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A Two-Level Highlighting technique based on gaze direction to improve targets pointing and selection on a touch screen.

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Abstract In this paper, we present an approach to improve pointing methods and target selection on tactile human-machine interfaces. The proposed approach defines a two-level highlighting technique (TLH) based on the direction of gaze for target selection on HMIs on a touch screen. The technique is based on the orientation of the user's head to approximate the direction of his gaze and uses this data to preselect the potential targets to be selected by the user. An experimental system with a multimodal interface has been prototyped to assess the impact of TLH on target selection on a touch screen, to compare its performance with that of traditional methods (mouse and touch). We conducted an experiment to assess the effectiveness of our proposition in objective terms of the rate of selection errors made, the time for completion of the task. We also made a subjective estimate of ease of use, suitability for selection, confidence brought by the TLH, and contribution of TLH to improving the selection of targets. Statistical results have shown that the proposed TLH significantly reduces the selection error rate and the time to complete tasks. For the completion time, the TLH added to the touch (TLHT) using the direction of the gaze gave performances equal to those obtained using the TLH added to the mouse cursor (TLHM). Finally, participants found that TLH has significantly improved target selection methods and expressed the wish to be able to use it in the future.

Keywords target selection · multimodal interaction · highlighting · head orientation · gaze direction · pointing improvement

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1 Introduction

With technological advances in electronics in general and the screen industry in particular, more and more screens are being created, some always more advanced than the others and a good majority are tactile. Thus, we find more and more modern touch screens on peripherals of all kinds. However, although touch screens are becoming the central stage of interaction between users and systems, their operation with our fingers creates problems with finger occlusion and imprecision. The situation is worsening with the trend towards miniaturization of devices and enrichment of content. Also, as the software industry continues to grow, we have more and more complex software with a considerable number of user interface elements that can be selected, which pile up on screens of finite size and often very small. Pointing or selecting these objects on the screen becomes difficult as their number increases. Since pointing and selecting targets are fundamental and the most executed tasks in graphical user interfaces, improvements in the performance of these tasks can have a significant impact on their usability and the overall usability of the software [12]. So, improving the quality of Pointing is one of the major challenges in the area of HMI [5–11, 13, 14]. This challenge is even more heightened in the case of touch screens where additional problems such as occlusion arise during the tactile selection of objects. There too, numerous works [3, 4, 15] proposed by researchers testify the importance of the question of the selection of targets on touch screens.

The work presented here, which is located around this second issue, was carried out within the SOS-DM project, which objective is to develop means enabling the monitoring of the activity of a swarm marine drones supervision operator. Indeed, an operator in charge of coordinating a swarm of drones is required to perform many tasks and he risks forgetting some. In particular those of the tasks which require only observation, because he will be very busy with other tasks asking him for explicit actions (such as validations or assignments). SOS-DM therefore aims to help the operator in his drone surveillance tasks, to limit errors, prevent him from forgetting tasks, and allow him to go faster in each task to reduce his cognitive workload. To meet these objectives, the system to be set up must offer possibilities for better human-machine interaction, follow in real time the activity of an operator using an HMI (follow-up of his gestures, his gaze, etc.), connect the events occurring on the HMI to an operator's task model execution engine and offer good feedback.

The present work is devoted to the search for a solution for a better quality of the operator's interaction with his surveillance environment. As the screen at its disposal is tactile, this proposal is therefore situated in a context of tactile monitoring using large screens. We propose an interaction technique based on the direction of gaze obtained through the orientation of the head, to preselect moving targets on a touch screen. The targets thus preselected are highlighted by a visual effect, to facilitate their possible selection by the user.

In the next section, we will review the efforts made to improve human-machine interactions, by presenting the state of the art on multimodal inter-

faces for pointing and selection of targets on screen. The third section returns to our problem, the research questions that arise from it and our objectives. The fourth section deals with the proposed technique and the approach to its implementation, then describes the experimental system designed and presents its prototype. The experiment carried out with users to evaluate the performance of our proposal, as well as the results obtained from this experiment, are detailed in the fifth section. Section 6 discusses the relevance of the proposed technique, and section 7 ends with a conclusion and gives future directions for improving our work.

2 Related work

Technological advances (especially computers and other peripherals) in recent years offer opportunities for the development of multisensory systems requiring a large amount of data processing. As a new application area that is starting to thrive, advanced multimodal HMIs have been developed in recent years, particularly in the area of virtual reality and 3D environments. Also, their efficiency and usability continue to be improved. Work on multimodal HMIs can be divided into two classes [17]. The first is centered on the man: it considers the human body as a multimodal system and explores the UIs according to the applicable human movements, in particular facial expressions, human affections, the gesture of the head, the gesture of the body, the look, muscle movements, brain activities, etc. The other is application-centric: it focuses on applications that have been developed using multimodal interfaces, including web browsing, virtual reality interaction, robot-human interaction, rehabilitation, assisted devices for the disabled and elderly, etc. More and more works are proposed on the interactions with parts of the body other than the hands. In this section, we present some works on multimodal HMIs in general and on targeting and target selection techniques in particular.

2.1 multimodal human-machine interface

Many authors have addressed the issue of multimodality in UIs. We have done a survey on this and present some of the work below.

The works carried out by Zouinar et al. in [16], focused on the implementation of a device to observe and record data on the use of multimodal systems in mobility. This device collects data on user activity, system interaction and context. It consists of three collection modules: a system for taking a wide view of the context (view of the observation context), a system for taking a view of the user's visual field (subjective view) and a system for automatic capture of user actions on the system and its outputs (capture log). This work contributes to users' understanding of multimodal interfaces, and can therefore help to better design these interactions. However, the scenes are saved for later analysis. This is contrary to one of the objectives of our work, namely to use the data from cameras in real time as a support for an interaction modality.

In [19], Pastoor et al. proposed a multimedia system including a 3D multimodal display and an eye-controlled interaction. Eye tracking based on computer vision and head tracking are used in the user interface. The user can interact with the 3D display by simply looking at the object. The head tracker can recognize the movement of the head and open the view of a document that the user has seen. These works use the gaze to interact with the objects of the interface, which is a great contribution. However, eye tracking is done by fixed eye trackers, which can limit the size of the screens to be used and reduce the user's possibilities of movement. Likewise, one of our objectives is to rely on the gaze to improve the selection and not to use the gaze to select the targets.

NaviGaze proposed by R O'Grady et al. [20], is a non-intrusive head tracking system for cursor control, associated with blinking recognition to emulate the mouse click. This system makes it possible for a a user to continue using a standard mouse and keyboard in addition to the methods mentioned above. These works bring considerable evolution in multimodal interactions. In particular that of the problem of tracking the head which also interests us in our work. But contrary to this proposal, we do not want to replace the touchscreen or the mouse with the eye controls, but rather use the orientation of this gaze to improve the usability of the touchscreen and/or the mouse.

