The Aircraft of the Future: Towards the Tangible Cockpit

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ABSTRACT

The future of the cockpit is undeniably tactile. To make this vision become a reality, several usability issues must be first addressed, being the most important one the eyes-free interaction. In fact, different ways of interaction (tactile, physical) will coexist, and it is paramount to identify those elements in the cockpit that can become tactile and those that must remain as *tangible* (*i.e.* physical) ones. This work intends to analyze the current situation and the requirements from the point of view of Human-Machine Interaction. In this regard, we propose a new approach that, leading to the concept of "tangibilisation of the cockpit", can facilitate the coexistence between tactile and physical actuators in the cockpit. We believe that this approach will foster and inspire the development of a tangible cockpit in the near future.

Keywords

Aircraft, Cockpit, Tangible, Tactile, Human Centered Design.

Categories and Subject Descriptors

H.5.m. [**Information Interfaces and Presentation (e.g. HCI)**]: H.5.2 User Interfaces - Input devices and strategies.

1. INTRODUCTION

The introduction of new equipment in aircraft's cockpits such as Head-Up Displays (HUD) or the Electronic Flight Bag (EFB) entails a growing complexity and demands a high degree of interaction by the crew members. State-of-the-art interactive technologies such as the Cursor Control Device (CCD) and tactile screens are becoming commonplace in the latest cockpit generations. At the same time, newer means of interaction have found their way among the general public, with remarkable examples such as tactile surfaces, gesture interaction, voice recognition, and sight or position detection. These provide more and more natural and efficient ways of interacting with electronic systems. Hence, if the cockpit is completely physical in 2015, future dematerialisation of aircraft panels allows us to foresee a more interactive, full-tactile cockpit in the dawn of 2035. During this transition period different ways of interaction must coexist, which leads to several questions: which functions will become tactile first? What actuators should imperatively become tangible or, at least, be kept as physical ones (see Figure 1)?

Figure 1: Cockpit's evolution context.

In this context, the objective of this article is *to identify criteria and properties within the cockpit's user interfaces that can facilitate the coexistence between its tactile and physical actuators*. We will use the loose term "*tangible cockpit*" throughout this article to refer to any device or technology able to provide a sense of "*touch*" to the information received from or provided to the cockpit. To this purpose, we will utilize the concept of physicality-based interactions, which can be defined as those that "*extend feedback beyond the visual, thus emulating the experiences gained through our interaction with the world via our non-visual senses and control capabilities such as gesture, speech and touch*" [32]. By adding a semantic dimension to the physical object depending on its *affordance* –or action possibilities provided to the actor by the environment [40] –, we address another research area, the Tangible User Interaction, defined by Iroshii Ishii in 1997, which goes a step further by "*giving physical form to digital information*" [19]. Finally, Organic User Interfaces refer to "*user interfaces with non-planar displays that may actively or passively change shape via analog physical inputs*" [38].

The rest of the article is organized as follows: we will first start by justifying the need for a tangibilisation of the cockpit. Next, the main elements on a generic aircraft's cockpit will be presented in order to henceforth provide a common vocabulary. We will then turn to present and describe a novel vision, strongly founded on Ishii's principles, that can contribute to make the tangibilisation of the cockpit a reality in the next twenty years. We will propose criteria and properties to provide a framework for cockpit design, creativity and design thinking. In addition, we will present a brief survey of the literature in order to show the current research in the aforementioned domains that, to our knowledge, can be applied to the tangibilisation of the cockpit. Finally, we will draw several conclusions and point out future trends in the field.

2. MOTIVATION

Tactile technologies have become ubiquitous in the last five years. By and large, we are witnessing a paradigm shift where typical physical controls are being replaced by touch-enabled surfaces on

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numerous devices of common use. We find touchscreens in a daily basis in cash machines and ticket-selling points at streets, in mobile phones, or in home appliances such as washing machines or microwaves, to cite some.

