3D Interaction with Mouse-Keyboard, Gamepad and Leap Motion: A Comparative Study

Fabio Pittarello(✉), Alexandru Dumitriu, and Elisa Piazza

Università Ca' Foscari Venezia, Mestre-Venezia, Italy
pitt@unive.it, {836110,838565}@stud.unive.it

Abstract. Serious gaming can represent a key for fostering learning and letting children to acquire new information and skills while doing engaging activities. Among the different types of games, those ones based on interactive 3D environments are widely diffused and appreciated. A key component of the design of these experiences is the choice of the input device that will be used by the players and the mapping of the users' intentions to the actions in the 3D environment. The choice of the proper device can lead to benefits in terms of user engagement, which often is the prerequisite for learning. There are also additional dimensions to consider, as the usability and the physical fatigue. Their undervaluation, in an educational context, can hamper the successful outcome of the experience. For this reason in this work we compared the use of three different input devices (a mouse-keyboard set, a gamepad and the Leap Motion, a sensor for recognizing hand gestures) for controlling a 3D educational gaming experience focused on environmental sustainability. We organized a comparative study with 30 children of the Primary School, evaluating the interaction in terms of usability, engagement and physical fatigue. The results evidenced the potential of the Leap for engaging the children, but also drawbacks in terms of usability and physical fatigue that should be taken into consideration for the development of this technology and the design of experiences based on it.

Keywords: 3D interaction · Children · Comparative study
Engagement · Gesture-based input · Physical fatigue · Serious gaming
Usability

1 Introduction

Serious gaming represents an opportunity for permitting the users to acquire new knowledge and skills while performing engaging activities. The creation of an engaging gaming experience passes through different important factors, among which the definition of how the user interacts with the game. The choice of a specific input device is an important choice that can make the difference. While at the beginning the properties of the input devices and their influence on the user experience were evaluated only in terms of usability, as a consequence of

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the Taylorist tradition of time and motion studies related to structured and paid work [4], the shift to other human activities determined a growing importance for other parameters, such as the engagement. According to O'Brien and Toms [13] engagement can be defined as the sum of six dimensions: perceived usability, felt involvement, focused attention, novelty, endurability and aesthetics. Please note that this analytical definition includes the usability as well, which accounts for a number of issues, among which the perceived effort in using the application, the ability to accomplish the task and the feeling of being in control [13].

The physical fatigue is another important factor for all those experiences that go beyond desktop computing or that however require an heavy physical involvement. The goal of this paper is to investigate the use of different categories of input devices and related interaction styles in the context of a 3D gaming experience, evaluating their points of strength and weakness in relation to all the parameters cited above. Although this kind of comparative study is not novel [1,10], we introduce a specific focus on mid-air hand gestures and the Leap Motion, a low cost device that permits to track accurately them. Mid-air gestures represent a specific category of gestures that can be used as an input medium and that typically are associated to actions such as confirmation, selection, navigation and modification. This study focuses in particular on mid-air hand gestures which don't take advantage of an assisted physical medium, such as a pen or a remote control [6]. We tried to give an answer to the following research question: how the Leap compares to the mouse-keyboard set and the gamepad for completing common interaction tasks in a 3D environment, in relation to usability, engagement and physical fatigue? The educational game that we designed for comparing these devices was focused on environmental awareness and tested with 30 children of the Primary School aged 10. The study gave mixed results, showing that gesture-based interaction was appreciated for a number of parameters that define the engagement, thus confirming its educational potential. However a number of drawbacks emerged, in terms of usability and physical fatigue, that should be taken in consideration when designing experiences based on this input modality.

2 Related Work

Gesture-based interaction has become popular in the last decade thanks to the proposal of commercial products, targeted mainly to the gaming domain. These devices are usually characterized by a low cost and an increasing level of accuracy and have become a viable alternative to the long-standing and often costly data gloves [3]. The interest for their potential is constantly increasing for different application domains. We can make a rough classification distinguishing systems which require to grab a device that embeds sensors or markers for monitoring the user gestures, such as the Nintendo Wiimote, and systems that rely on an external sensor for tracking the user motion, such as the Microsoft Kinect and the Leap Motion [7]. Many applications of gesture-based technology are related to interactive 3D environments. This is not surprising, given that 3D environments mimic the real world and gesture-based interaction seems an interesting