Masterpiece is a multimodal interface with gestural and voice control which was proposed by Moustakas et al.[21]. This interface can help the user to generate and manipulate simple 3D objects by interacting with a virtual 3D environment on a large screen. The user's pointing direction is estimated by tracking the position of the user's head and hands in 3D space using an image from a stereo camera, then projecting the head-hand axis followed on the screen. Masterpiece improves interaction through the interpretation of the combination of head and hand gestures. However, the head is not followed directly by tracking, but the analysis of an image taken by a camera. This can alter the response time and therefore produce less fluid movements.

A combination of hand gestures, voice, and head position has been used by Kolsch et al.[22] to operate a portable augmented reality system outdoors. The device worn on the head includes a computer vision module based on texture and color, making it possible to recognize hand gestures. They then conducted assessments that lead them to conclude that multimodal user interfaces can well meet the diverse requirements of demanding application interface input on a laptop interface. This work provides a solution to portable multimodality in the open air. This avoids the constraint that generally requires being in a room with a tracking device. On the other hand, contrary to the approach which consists to carrying a device on the head to analyze and interpret the hand gestures, it could be interesting to study the possibility of tracking these gestures.

The work of Land et al.[23] aims to find out whether the eye movements performed during the performance of a well learned task are essentially random, or are intimately linked to the requirements of the motor task. They offer a system consisting of two video cameras: the first, mounted on the head

and responsible for monitoring eye movements; the second, fixed in the room and responsible for recording the user's activities in said room. Thereafter the recordings are analyzed image by image. Their conclusion is that: The foveal direction was always close to the object to be manipulated and very few fixings were foreign to the activity concerned (the one being executed). The work carried out has a valuable interest in the study of eye movements when performing a task. However, they make video recordings for a posteriori analysis, which does not meet our expectations for this work.

In their work presented in [24], Hürst et al. have explored different interaction approaches based on the input of multimodal sensors and aimed at providing a richer, more complex and more engaging interaction experience. They presented new interaction metaphors for augmented reality on mobile (AR mobile). This work, which has evaluated several multimodal interaction approaches, provides satisfactory and enriching responses in multi-modality in HMI. Like these authors, our goal is also to improve multimodal interaction. But unlike them, we are interested in tactile interaction and an improvement approach that would use user attention.

Many works have dealt with the problem of multimodal interactions. We have presented some here. As we have seen, each of these works has brought a beautiful stone to the understanding and the conception of multimodal interactions. We have also positioned each work presented in relation to the approach and means envisaged to achieve our objective. The following section is devoted to works dealing with pointing and target selection.

2.2 pointing, cursor and area, target selection

Several studies have dealt with the problem of scoring and the selection of targets. Some are presented in this section.

In [3], Lee dealt with the problem of finger occlusion and printing created by the interaction of fingers with touch screens. A problem that worsens with the trend towards miniaturization of devices and enrichment of content. He proposed a technique that uses an energizing finger probe for selecting objects on the screen and enlarging the display, via scaling the visualization to solve occlusion problems. This solution takes into account the fact that an area is created when the finger has contact with the touch screen, and that this area is likely to change depending on who uses it and how it is used. He then compared his proposal to a conventional tactile technique using objective and subjective measures. The results showed that the proposed technique had a shorter travel time with small targets and a lower error rate in extreme conditions. This work provides a solution to the thorny problem of occlusion in tactile interactions. It is a good approach but which could certainly be improved by anticipating, for example, the touch during the interaction.

The problem of target selection was dealt with by Kwon et al.[4]. These provide a two-mode target selection method (TMTS) that automatically detects the target layout and switches to an appropriate mode using the concept

of "activation zone". An activation zone around the point of contact is created when the user touches the screen. Based on the number of targets within the activation area, TMTS identifies whether the target layout is ambiguous or not, and changes its mode to the corresponding ambiguous mode or unambiguous mode. The usability of TMTS has been experimentally compared to that of other methods. The authors explain that during these experiments, TMTS successfully switched to the appropriate mode for a given target layout and showed the shortest task execution time and the least touch input. This work, which gives satisfactory results, takes into account various arrangements resulting from different sizes and densities of the targets on the screen. However, it takes a first finger contact with the screen to define the area and then a second touch to select the target. It might be interesting to explore a solution/approach that would have the same effect as the first touch here, but without having contact with the screen.

The studies that Sears and Shneiderman [15] have carried out have compared speed performance, error rates and user preference scores for three selection devices. The devices tested were a touch screen, a touch screen with stabilization (the stabilization software filters and smooths the raw hardware data) and a mouse. The task was to select rectangular targets of 1, 4, 16 and 32 pixels per side. They proposed a variant of Fitts' law to predict touch screen pointing times. Touchscreen users were able to point to single-pixel targets, countering widespread expectations of poor touchscreen resolution. The results showed no difference in performance between the mouse and the touch screen for targets ranging from 32 to 4 pixels per side. This work helps to predict the pointing time, which could help to improve touch interactions. It also helps to compare the performance of interaction modalities, an exercise which also interests us. On the other hand, it might be wise to study in addition to the cases proposed, a situation where the objects would be highlighted.

The bubble cursor proposed by Grossman and Balakrishnan [12] is a new target acquisition technique based on area cursors. The objective of the bubble cursor is to improve the zone cursors by dynamically resizing its activation zone according to the proximity of the surrounding targets so that only one target can be selected at a time. Following this proposal, the authors carried out two experiments to evaluate the performance of the bubble cursor in the tasks of acquiring 1D and 2D targets, in complex situations with several targets and with varying arrangement densities. The results of their work show that the bubble cursor considerably exceeds the point cursor and the object pointing technique[8] and that the performance of the bubble cursor can be modeled and predicted with precision using the Fitts' law. However, the technique is applied in the case of an interaction with the mouse and therefore, it would not make it possible to anticipate touch in the case of tactile interaction.

Zhai et al.[13] studied the dynamic acquisition of 3D targets. Emphasis is placed on the relative effect of specific perceptual cues. The authors have introduced a new technique and have carried out an experiment which evaluates its effectiveness. Their technique has two aspects. First, unlike normal practice, the tracking symbol is a volume rather than a point. Secondly, the surface

of this volume is semi-transparent, thus offering signs of occlusion during the acquisition of the target. Ghost-Hunting(GH)[14] proposed by Kuwabara et al. is a new technique that improves pointing performance in a graphical user interface (GUI), by widening the targets to facilitate access. In GH, the goal of the authors is to improve the graphical interface. To do this, they decrease the distance the cursor moves by increasing the size of the targets on the screen. Their technique then shows the guides of the endpoint of the shortest movement trajectory, called ghosts, inside the extended target areas. Users can then optimize their cursor movements by only moving their cursor to ghosts in GH. Unlike other techniques like Bubble Cursor[12] which use the invisible outline of an enlarged target, areas called ghosts are visible to users. This work improves the quality of the interaction and the authors obtained satisfactory results during an experimental evaluation. On the other hand, this proposal deals with interactions with the mouse only.