The aeronautical industry is not oblivious to this tendency, and avionics manufacturers have been experimenting with prototypes of touchscreen-based cockpits. Two main foreseeable benefits arise from the adoption of this technology: Firstly, manufacturers are addressing pilots that are still 5-year-old children. This means that they will grow up accustomed to the use of touchscreens and many other types of tactile devices, and hence this type of interaction will be intuitive and efficient for them. Secondly, the multi-purpose nature and flexibility of a full software-based system will reduce both capital and operational expenditures, allowing for shorter development-and-testing periods of newer cockpit generations.

Of course, an interactive cockpit based on a continuous tactile surface presents several potential usability problems that must be addressed. Examples are the need for a good visual perception of the on-screen objects, a proper response to fine-motor skills, or hand comfort and palm detection on the touchscreen. There exist also important issues regarding the situational awareness and performance under degraded conditions that could cause instability in a plane such as turbulences, smoke in the cabin, etc. These drawbacks have limited, for a long time, the adoption of tactile surfaces in the cockpit and, hence, have led to an understandable resistance from the aircrew to remove critical controls from their physical form. However, recent studies indicate a clear performance advantage of touch systems accompanied by less workload when compared to, for example, trackball interaction [16]. In the context of the ODICIS project, Alapetite et al. [9] carried out an experimental evaluation of a user interface concept to compensate for the loss of tactile feedback in touchscreen-based panels. They proposed a "deported view" strategy in which a user manipulated a lower-positioned multi-touch panel and, then, a visual front-view feedback with a copy of the peripheral panel was provided. Their results showed that this strategy attracted greater preference and was more efficient than a trackball or head-down interactions, although it was slower to operate than a touchscreen directly on a front panel. Some additional tests [11] have proved that the use of touchscreens in the cabin is not incompatible with degraded flight conditions, and this has leveraged the design of newer prototypes for tactile cockpits.

So, while it is accepted that some issues exist, the idea of a tactile cockpit is to be kept at the expense of addressing their limitations. This is the reason why newer ways of interaction must be envisioned, and the idea of mixing the digital and the physical world leads us to the concept of a tangible cockpit. Consequently, a first step in this process it to carry out an exploratory work to study the projects, technologies and actors that can contribute to this process of "tangibilization", since there is a clear need for reorganizing the current literature to obtain a clear picture of the state of the art.

To our knowledge, this is the first work of its class. The closest article is that of Letondal et al. [23]. In it, authors explored how advanced interaction techniques (tangible, haptic, organic, etc.) could better support pilot flying and navigation activity. They postulated several general requirements for interactive instruments in the cockpit and, based on them, they drew a set of design principles that were translated as dimensions: shape, embodied perception and action, and programmability. There is a point of convergence with our work as we both acknowledge the existence of similar cognitive requirements in current cockpits (performance in a degraded context, situation awareness, etc.). However, whereas they review several technologies and projects that comply with the requirements that they proposed, our work's starting point is the actual existence of a tactile cockpit and how to deal with the potential problems that might prevent its adoption. To do so, our objective will consist in adding a *tangible* dimension to the tactile cockpit, always following the concept of Organic User Interfaces proposed by Ishii.

3. THE COCKPIT

A study about the tangibilisation of the cockpit requires a preliminary identification of the actual elements that can be found on a plane's cockpit. There exist some standards in the aeronautical industry regarding Human Factors for embedded systems in the cockpit (CS25-1302, RP-5056). However, it is not possible hitherto to find a standard that determines the devices to integrate in the cockpit or their distribution. Indeed, the function and number of instruments will differ depending on factors such as the type of plane (passenger, cargo, military...), complexity of the aircraft or manufacturer preferences, to cite some. We will not focus therefore on particular switches, displays or gauges, but rather on families of instruments which provide a specific functionality in a generic cockpit.

3.1 Instruments

Five main categories of instruments are present on any modern cockpit [1, 15, 8, 2, 18]:

3.1.1 Flight instruments (FLY):

Used to control the aircraft's flight. These comprise mainly the altimeter, airspeed indicator, magnetic direction indicator, artificial horizon, turn coordinator and vertical speed indicator. In modern aircraft they are grouped into the *Primary Flight Display* (PFD). Related control devices are the Flight Control Unit (FCU) for automatic guidance, the throttle to control the power level and a side-stick or a yoke to guide the plane.

