIs offer the operator richer memorization possibilities (because they are rooted in sensorimotor capacities) than graphic interfaces. The sensorimotor nature of tangible interfaces *de facto* reduces the place of the visual in the panorama of UAV operators, the latter putting their hitherto neglected sensorimotor system to greater use.

3.3 Spatial representations are rooted in sensorimotor processes

A spatial representation is a mental representation that an individual makes of a concrete situation (*i.e.* not of language) in the absence of this external stimulation (*i.e.* without direct perceptual processing being possible). A spatial representation integrates mental imagery in a dynamic, evolving form and can, in some cases, account for the actions to be performed in the represented situation. The main components of a spatial representation are the visuo-spatial and sensorimotor knowledge stored in memory (the *off-line* process as described in the previous section). If the situation to be represented has already been experienced (the same or a similar situation) then the spatial representation should be faithful and accurate. In the case of a new situation, the spatial representation can also be constructed on the basis of sensorimotor environmental information (*on-line process*). The richer the two sources necessary for the elaboration of a spatial representation, namely memory and perception, are in terms of knowledge and/or sensorimotor information, the more efficient the spatial representation will be.

A spatial representation would also have the purpose of guiding action, and would be constructed, first of all, from perception, which would extract affordances from the environment. These affordances extracted from *on-line* information would be completed by affordances stored in memory related to the knowledge of the function of objects in the environment, and to the memory of the former interactions of the organism with this environment. The format of these spatial representations would be sensorimotor, not only because they originate in perception, but also because the memory serving as their sources would also be anchored in the sensory and motor systems (cf. figure 5). From this point of view, a spatial representation can be seen as a sensorimotor simulation of the environment it represents [7]. According to the embodied approach to cognition, the sensorimotor nature of spatial representations is fundamental, because in order for them to guide action, they need to retain sensorimotor information crucial for action, such as distances, object shapes, texture, *etc.* [7]. Research on spatial models has shown that a spatial representation can incorporate information about the physical properties of an object as well as the distance to another (see Zwaan & Radvansky [27] for a review), which supports the conception of a spatial model as a sensorimotor simulation. Taken together, these results suggest that spatial representations are not completely separate from the sensorimotor system and free from the perceptual system, but are rooted in past experiences (visual, motor, vestibular, proprioceptive, *etc.*).

Perceived scene



The table is made up of :

1- 4 legs of equal height;
2- a flat surface used as a table top;
3- The legs are fastened to the top to ensure its stability
4- *Etc.*

The chair is made up of :

1- 4 legs of equal height ;
2- A flat surface used as a seat;
3- The legs are fastened to the seat to ensure its stability
4- *Etc.*

The chair is placed to the left of the table at a distance of 40 cm

Amodal propositional representation

Analogical mental representation

Figure 5: According to the currents of cognition, a scene can be represented in the form of amodal propositions or in an analogical form that respects the position, size, appearance of the stimuli of the perceived scene. In the latter case, the analogical mental representation can also include action possibilities such as sitting on the chair or table, pulling the chair, *etc.*

The notion of spatial representation is also central to the development of a TUI. In fact, TUIs allow the creation of a richer sensorimotor memory than GUIs. The manipulation possibilities (see Chapter 1) offered by TUIs to users embed their experiences of use in their sensorimotor systems. During the first manipulation of a tangible interface, the spatial representation will be built on the on-line information that it will provide to the user. Following the manipulations of the props, the operator will acquire an experience which will enrich the off-line information concerning the manipulation of the latter. The physical existence of the props will embed its off-line information in the sensorimotor process much more than a graphical interface (which is limited to the visual) could do. In addition, the use of metaphor in the design of a prop will allow the off-line information to be called up more quickly. For example, the operation of a prop such as the I/O Brush (see Figure 3), which is reminiscent of a paintbrush, will be quickly (if not directly) understood by the user. Following this first manipulation, the user will explore the possibilities of the props and enrich its

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representation (he will discover, for example, that it can capture the colors from the real world). A graphical interface doing the same actions is more difficult to grasp and the first use will probably be laborious because the user will have no (or little) off-line information allowing him to quickly understand the operation.

In the context of UAV controls, current graphical user interfaces have been designed to provide as much information as possible to operators. As their experiences have not been taken into account, it is sometimes difficult for them to understand how the system works. By integrating into the interface a prop that takes into account the fact that most operators are former pilots, it is possible to improve their ability to understand the system and its operation. Thus, by improving the way in which the information is understood and manipulated by the operators, the difficulties linked to the interface are reduced, allowing them to concentrate more on the operational elements (mission objectives, state of the drone, communication, *etc.*).

3.4 Conclusion

TUI has been developed mostly in rather playful or even artistic fields of application. The central idea presented here, which consists in adapting the fundamental principles of TUI to the problems inherent in the remote control of UAV systems, is a real challenge. Spatial representation, as defined in the embodied approach to cognition, is the key concept that will enable this challenge to be met. We defend the hypothesis that the association of concrete proposals from TUI with theoretical concepts of embodied cognition will eventually lead to the development of innovative tangible interfaces that will constitute the elements of a real paradigmatic break with GUIs.

If GUIs have for them the ‘universalism’ of their use (since they recycle the peripherals – mouse, keyboard, joystick – of office automation), these interfaces only exploit the visual mode of the operator and his computational capacities, which are known to be weak and unreliable (as is the case for any individual). TUI’s offer operators to manipulate tangible objects that embody incoming or outgoing digital data. By soliciting the sensorimotor capacities of the users, TUIs promote a kind of ‘alignment’ between the affordances of the TUI (*i.e.* of its props) and those of the knowledge stored in the memory of the operators. This alignment will contribute to the elaboration of a more precise and functional (*i.e.* action-oriented) spatial representation in the operator’s mind.

In the case of UAV operators, this alignment should allow a significant reduction in their workload by drawing more on their sensorimotor capacities than on their purely cognitive resources. Finally, favoring action over calculation will undoubtedly reduce the level of human error involved in controlling a system that flies thousands of kilometers from its operator.

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