A 3D pointing facilitation technique based on Raycasting, called RayCursor, has been proposed by Baloup et al.[25]. They started from the observation that raycasting is the most common target pointing technique in virtual reality environments. And this pointing performance on small and distant targets is affected by the accuracy of the pointing device and the user's motor skills. They proposed improvements to Raycasting, obtained by filtering the radius and adding a controllable cursor on this radius to select the targets. Studies have shown that filtering the radius reduces the error rate and that the RayCursor has advantages over Raycasting. RayCursor thus provides an effective solution to the selection of remote objects in 3D environments. However, for use in our context, it might be a good idea to have other additional interaction modalities. Indeed, using Raycasting while being very close to the screen could affect the efficiency of the selection.

The work presented in [26] by Peng et al also deals with improving the selection of targets on the touch screen. The authors present PersonalTouch, an improvement in the usability of the touch screen by customizing accessibility settings. They are based on touch screen interactions made by individual users. PersonalTouch collects and analyzes the gestures of these users, and recommends personalized and optimal accessibility settings for the touch screen. The results of their user study show that PersonalTouch significantly improves the success rate of tactile input for users with motor disorders and also for users without motor impairments. On the other hand, evaluating the performance of PersonalTouch in the case of an HMI which would use the highlighting of objects to facilitate their selection could be a track to explore.

The work carried out by Yin et al.[27] proposes four new techniques for target selection in augmented reality interfaces for portable mobile devices. The goal is to accurately select small targets even when they are occluded. The main idea of the authors is to make a precise occlusive or small selection in augmented reality, by selecting a larger and more easily selectable alternative target. An experiment was carried out in which the authors compared the usability, the performances and the error rate of the proposed techniques with the existing one and the results obtained were satisfactory. Yin et al. make a

real contribution to the problem of occlusion during tactile interactions. However, instead of having an intermediate target, a contactless approach which would anticipate the selection of the user could improve the quality of the interaction by avoiding, for example, the pre-selection touchdown.

The work presented in this section has for some, [16,18–24] contributed to the advances observed in the development of multimodal interactions, as mentioned in the description of the various works and for others, [3,4,15,12,14, 25–27] improved the performance of the pointing and the selection of targets, as also explained above. Some of the works have dealt with the problem of head movements [22] and eye movements [16,19]. On the other hand, it would be interesting to study the possibility of using the head and/or the gaze as input for a new modality or in complement to a traditional modality, to improve multimodal interactions in general and tactile in particular. This requires the ability to acquire head orientation data in real-time. Thus, we are addressing the issue of improving tactile interaction by an approach that would use the user's attention obtained by tracking his head and the direction of his gaze, to anticipate pointing and selection of objects. The questions and objectives that support our study are detailed in the next section.

3 Problem and objectives

Because most graphical user interfaces (GUI) are generally designed with the mouse in mind [3], it is almost normal that the interfaces using the mouse as a mode of interaction are more elaborate, more developed, easier to use and therefore allow to commit the least error than with other methods. Besides this observation, we also note that more and more devices are produced with touch screens.

It is convenient for a touch screen to use an anchor point to represent the location of a touchdown. However, it is a contact area, instead of a point, that forms when the finger touches the screen. The shape of the contact area can also change under various circumstances, as users can use the touch screen with different fingers [1]. Also, with the use of touch screens, there is the occlusion problem [4]. In addition, people of different sex, age or ethnic group have different finger diameters and different finger sizes which lead to different target tolerance levels [2]. This justifies work on taking the size of the finger into account in the design of interaction techniques for touch screens. Although the inclusion of finger size in the design of the interaction technique may have untapped potential with regard to touch screens, and although several studies have addressed this issue, the problem of occlusion remains and continues to be explored.

Faced with this state of the art and the quality that is recognized by the use of the mouse for interactions, we asked ourselves a few questions: (i) Wouldn't it be interesting to define an interaction method based on touch and using a technique allowing to reduce or even eliminate the occlusion problem

and which would do as well as the mouse with the same technique? One way would be to add a highlight effect to the touch interaction mode. (ii) So is it not possible to do as well with the touch as what one could do with the mouse with a highlight effect (for example magnification) on the objects overflown by the cursor? From this question follows another. (iii) The use of the touch being done without the presence of a cursor indicating on the screen the place which will be touched (as it is the case with the mouse), by what means should we add an effect of highlight for touch? Because if we would like to see the objects grow as in the case of the mouse when we fly over them, we would have to find a way to fly over them also for the touch before possibly touching them.

The goal of this work is to propose an approach to improve tactile interaction based on anticipating of pointing and of targets selection. The main idea is to use the gaze direction that could be obtained through the head orientation to try to know where the attention of the user is and then highlight the objects thus targeted.The work also aims to evaluate the proposed technique using the combination of the mouse and the same highlight effect as a baseline. The goal is to see if adding the highlight to the touch does as well as adding the highlight to the mouse. This assessment will be made on two objective aspects: the rate of errors made and time, and also on subjective aspects, such as user preferences.

4 Interaction modalities used and description of the experimentation system.

We describe in this section the different interaction modalities used for our proposal, as well as the system implemented to experiment and evaluate the proposal.

4.1 Interaction modalities

To carry out this work, four selection methods are offered to users:

- *Mouse*: it is used to select objects by simple click of the left button.
- *Touched*: a touch screen allows users to select objects by touching them.
- *Mouse and highlighting*: the selection is made by a simple click on the left mouse button. But this time, when the mouse cursor rolls over objects, they are magnified to mark their targeting by the user. This notion of highlighting and its operating principle are described in section 4.2.
- *Touch and highlight*: the selection is made by touching the objects. But this time, the direction of the user's gaze, given by the orientation of the user's head, is used to magnify the objects to which the gaze is directed. For this first work, the direction of the gaze is limited to the position on the screen of the central point which is located between the two eyes of the

user. This is retrieved in tracking the position and orientation of the user's head relative to the screen.

4.2 How highlighting works and its interest

The highlight is materialized by the magnification of the targeted objects. Two levels of highlighting are defined:

- A first level allows to highlight objects located within a defined perimeter around the mouse or the orientation of the head (gaze) on the screen. These objects are magnified to have a size $s1 > s0$. s0 being the initial size of the objects.
- A second level allows to highlight only one of the previous objects (those located in the perimeter), in this case the one on which the mouse or the position of the gaze is directed. This object thus pointed is magnified a little more than the others in the highlighting area, it has a size s2 such that $s2 > s1$. The objective is to facilitate its selection by the user.