3.1.2 Navigation instruments (NAV):

Which provide location information to guide the aircraft, such as a compass or a GPS-based location system. These elements are grouped into the Electronic Flight Instrument System (EFIS) control panel, the *Navigation Display* (ND) and the *Flight Management System* (FMS). The EFIS controls the information related to lateral navigation of the aircraft shown into the ND. The FMS is a master computer system that has control over all other systems, computerized and otherwise. It coordinates the adjustment of flight, engine and airframe parameters. Its main component is the *Flight Management Computer* (FMC), which communicates with the pilots either via a *Control Display Unit* (CDU) or a more modern KCCU (*Keyboard and Cursor Control Unit*).

3.1.3 Communication systems (COM):

They permit communication with the air traffic control. Concerned devices are the *Voice Comm* pilots interface and the *DataLink* interface.

3.1.4 Systems Management (SYS):

For system supervision and operating parameters of the aircraft's engine, such as temperature, pressure, fuel and oil. Those systems are typically materialised into the Overhead Panel and the Checklist & KCCU.

3.1.5 Mission Management (MIS):

Such as passengers and crew management. In this case, pilots interact with the *Onboard System Information* panel and the *Flight Ops* applications.

Figure 2: Types of cockpit. Left: Concorde's analog cockpit; Center: glass cockpit in the A320; Right: interactive cockpit in the A380.

3.2 Evolution of Cockpit Manufacturing

Looking at the current evolution of the cockpit in the last sixty years, we observe how manufacturers have gravitated towards grouping the maximum number of related functions into a common display, as well as increased the number of functions and information available to pilots. Three categories or types of cockpits can therefore be identified [39] (see Figure 2):

3.2.1 Steam or analogue cockpit

Most of instruments and, in particular, flight instruments, are mechanical and analogue, typically operated by air pressure and the use of gyroscopes without the need of any electrical system. There is little or no functional aggregation, having one instrument per function. This typically results in a cognitive overload for the pilots, who must keep a continuous situational awareness. Representative examples are the Concorde or the Douglas DC7.

3.2.2 Glass cockpit

Glass refers to the use of solid-state, flat-panel display screens in cockpit instrumentation. In these screens, computer-produced images have replaced individual mechanical gauges, and multi-function displays show flight information as needed. This simplifies aircraft operation and navigation, as well as cognitive load [41]. The most paradigmatic example is the Airbus A320 family. This aircraft introduced another technology that concerns our study as well: the digital *fly-by-wire* (FBW) flight control system, in which the movements of flight controls are converted to digital signals, and flight control computers determine how to move the actuators at each control surface to provide the ordered response [12].

Currently, the adoption of newer technologies such as *Synthetic Vision Systems* allows display screens to provide the pilot with computer-generated information (such as terrain representation, traffic, weather forecast, etc.) to improve its situational awareness.

3.2.3 Interactive cockpit

Interactive cockpits go a step further to traditional glass cockpits and provide WIMP (*Windows, Icons, Menus, Pointers*) interactive displays that look and behave similarly to other computers, with windows and data manipulated with point-and-click devices. Successful examples are the KCCUs integrated in the Airbus A380 family. In this case, displays have different widgets, tabs and labels to group related functions in windows that will be displayed according to the context or the requests from the KCCUs.

In order to bridge the gap between pilots and systems and help them handle complexity, the adoption of 3D, tactile and speech-recognition technologies is being assessed. For example, Honeywell Aviation is performing tests to evaluate the feasibility of using tablets with voice recognition as a substitute of the physical FMC in their aircraft [4]. Thales Avionics, in the frame of the SESAR initiative to overhaul the European airspace and its air traffic management [5], has developed a demonstrator of a Continuous Tactile Surface for the EU FP7 Project ODICIS [11, 43] as well as *Avionics 2020*, a multi-screen, tactile cockpit [7]. Eichinger and Kellerer performed a set of tests on pilots to determine that interaction through touchscreens is faster than trackball interaction for any task, and with a lower workload for most conditions [16]. In fact, some of these interactive technologies can be currently found in US aircrafts, such as the use of iPads as a means of having Electronic Flight Bags to perform mission-management, non-critical tasks [36].