Figure 1 describes how the highlight works.

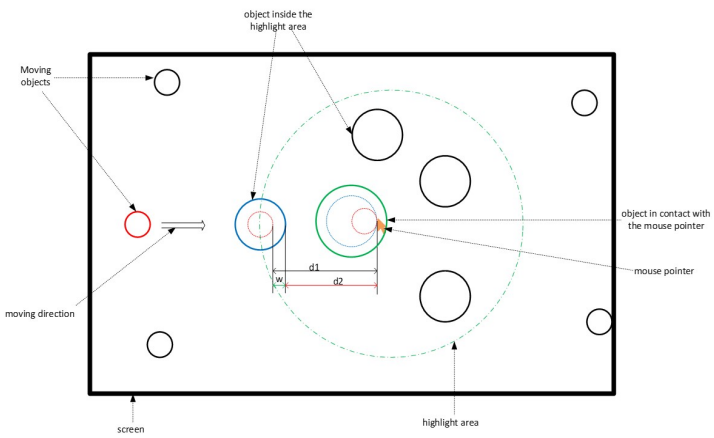

Fig. 1: Highlight operation mode

Taking the special case of the red object, when the latter enters the highlighted area it increases in size (we materialized it by the blue object). Then, when it comes into contact with the mouse (green circle) it increases in size again.

The two-level highlighting works as follows:

- First, it preselects a set of potential objects to be treated. This quickly lets the users know whether their mouse or their gaze position is in the correct area (the one where the target object is located). This limits the errors

that the user can make, reduces the distance between these objects and the position of the mouse and thus saves potential time. On the diagram of the figure 1, the targeted object here would have had to cross the distance d1 before coming into contact with the mouse, if this object had not undergone the highlight effect (red dotted circle). But with the effect of the highlight (circle in solid blue line), it travels the distance d2 to come into contact with the mouse. There is therefore a possible gain in distance w = d1-d2, and consequently in the time taken to select the object, since the speed of movement of the object is constant.
- Then, it preselects the only potential object to be treated, distinguishing it from others in the area. This increases the selection area and therefore makes the task easier for the user (reduced risk of selection error).

The system and its functioning having been described, we present in the following section its physical structure.

4.3 Description of the experimental system

The experimentation system is made up of 2 parts: a part which ensures the interaction and a part which takes care of the treatments. The interaction part defines a user activity area, in which the user must be for everything to work. This area is delimited by cameras making it possible to locate the user's position and track the movements of his head using a target that he must carry on his head. There is also a touch screen and a mouse. The processing part consists of a computer on which an application produced with unity 3D. is deployed. This part is responsible for creating, displaying and managing the movement of objects on the screen, intercepting and interpreting user gestures (click, touch, head orientation), managing the rendering of information according to the actions taken, etc. Figure 2 shows the block diagram of the experimental system. The diagram in Figure 2 gives a general view of the different physical components that make up the system and their interactions and interrelations.

In the diagram in the figure 2, the system is separated into 2 parts as mentioned above:

- the human-machine interaction, consisting of: mouse for selection by click, a touch screen for selection by touch, a virtual reality system for tracking the user's position and consisting of headset, base stations(camera), controllers, live tracker target (for tracking the head).
- the processing: it is provided by a Unity 3D application.

4.4 Experimental design and prototype

To experiment and evaluate the proposed concepts, we used Unity 3D to design a simulator of drones in motion, using the C# programming language for

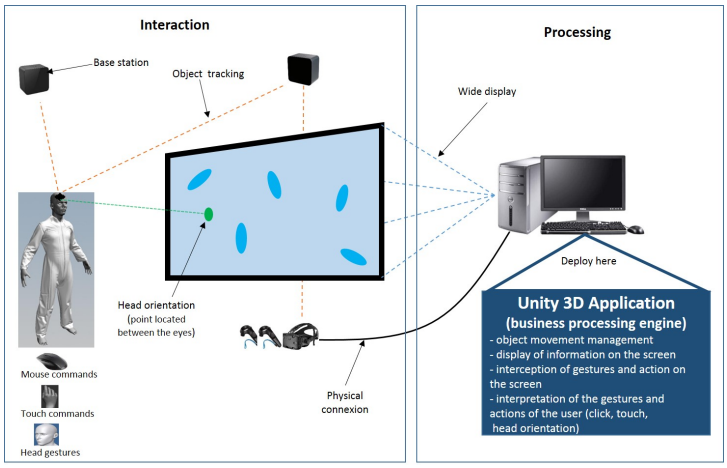

Fig. 2: Physical architecture of the system

scripting. Drones are represented by 3D objects which move randomly on a flat and delimited surface. At regular time intervals, one of the moving objects is chosen randomly by the system to be the target object. The user must select this target object each time.

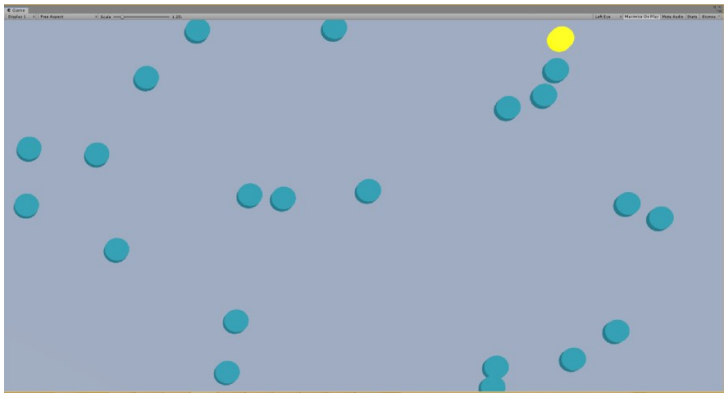

Fig. 3: the main application interface

Figure 3 shows the main system interface. We see a set of moving drones among which one is elected (yellow object) for selection by the user.
We have reviewed the various elements implemented to test our proposal. An experiment was carried out to assess the relevance/impact of the proposal thus made. The following section is devoted to it.

5 Experimentation

We conducted an experiment to evaluate on the one hand the performance of the effect of the highlight on the touch and on the other hand the performance of the combination (touched, highlighted) compared to that of the combination (mouse, highlighted). This section deals with this experiment. It is structured in two sub-sections: the first one describes the method used to conduct it and the second one presents and analyzes the results obtained.

5.1 Method

The chosen method consisted of setting up the experimentation space, defining the task to be accomplished and the procedure, defining the evaluation metrics and selecting the participants.

5.1.1 Context and task to be accomplished

Adding a highlight effect to the selection using the mouse makes it easier to select objects. The objective of this experiment is to see if, as it is the case with the mouse, adding the highlight to the touch improves the selection of objects by touch, and if this improvement is similar to what brings the highlight to the mouse. Two measurement criteria are used for this evaluation: the time taken to complete a task and the error rate made during the completion of the task. The scenario defined to conduct this experiment is an observation and supervision activity of drones on mission. We simulate such a system in which objects representing drones move randomly on a flat surface. At the beginning all the objects have the same color. At each time step i defined before the start of the mission, one of the objects is chosen (chosen) randomly by the system and marked with a color, yellow in this case. We call this object the elected or target object. The user must select the chosen object. This object remains available for selection for a period of s (selection time). Three scenarios arise during the selection:

- the user selects the target object during this time step s: the object changes its color to green for a duration g (good selection time), then returns to the initial color (color at the start of the mission); this is a correct selection.
- the user cannot select the target object during the time step s: the object changes its color to red for a period b (time of bad selection), then returns to the initial color; a selection error is recorded.
- the user selects an unelected object (not the target object): the object changes its color to red for a period b, then returns to the initial color; a selection error is also counted.

The total number of objects on the stage, the number of objects to be selected, the selection methods (mouse, touch, etc.), the time between two selections (i), the duration of a selection (s), the duration for which the colors of good

(g) or bad selection (b) are maintained, are parameters defined before the beginning of the experiment.

5.1.2 Population

Twenty-eight subjects including 4 women and 24 men, aged from 18 to 40 (18-25: 6, 25-35: 16, 35-40: 6) took part in this experiment. These participants were from 5 different profiles, distributed as follows: 7 undergraduate students, 9 doctoral students, 7 research engineers, 4 post-doctoral researchers and 1 teacher. They were recruited through an email which we passed in the mailing list of our engineering school. Users have not received any reward for this work.

5.1.3 Experiment settings

Several parameters have been defined: the different methods to be used, the number of objects present on the screen during a passage, the total number of objects that will be selected for a passage, the time available to select an object, the time between a selection and the choice of the next target to be selected, etc. For this experiment, we therefore had:

- 4 methods of selecting objects: mouse, mouse + highlight, touch, touch + highlight (by the orientation of the gaze);
- 3 different densities (total number of objects on the screen) of objects: 10, 30 and 50 objects;
- 10 objects to be selected per mission (passage);
- i = Time between two elections of the target object = 2s
- s: Hold time of the target object in the "selectable" state by the user = 2s
- g and b: Respective times of green color after a good selection and red after a selection failure = 1s.

With this demarcation of the various elements, a mission is limited in time. An example of a mission is defined as follows: its modality (m) = hit, the density of the objects on the screen (d) = 30, the number of objects to select (f) = 10, i = 2s , s = 2s, $g = b$ = 1s. A mission is successful if before the end of its duration the user has selected all the f objects. In the example of the previous mission f is equal to 10.

5.1.4 Procedure

We established a participant time schedule and a charter that explained the project and the experiment, as well as the rights of the participants. Before starting, each participant was briefed on the purpose of the experiment and the operation of the system to be used for this, then followed by an environmental training phase. During the training, each participant made 4 passages, at the rate of one passage for each modality. On each pass, they had 10 objects moving on the screen, among which it was necessary to select 5. This session allowed the participants to familiarize themselves with the environment and

especially to understand the purpose of the experiment. During the evaluation session, each participant used the 4 modalities (**M**: Mouse, **MH**: Mouse and highlight, **T**: Touch, **TH**: Touch and highlight), and for each of them, he made 3 passages with 3 different densities of objects: 10, 30 and 50 objects, for a total of 12 passages per participant. Each time he had to select a total of 10 objects. Questionnaires were also submitted to participants: 1 questionnaire after each modality and 1 final questionnaire on the experiment. For the whole experiment, we had a total number of 28 x 4 x 3, that is 336 passages. The order of use of the interaction modalities changed from one participant to another. We have numbered the modalities: 1: M, 2: MH, 3: T and 4: TH. Then we built a Latin square with these 4 numbers. The first line of this matrix gives the order of passage M - MH - T - TH.

Table 1: illustration of the variation of the orders of passage

participants	order modalities
participant 1	M – MH – T -TH
participant 2	MH – T – TH - M
participant 3	T – TH – M – MH
participant 4	TH – M – MH – T
participant 5	M – MH – T -TH
.....	.....

Based on this principle, we determined 4 passages orders as shown in Table 1. For these four passages, each modality is used one time at each of four positions. This order was repeated every four participants; we did 7 repetitions for the 28 participants. This has ensured the equitable use of the modalities and therefore reduced the learning effect of the modalities on the results of the experiment.

At each passage, the mission data were saved in a file for later analysis. As data we record among others: the participant's identifier, the modality used, the density of objects in the environment, the duration of the mission, the state of the mission (success or failure), the number of selections made at total, the number of wrong selections, etc.

5.1.5 Materials and apparatus

The hardware platform used in this research consisted of:

- a computer running a Windows 7 Enterprise Edition 64-bit operating system; It had an Intel Xeon 3.5 Ghz processor, 64 GB of RAM and an Nvidia Titan XP graphics card;
- a Sony touch screen of size 9/16;
- a mouse;
- a virtual reality system consisting of: 1 HTC Vive headset, 2 base stations, 2 controllers, 1 htc vive tracker target.

The touch screen was placed vertically on a table so that participants could use touch while standing. There was a table and chair placed in front of the touch screen to use the mouse and mouse + highlight modes. Figure 4 shows

Fig. 4: participant following the object to be selected

a participant during a mission, looking at the target object (yellow color) to select. The direction of his gaze is given by the blue circle on the screen.

Fig. 5: target object already selected

In Figure 5, the user has already selected the object which has turned green. Objects 1, 2, 3 are outside the highlighted area defined around the position of the gaze. Their size has not changed. On the other hand, the object 4 which is the target already selected (green color) and which is located in the highlighting area thereof has a size greater than those of the objects 1, 2 and 3 (first level of highlighting). On the other hand, the size of the object 4 remains smaller than that of the object 5 which now has the gaze direction represented by element 6 (second level of highlighting).

5.1.6 Assessment metrics

In order to assess the four interaction modalities, and in particular to compare the contribution of highlighting with the mouse and the touchscreen, we defined 2 objective criteria (variables of interest): the time taken to complete a mission and the rate of selection errors made during a mission. The definition of selection errors was made in the 5.1.1 section. We also offered subjective questionnaires to participants.