4. TOWARDS THE TANGIBLE COCKPIT

As described in the section "Motivation", despite numerous advantages supported by the tactile technology, a full-tactile cockpit is not yet an optimal solution. This is the reason why a process of tangibilisation of the cockpit is deemed necessary, aimed at adding a *tangible* dimension to a tactile screen.

We have envisioned the process of tangibilisation of the cockpit as the ultimate implementation of an Organic User Interface, following Hiroshi Ishii's three-statement definition [38]:

S1 *Input equals output*: The display is also the input device. Applied to a cockpit, it means that the same continuous surface that provides information to the pilots will be used to introduce commands and control the aircraft.

S2 *Function equals Form*: The shape of the display equals its function. Applied to the cockpit, it means that the shapes of its devices afford their function.

S3 *Form follows flow*: The display can take different shapes. In our context it means that, triggered by events like the context or the flight stage, sections of the cockpit will be capable of showing up or modifying their shape to adapt accordingly.

In other words, we envision a cockpit that conveys information in a much more advanced and richer way than traditional systems, which are limited to showing information on a screen and receiving input from buttons or handles. So, based on these statements, we have adopted a set of well-known usability properties in the aeronautical and HMI world and we have reformulated them in the light of the previous definition. We consider those as essential properties that a pilot should find in such a futuristic cockpit:

P1 *Free form*. We suggest a cockpit built as a continuous tactile surface in which there are not fixed elements attached to any zone.

P2 *Interactive*. The capabilities of the cockpit will allow for a rich interaction with the pilots. It will be capable of providing information all over its surface, receive commands and provide feedback as well, both in tactile and visual ways. This property reflects statement **S1**.

P3 *Morphable*. The cockpit's surface can generate dynamically newer shapes. Not only will it be capable of being physically pressed and deformed to receive commands from the pilots, but also of actively create new shapes by itself for input or output purposes, as statement **S2** conveys.

P4 *Reconfigurable*. The type and number of physical elements, as well as their distribution in the cockpit, are not fixed and can be rearranged by the pilot or the system, at any time, in the same way as icons in a GUI can be rearranged on a computer's screen. This complies with Statement **S2**.

P5 *Context-aware*. Different parts of the cockpit will morph to provide the required controls according to the context, flight stage or as a response to a pilot's emotional state. That is, the system will be capable of withstanding variations of context of use while preserving usability, property known as *Plasticity* [37], which adheres to Statement **S3**.

P6 *Eyes-free*. The pilot will be provided with an environment in which s-he does not have to distract her visual attention (i.e. looking at her hands) while s-he is performing any manual action. In this context, the cockpit must convey accurate learning and representation of information, perhaps not necessarily the same way as a visual display does, but provided through physical contact.

Under the assumption of these properties, we will classify state-of-the-art technologies and projects according to what, in our expertise, will comprise the main elements of interaction in our vision of the future *tangible* cockpit. From our tangibilisation point of view, we must go beyond classical components and look for those technologies that take into account not only data input and output, but also feedback and shape-variation capabilities. However, it is not easy to set up a classification since the line between interaction domains is not well defined. Indeed, in how many ways can a user interact with a technology or a project? Most of interactions with an interface are performed through sight or touch[1] and may permit data input or information output. However, these properties are by no means exclusive to each other, so we cannot draw a clear line to classify them by, say, input/output or by sight/touch. For example, a screen can provide a visual output but, if it has also tactile and vibratory features, it will allow as well for touch input and haptic feedback.

Another constraint for a plausible classification is the degree of compliance of a technology with the statements from Ishii's definition. A given technology may adhere to one, two or three of the statements **S***. For instance, a typical flexible, non-tactile screen is able to change its shape but neither can change it depending on the context nor can receive input data. Therefore it will comply with statement **S2** but not with statements **S1** or **S3**.