5.1.6.1 Completion time

Mission completion time is a measure of the effectiveness of a modality. Because we consider that performing a task quickly with a modality is a sign of a certain ease of use. Likewise, this means that the modality is well suited to carrying out the task. For each mission, the application records the time taken to complete it for each participant. At the end of a mission, the environment changes color from light gray to dark gray to indicate the end to the participant. The software then ceases to determine the target objects and therefore no further selection is possible for the participant.

5.1.6.2 Selection error rate

The rate of errors that occur when selecting objects is also a measure of the effectiveness of the means used for this selection. Because we consider that the fewer errors made, the less difficulty there is in using this means for the task and therefore the user is more comfortable. For each mission, the software records each selection or attempted selection made by the participant, distinguishing the good from the bad. More precisely, if we take the case of the mouse, each click made by the participant during a mission is recorded. At the end of the mission, the recording stops.

5.1.6.3 Subjective questionnaires

Two types of questionnaires were offered to each participant: a questionnaire at the end of each modality to evaluate the latter, and an end-of-experimentation questionnaire to compare the modalities and give a general opinion on the experimentation. At the end of the use of a modality, the participant was asked to fill in a questionnaire with a subjective evaluation according to certain

criteria among which: familiarity with the modality, ease of use, self-confidence during use, tiredness. At the end of the experiment, the participant had to give his opinion on: his preferred modality, the least preferred modality, the effect of the highlight on the traditional modalities, etc. Demographic data was also recorded detailing age, gender, function, experience with 3D environments.

At the end of the experiments, the data collected were analyzed. The following section presents some results and findings that emerge.

5.2 Results

Using the data collected from the experiment, we carried out a statistical analysis to assess the impact of the factors of selection modality and density of the objects on the scene on our variables of interest which are the duration of the mission and the rate of mistakes made. The ultimate goal is to compare the mouse + highlight and touch + highlight modalities, in order to see if the highlight added to the touch allows users to do as well as with the mouse doubtful of a highlight effect. We have conducted ANOVAs. We have 2 interest variables (error rate and completion time) and 2 factors (interaction modality and density of objects) that can influence them. For all our analyzes, the risk of the first species chosen is $\alpha = 0.05$, that is to say a confidence interval of 95%.

5.2.1 Error rate

5.2.1.1 Error rate by modality

Graph 6 shows the error rate committed according to the interaction modality used.

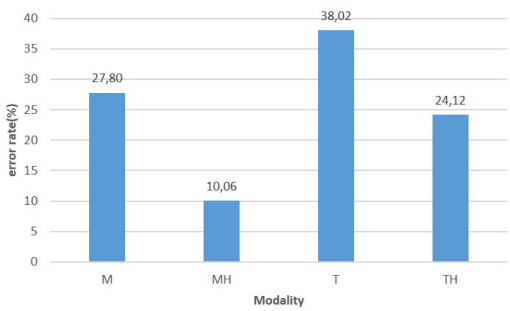

Fig. 6: error rate by modality

The graph in Figure 6 shows that adding highlighting to the mouse and touch reduces the rate of errors made by using these modalities respectively

for the selection of moving objects. The error rate goes from 27.80% to 10.06% for the mouse and from 38.02% to 24.12% for the touch screen. The ANOVA carried out shows that the effect of the interaction modality on the rate of errors made during the selection is significant with a p-value = 7.839E-13.

The result obtained above gives the general impact of all the conditions on the error rate. To verify that this impact is not the effect of a single modality which dominates all the others, we conducted an analysis between modalities taken 2 by 2. The results are summarized in table 2.

Table 2: Detail of the effect of the modalities taken 2 by 2 on the error rate

Comparison case	**p-value**	**conclusion**
M / MH	7.874E-08	significant
T / TH	0.00039	significant
T / M	0.01723	significant
TH / MH	1.766E-07	significant

As shown in Table 2, by comparing the effects of the interaction methods taken 2 by 2 on the rate of errors made, the impact remains significant. This means that the reductions in the error rate obtained by adding a highlighting effect on the mouse and touch modes, and which are observed in the graph in Figure 6 are significant.

5.2.1.2 Error rate by modality and density

The graph in Figure 7 shows the rate of errors made as a function of the interaction modality and the density of the objects.

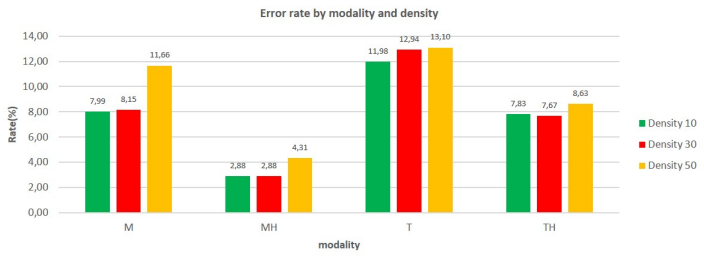

Fig. 7: error rate by modality and by density

Two observations are made: (i) the error rate increases with density; (ii) although the selection error rate increases with the number of objects present on the scene, adding highlighting to the interaction mode makes it possible

to considerably reduce this error rate and therefore improve the quality of selection.

ANOVAs were carried out to judge the relevance of this impact of density on the selection error rate. Tables 3 and 4 summarize the results obtained from these analyzes.

Table 3: Impact of the modalities on the error rate depending on the density

Density	**p-value**	**conclusion**
10	9.06E-06	significant
30	1.7229E-05	significant
50	0.0005989	significant

In table 3 all p-values are smaller than 0.05. This shows that there is a significant impact between the 2 factors of interaction modality and density of objects on the error rate committed. A comparison of the different modalities gave the results of the table.4.

Table 4: Detail of the impact of the modalities taken 2 by 2 on the error rate depending on the density

density	**comparison case**	**p-value**	**conclusion**
10	M/MH	0.0011081	significant
	T/TH	0.03009074	significant
	T/M	0.04625601	significant
	TH/MH	0.00059825	significant
30	M/MH	0.00251564	significant
	T/TH	0.0167831	significant
	T/M	0.04738984	significant
	TH/MH	0.0006457	significant
50	M/MH	0.00131617	significant
	T/TH	0.04978445	significant
	T/M	0.58041257	Not significant
	TH/MH	0.0156399	significant

For a better understanding we will name the lines by the pairs (Density, comparison case), for example (10, M/MH) means the results obtained for the comparison between the modalities M and MH for the density 10. Table 4 gives several information: (i) the line (50, T / M) gives a p-value of $0.580 > 0.05$. So, from 50 objects on the scene, the difference between the error rate made with the mouse only and the touch alone is not significant; (ii) all the other differences observed in the graphs in Figure 7 are significant. In particular :

- the lines (10, M/MH), (30, M/MH), (50, M/MH) all have p-values less than 0.05. So regardless of the density of objects in the environment, adding a highlight effect on the mouse significantly decreases the error rate of object selections.

– the lines (10, T/TH), (30, T/TH), (50, T/TH) all have p-values less than 0.05. So regardless of the density of objects in the environment, the addition of a highlight effect on the touch significantly decreases the error rate of object selections.

5.2.2 Mission completion time

The second variable we were interested in was the time that each participant took to complete a mission. And for this variable of interest, we also studied the influence of the modality and density factors on the different values obtained.

5.2.2.1 Mission completion time by modality

The graph in Figure 8 shows the variation in the average completion time depending on the modality used.

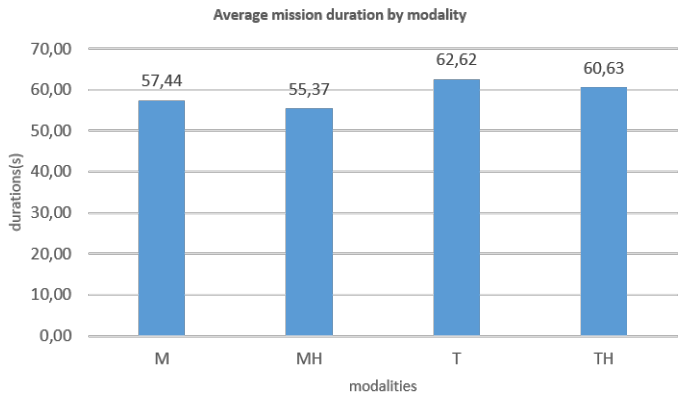

Fig. 8: Average mission duration by modality

You can see that adding the highlight to a modality reduces the time taken to complete the mission. We obtain a reduction of 3.60% from 57.44s to 55.37s for the mouse, and a reduction of 3.20% from 62.62 s to 60.63 s for the touchdown. The ANOVA performed gave us a p-value of 1.064E-44. The impact of the interaction modality on the completion time thus observed in the graph in Figure 8 is therefore significant. The result obtained above gives the general impact of all the modalities on the completion time. We conducted an analysis of modalities taken 2 by 2. The results are summarized in table 5. All the p-values obtained are smaller than 0.05, so we can say that the modality of interaction significantly influences the completion time of a mission, especially when adding highlight to the mouse and touch modes.

Table 5: Effect of the modalities taken 2 by 2 on the mission duration

Comparison case	p-value	conclusion
M / MH	7.30E-07	significant
T / TH	0.000199	significant
T / M	4.667E-21	significant
TH / MH	6,065E-23	significant

5.2.2.2 Mission completion time by modality and by density

The graph in Figure 9 shows the average completion times based on terms and densities.

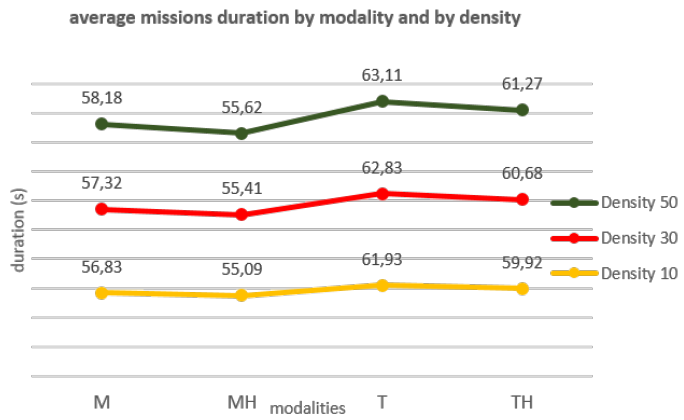

Fig. 9: Average completion time depending on modalities and densities

We note that, although the duration of the mission increases with the density of the objects, adding the highlight to a modality still makes it possible to decrease this duration despite the increase in the number of objects on the scene.

Two other observations are also made: (i) the time to complete a mission increases with density; (ii) although this time increases with the number of objects present in the environment, the addition of the highlighting to the interaction modalities reduces the completion time. ANOVAs were carried out to assess the relevance of this impact of the modality according to the density of the objects. Tables 6 summarize the results obtained from these analyzes.

In table 6 all p-values are smaller than 0.05. This shows that there is a significant impact of the 2 factors, interaction modality and density of objects on the mission completion time. The results obtained by comparing the impacts of the modalities taken 2 by 2 for each density are summarized in table 7.

Table 6: Impact of modalities on the completion time depending on density

Density	**p-value**	**conclusion**
10	2.0186E-17	significant
30	2.8251E-16	significant
50	2.2041E-12	significant

Table 7: Impact of the modalities taken 2 by 2 on the completion time depending on the density

density	**comparison case**	**p-value**	**conclusion**
10	M/MH	0.009579023	significant
	T/TH	0.00773145	significant
	T/M	8.69003E-10	significant
	TH/MH	3.40811E-09	significant
30	M/MH	0.002702444	significant
	T/TH	0.024301863	significant
	T/M	3.79286E-09	significant
	TH/MH	9.58173E-09	significant
50	M/MH	0.002673902	significant
	T/TH	0.008455333	significant
	T/M	0.003893396	significant
	TH/MH	5.34789E-08	significant

In table 7, all the comparison cases carried out give a p-value smaller than 0.05. There is therefore a significant interaction between the modality and density factors over the completion time, regardless of the density and modality used.

5.2.3 Subjective questionnaire

As indicated in section 5.1.6.3, the participants were subjected to a subjective questionnaire at the end of the experiment. The questions contained in the questionnaire made it possible to collect the opinions (ratings) of the participants on various criteria. The participants first had to give a score between 1 and 5 on the following criteria:

- *Ease of use*: Would you like to use this modality for the selection of moving objects?
- *Suitability for selection*: is the modality suitable for the selection of moving objects?
- *Complexity*: is the selection procedure unnecessarily complicated?
- *Size of the objects*: is the size proposed for the objects appropriate for their selection?
- *Density and difficulty*: does the increase in the number of objects in the environment make selection more difficult?
- *Self-confidence*: what level of confidence did you have when using the modality?

Then they ended the session by giving their opinion with a score between 1 and 10 on the contribution of the highlight (did the addition of the highlight to the modalities improve / facilitate the selection?). Friedman's ANOVAs were performed on the questionnaire responses, the observed means and the p-values are presented in Table 8.