As we stated at the beginning of this article, beyond the now classic property for manufacturers of the cockpits (Property **P1**), we argue that the cockpit of the future will allow for a reconfigurable physical surface (Property **P4/S2**) with visual and tactile interaction (Property **P2/S1**) in order to permit an eyes-free interaction (Property **P6**). And this will undeniably require the integration of materials capable of changing its shape and behavior under request (Property **P3/S2**) and which are context-aware (Property **P5/S3**). Our study then turns mostly into the analysis of Kinetic Organic Interfaces (KOIs). KOIs are organic user interfaces that employ physical kinetic motion and shape to embody and communicate information [29]. These motions can be perceived not only visually but also haptically, and will comply (partially or totally) with the aforementioned properties. Therefore, in the following section we will present several projects and promising technologies that can be applied as elements of actuation in dynamically reconfigurable physical controls and as elements of embodiment of actuation. All of them satisfied the Property **P6**.

5. DYNAMICALLY RECONFIGURABLE DEVICES

PICO [30] is an example of macro-scale kinetic physical control system. PICO uses an array of electromagnets embedded in a table to physically move pucks on a table top that work as input (when the user moves or adds new pucks) or output (when the pucks are moved by the system). One of their applications was computing locations of cell phone towers. Every time the layout of towers was recomputed, pucks physically moved to reflect the new configuration. An interesting point of PICO is that it keeps out of the system everything that it is not related to the physical position of the pucks. Considering this, such a project, related to Property **P4, P5**, could inspire a system in which a pilot places a puck on the cockpit in the region of the screen that shows the cockpit's digital airspeed indicator to, say, limit the maximum speed that the plane can reach. In fact, such a system would be nothing but a modern version of the "speed bugs" used in old steam cockpits [18].

An interesting system is Teslatouch, by Bau et al. [10]. They developed a technology that, based on the electrovibration principle, provides tactile feedback in touchscreens. Authors created a prototype of a tabletop surface in which electrovibration created a feeling of "rubbing" when a user slide a dry finger over the screen. Different frequencies simulated different textures such as wood, paper, etc. (see Figure 3). Another technique to modulate friction, but using electrostatic force, was done with the T-Pad [42]. It is not difficult to see how these technologies could be applied to current touchscreens in general –and also within a tactile free-form cockpit (Property **P1**)– in order to provide feedback (Property **P2**) or delimit areas when pushing and pulling controls.

In 2011, Coelho and Zigelbaum provided a survey of shape-changing materials that can leverage the construction of a new generation of tangible user interfaces [14]. For nine different materials, they specified the type of stimulus required to activate them (heat, magnetism, electricity, etc.), whether they kept their shape

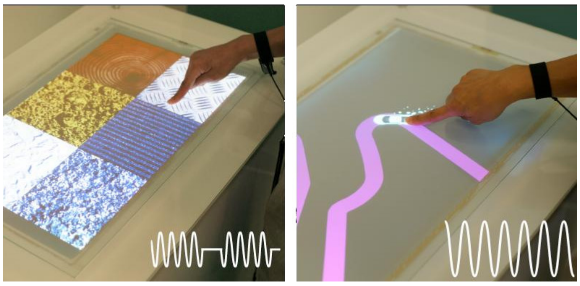

Figure 3: Tesla touch [10].

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[1] Although hearing is another sense used in UI, it is out of the "tangible" scope of this work.

after stimulus removal, the size of displacement, number of 'memory' states and force exerted. A list of ten relevant properties to be taken into account in the design of shape-changing objects is proposed, given that they will affect objects' behavior. Authors emphasize the whole range of possibilities of homeomorphic surfaces (those capable of transforming into one another when they are continuously stretched and deformed without cutting or joining distinct parts), and they envision a future where designers could create three-dimensional transformable surfaces by digitally drawing their initial and final states.

More recent and impressive developments have permitted the creation of electro-stimulable artificial muscles, or materials that can variate volume or shape according to an electrical stimulation. A main actor in the development of this technology is the LAAS Laboratory at Toulouse, who proposes the creation of polymer-based muscles by inkjet printing for polymer deposition [34]. Another work at LPPI Laboratory (Cergy, France) uses organic elements to create artificial muscles [31]. An advantage of the use of organic materials is that they can be easily merged with OLED-based photodetectors to develop organic tactile sensors that not only sense pressure or proximity, but can also provide haptic feedback by changing its shape. Still in an early stage of development, these promising techniques open the door for the creation of electrically-triggered reconfigurable physical controls (Property **P4**), such as buttons that can modify their shape (Property **P3**) as feedback to a user's input, or a surface able to adjust itself to a pilot's hand in order to provide a handle (Property **P5**).

Concerning the provision of an *"eyes-free"* environment for the cockpit (Property **P6**), it seemed natural to look at those technologies aimed at helping people with visual impairment. In this regard, authors in [27] review six types of devices capable of rendering tangible images, some of them concern our work: *Surface Haptic Displays*, such as those analyzed on [10, 42]; *Lateral Skin Displacement Displays*, which apply differential stretch to the surface off the skin within the contact patch [24]; *Vibrotactile Displays*, such as those embedded motors or piezoelectric transducers found on mobile telephones; *Force Displays*, such as the commercially available *PhanToM* [3]; *Bubble Displays*, an emerging technology in which small cavities beneath a flexible surface can be selectively inflated to create tangible surface features such as bumps and edges [33].

In line with these aforementioned solutions, there exist diverse technologies that, most of the times, have been aimed at creating small pins for Braille displays, either as the final objective or as an example of proof of concept. However, they can be aggregated to create more complex shapes. Factors to take into account in order to create tangible controls based on those technologies are the response time, pressure resistance, capacity of integration with sensors and required power, to cite some.

Another technology that can be used to efficiently create shapes similar to Braille pins are **magnetic actuators**. These systems are typically built using Microelectromechanical Systems (MEMS) to provide embedded coils which, when a current is applied, turn into an electromagnet that can push or pull a pin. Not only the force applied is quite strong in these systems, but also the response time is high. For example, Streque et al. [35] propose a Poly (DimethylSiloxane) (PDMS) elastomeric membrane, magnetically actuated by coil-magnet interaction, to create a flexible microactuator array with a resolution of 2 mm and a power consumption up to 100 mW per microactuator (see Figure 4).

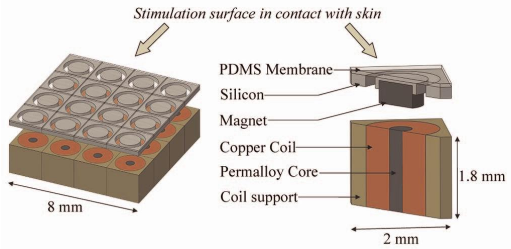

Figure 4: PDMS magnetically actuated [35].

Figure 5: Unimorph-based petal [17].

Another approach to provide shape-changing devices are **alloy-based systems**. By using a combination of metals with different thermoelectric characteristics, composites can create flexible shapes actuated by either environmental temperature changes or active heating. The most paradigmatic example in HMI is surely uniMorph [17], a technology for rapid digital fabrication of thin, reversible shape-changing interfaces. Using this technology, authors implemented several example prototypes, such as a flower lamp that blooms to reveal light (see Figure 5), a bookmark that detects darkness and curls up to provide light to the reader, post-it notes that curl up depending on their content, or an iPad cover that opens with different angles to indicate a message arrival.

The Tactus Intelligent SurfaceâĎć transforms tactile interfaces by shape shifting [6]. With this technology, buttons can appear on the surface when it is necessary and be gone when it is not. When the buttons are disabled, they recede into the screen, becoming invisible and leaving a seamless flat touch-screen with maximum viewing area. The application of such a shape-changing surface in a cockpit would definitely satisfy all properties from **P2** to **P6**.