Table 8: Mean scores and p-values off the subjective data of the experiment

Criteria	M	MH	T	TH	p-value
Easy to use (1-5)	3,536	4,536	3,071	4,25	2,566E-09
Suitability for selection (1-5)	3,25	4	2,964	3,786	8,523E-10
Complexity (1-5)	1,893	1,321	2,286	1,464	2,806E-05
Size of objects (1-5)	3,643	4,357	3,5	4,25	0,0002302
Difficulty and density (1-5)	3,642	2,964	3,786	3	0,0030581
Self-confidence (1-5)	4	4,286	3,357	4,143	0,0021407
Contribution of the Highlight (1-10)		8,929		8,679	0,5743486

According to this data, first, the participants found that the highlighted modalities were very easy to use, that they are more suitable for the selection of objects than the traditional modalities and that they had more self-confidence during the use of highlight. They also found that the size of the objects seemed correct for selection and that the density of the objects in the environment made selection more difficult.
Secondly, participants found that adding highlighting to a modality greatly improved (average > 8.5 out of 10) the selection of objects. The p-value of this criterion is $0.5 > 0.05$; therefore the difference in sentiment observed in the participants' response to this question is not significant. In other words, the latter note that the comfort brought by the addition of highlighting on the mouse and the addition of highlighting on touch for the activity of selecting moving objects is substantially the same in the 2 cases. Finally, when asked which method they preferred, 16 participants, that is to say 57.14% chose the mouse and the highlight against 12 or 42.86% for the touch and the highlight.

6 Discussion

In this experiment, the addition of the highlighting to the traditional mouse and touch modalities brings a clear improvement to the quality of the pointing and the selection of the targets. For the error rate made by the participants during the experiment, it decreased considerably with the addition of highlighting to the touch screen. This rate fells from 38.02% to 24.12% as shown in the diagram in Figure 6, a decrease of 36.56%. This improvement in the quality of the selection brought by the highlighting is significant for both the mouse and the touchscreen. Indeed, the ANOVA on this criterion having given statistically significant results. By observing the distribution of the error rate

over the different densities of objects that have been tested, we observe a decrease of 34.64% (from 11.98 to 7.83), 40.73% (from 12.94 to 7.67) and 34.12% (from 13.10 to 8.63) respectively for the densities 10, 30 and 50 objects, as shown in the graph in the figure ref tab: error-rate-by -modality-detail. So we can say that in our approach, the quality of the selection seems to be resilient to the increase in the density of objects on the screen. However, for the error rate criterion, the improvement brought by our combination approach (touch, highlight) remains lower than that brought by the combination (mouse, touch), which is 63.81% (decrease from 27.80% to 10.06%). This can be explained by the two main remarks made in the subjective questionnaire by almost all the participants: the touch screen which did not seem very responsive and its size which they found very large. According to the participants, the size of the screen did not allow a large view of the screen when using the touch screen, as was the case when using the mouse (the table was distant from the screen, with a wider angle of view). This undoubtedly justifies the very high error rate with the touchscreen.

The average task completion time has also been improved by adding touch highlighting. We determined the time saved by adding highlighting to a modality, and this according to the density of the objects. Table 9 gives details of the differences observed. The data that is expressed in seconds reads as follows: for the cell located in the 2nd row and 2nd column, adding the highlight to the mouse saves 1.73 s for a density of 10 objects.

Table 9: Comparison of improvement in completion time

Modalities	Density 10	Density 30	Density 50	Average duration differences
MH vs M	1,73	1,91	2,56	2,07
TH vs T	2,00	2,14	1,84	1,99

As we can see, we went from 57.44s to 55.37s (-2.07s) for the mouse and from 62.62s to 60.63s (-1.99s) for the touch screen. We therefore see that for the completion time criterion, using the direction of the gaze to add a highlight effect makes it possible to do as well as adding the same highlight effect to the mouse. And this despite the remarks made by the participants, and relating to the size and quality of the screen.

Statistical analysis of the data collected through the subjective questionnaire shows that the participants felt more comfortable using a modality with highlight than a modality without. Indeed they found that adding highlighting to a modality made it easier to use and more suitable for selecting objects. For them, the highlight improved the usability of the mouse by 28.28% with an average score increased from 3.57/5 to 4.57/5; and that of the tactile of 38.39% with an average note passing from 3.07/5 to 4.25/5. It also made it possible to make the methods more suitable for the selection of objects, with an improvement of 23.08% for the mouse and 27.73% for the touchscreen. We see that the improvement rate for the two criteria is higher with the touch screen

than with the mouse. Participants gained confidence in the performance of their task with the addition of highlighting; they went from an average confidence level of 4/5 to 4.29/5, an improvement of 7.15% for the mouse and from 3.36/5 to 4.14/5, an improvement of 23.41% for touch. This means that the addition of highlighting to the touchscreen seems to multiply by 3 the users' confidence in the exercise of their mission with this selection method. For all this data, the differences thus observed were all significant. In fact, as shown in the data in table 8, the ANOVAs performed on these criteria gave p-values all less than 0.05. Participants found that highlighting as implemented brought them substantially the same level of comfort with the touch as with the mouse. Indeed, the scores assigned, namely 8.93/10 and 8.68/10 respectively for the mouse and the touchscreen, are not significantly different with regard to the results of ANOVA which gave a p-value of $0.57 > 0.05$ for this criterion. However, participants preferred the use of highlight added to the mouse at 57.14% versus 42.86% for the highlight added to the touch. According to the data extracted from the free comments made by the participants at the end of the experiment, those who preferred the mouse + highlight seemed to justify this unfavorable choice for the touch screen by the quality of the touch screen and its size (size of the interaction interface).

7 Conclusion and future work

In this paper, we have proposed an approach to improve tactile interaction based on a two-level highlight, which allows anticipating the pointing and targets selection. The gaze direction obtained by the head orientation is used to determine where the attention of the user is focused on his screen. A perimeter is defined around this position and all the objects found there are highlighted. If one of the objects thus preselected intercepts the gaze direction, it is differentiated from the others by a second level of highlighting. In this way, we anticipate the action of the user. As detailed in section 6, the results obtained are satisfactory. The comparative analysis carried out shows that the proposed approach improves tactile interaction in the same way as it improves interaction with the mouse.

Currently, the direction of the gaze is given by the orientation of the head. The use of the actual position of the user's gaze on the screen could allow greater precision and therefore better results in our approach to improving the performance of pointing and targets selection. However, note that it is quite difficult to have its gaze fixed in one place by ensuring that the latter does not move. Indeed, the human eye is constantly in motion and even when we decide to fix a point, it is difficult to stay there. As a result, an object/ray representing the position of the gaze may be unstable on the screen and therefore may lack precision in the movements. It may be interesting to compare the performance of a solution using the gaze position with that using the gaze direction in order to decide. Thus, we intend to use an eye-tracker to obtain the position of the gaze and then compare the two approaches. In addition, depending on

the results obtained from this first work, the use of eye movements could be envisaged to facilitate pointing tasks and the selection of objects. Finally, in the particular case of the SOS-DM project, we plan to develop a contactless interaction, based on the gestures of the supervisor.

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