Concerning the use of handheld devices for tangible interaction, Leigh et al. developed THAW (Tangible, Handheld, and Augmented Window) [22], a near-surface interaction system that allows a smartphone to be used as a UI when placed in front of a computer screen. Several use cases are proposed, such as a magic lens that shows hidden content on the phone screen when it is placed over a given region of a computer screen, or a clipboard to capture and transfer digital elements (images, text) between computer screens. Whereas it is difficult to see a direct application of this work for the tangibilisation of the cockpit, a niche might be found as a checklist application for the Electronic Flight Bag. In fact, we can think of a software that, by pointing a tablet's camera to any of the cockpit screens, it registers automatically the mission state and conforms a checklist before and after the flight in an automatic manner.

Lee et al. introduced AnnoScape [21], a remote collaboration system that allows users to add hand-drawn annotations as well as materials on the physical desktop in a shared 3D virtual workspace. Again, there is nothing new in the technology used, but a similar system could be used to interact with the Synthetic Vision System.

Figure 6: Ultrahaptics [13].

In fact, imagine an air traffic controller introducing new information in real-time for the pilot to have it displayed on its SVS. Or, otherwise, a pilot could sketch an obstacle seen only from its window but oblivious to the tower control so that this new information is available to everybody.

Lakatos et al. designed T(ether) [20], a spatially-aware display system for multi-user, collaborative object manipulation and animation of virtual 3D objects through a tablet. They introduced gestural interaction techniques that exploit proprioception to adapt the tablet's UI according to the hand's position above, behind or on the surface of the display. Applied to the cockpit, whereas mid-air interaction can affect precision and quality of interaction, it could be used to interact with the displays. Somehow similar to the previous project, SynchroLight by Ou et al. [28] proposes a remote pointing system to refer physical objects, via synthetic light, between members in a video conference.

Finaly, not at all tangible, but undoubtedly complementary to these technologies, *Ultrahaptics* [13, 25] is a very recent development that, by controlling the acoustic radiation force field, is able to produce volumetric haptic shapes in mid-air. That is, a user can feel the geometry of an interface and localize on a specific item (Figure 6). The authors argue that their technology can be integrated in a cockpit or a vehicle allowing the user to operate the system while their eyes are busy on another task.

6. DISCUSSION AND CONCLUDING REMARKS

The introduction of tactile and tangible interaction in the cockpit not only is a disruptive innovation but also it is changing the way pilots will interact with the aircraft. Factors such as the different "feeling" of the cockpit, postural comfort, perceived physical effort, task performance (accuracy, difficulty), etc., must be taken into account in future research, let alone the acceptability of this new paradigm by the pilots' community.

Along this work several questions and discussions arose, being the *proprioception vs reconfigurability* problem the most important one. Proprioception is the sense of the relative position of neighboring parts of the body and strength of effort being employed in movement. In our context, it concerns the pilot's awareness about the position of the instruments in the cockpit: If a pilot is aware that a given function is always in the same place, this knowledge will end up stored in her long-term memory, therefore decreasing the cognitive load when s-he needs to recall the position of such a function (automatic process [26]). In this sense, the proposal of a reconfigurable cockpit, in which the position of the instruments may change, could go to the detriment of the affordance and the operational efficiency, requiring a controlled process that is more costly from the cognitive point of view. In this regard, we can propose a breakthrough scenario to provide a solution to this situation: by considering that the pilot's hands always rest at the same place, it would be a task for the actuators for control command to select the position where to appear depending on the context of the situation.

In this work we have approached the process of tangibilisation of the cockpit, intended by the major aeronautical manufacturers, as a process based on the implementation of Organic User Interfaces. We have presented a novel vision and shown that it is fully compatible with Hiroshi Ishii's three-statement definition of Organic User Interface. Based on this definition we have proposed a set of 6 properties, from a usability point of view, that we would find in a "tangible" cockpit: *free-form*, *interactive*, *morphable*, *reconfigurable*, *context-aware* and *eyes-free*. Thereby, we envision a cockpit that, based on both existing and novel technologies, can convey information to the pilots by modifying their shape according to the context. And to do so, we have presented and discussed several technologies and projects that convey our vision.

As a conclusion, it is undeniable that the future of the cockpit is tangible. To achieve this goal, several known issues already identified, as well as others that will become apparent in the long term, must be addressed. This work has provided a first step in the search for projects, technologies and actors that can contribute to make the tangible cockpit a reality.

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