Table 1. Mapping actions in the 3D world to input devices

Action	Mouse & K.board	Gamepad	Leap motion
Walk forward	Up arrow	Left stick f.ward	Closed hand f.ward
Walk backward	Down arrow	Left stick b.ward	Closed hand b.ward
Turn left	Left arrow	Left stick to the l.	Closed hand to the l.
Turn right	Right arrow	Left stick to the r.	Closed hand to the r.
Grab object	Left mouse butt.	A button	Grab
Ungrab object	Left mouse butt.	A button	Open hand
Raise hand	f.ward mouse wheel	LB button	Raise hand
Lower hand	b.ward mouse wheel	RB button	Lower hand
Move hand forward	Mouse f.ward	Right stick f.ward	Hand f.ward
Move hand backward	Mouse b.ward	Right stick b.ward	Hand b.ward
Move hand to the left	Mouse to the left	Right st. to the l.	Hand to the left
Move hand to the right	Mouse to the right	Right st. to the r.	Hand to the right

opportunity to extend the mimesis also to control it. The design of interaction for 3D worlds requires to manage a number of actions, from the navigation to the manipulation of objects that are contained inside of them. In spite of all the research work done for trying to improve the usability of interactive worlds [11,14], the complexity and the variety of the issues has prevented from coming to a satisfactory solution, available for all the situations. Lapointe et al. [10] in 2011 stated that *research shows that, in the case of 3D interface, there is still not an input device that demonstrates its superiority for accomplishing basic 3D tasks such as navigation, manipulation and selection*. This statement is still true, as shown also by additional surveys [8,9] suggesting that different solutions are suited to different contexts and application domains. In this scenario there are interesting studies that compare the use of different input devices and mappings [1,10]. The study described in this paper belongs to this category and tries to enlarge the comparative approach to other categories of devices not previously considered, such as the Leap, for highlighting points of strength and weaknesses in a specific context of use.

3 Designing the 3D Experience

The educational experience was focused on the exploration of a park (see Fig. 1 on the left). The visitors had to retrieve different types of waste in the shortest time and put them in the proper recycling bin, in order to improve their environmental awareness. Any error performed during the interaction, such as the involuntary ungrabbing of the waste or its association to the wrong recycling bin caused the object to return to its original position.

For giving generality to the study, we established that the user experience should have been based on a set of actions that are usually available for 3D

Fig. 1. The 3D interface and one of the tutorials related to the mouse-keyboard set

games. The first column of Table 1 displays all the available actions. For avoiding to add unnecessary degrees of complexity to the experience, we limited the degrees of freedom for locomotion, considering only forward and backward walking and the possibility to turn left or right. Concerning the interaction with the objects, we considered the actions for controlling a 3D counterpart of the user's hand and grabbing 3D objects. All these actions were mapped to the input devices selected for this study (mouse-keyboard, gamepad, Leap Motion), for granting the same level of expressivity for each situation and easing the comparisons. For mapping the actions to the input devices we took into account the configurations that can be found in gaming, although in some cases we had to choose among possible alternatives. In particular, for the mouse-keyboard, we mapped the locomotion to the four directional arrows of the keyboard, as an alternative to the more common WASD solution, because we wanted to avoid an excessive bias due to previous gaming experiences. For the Leap we couldn't count on any established praxis. Additional restrictions came from the limitedness of its library of gestures. In this case, following the results of studies [2,5] which underline a preference by the users for gestures that mimic the action of the real world, we used *pantomimic* gestures for all the manipulation gestures, including the hand movements and the act of grabbing an object. Where it was not possible, such as for the locomotion, we preferred *deictic* gestures to *symbolic* gestures that have to be learned and whose meaning can vary for different users, contexts and cultures. We chose also to maintain simplicity, avoiding bimanual gestures that would have added a level of complexity. For this reason we designed locomotion gestures that took advantage of the hand already in use for grabbing the objects, for guiding navigation as well.

The output interface, displayed in Fig. 1, was characterized by the subjective view of the user in the 3D world and included a simple HUD showing information such as the score, the number of objects available in the park and collected, the name of the object currently grasped. Textual messages appeared in the center of the screen for underlying important actions, such as the act of placing an object in the proper/improper waste bin and for warning the user if she inadvertently went away from the operation zones. For the manipulation of the objects, the feedback was given by the 3D counterpart of the hand of the user and by the change of color of the object to collect, when the hand had reached the right position for grasping it. The interface was multimodal in that it was complemented by audio tones associated to the main events. Ambient audio effects were added as well, for improving the sense of presence in the 3D world. The system was developed taking advantage of Unity3D, a well-known SDK for gaming development. During the development of the system, a keen attention was devoted to obtain a smooth and precise interaction with all the devices. We dedicated a complementary attention for defining comparable locomotion and manipulation speeds for each device, in order to obtain a fair comparison of the time necessary to complete the experience. During this process we organized also an informal pilot study with two children aged 10 that tried all the different interfaces. Their feedback was very useful for refining the results. At the end of the development we had three distinct and comparable systems with the same functionalities that differed only for secondary issues (e.g., the shape of the 3D hand in the 3D environment).

4 The Comparative Study

We organized the comparative study with the collaboration of the teachers of two classes of the Primary School "S. Giovanni Bosco", located in a small center of Northern Italy, and the participation of 30 children (13 boys and 17 girls) aged 10. The parents of the children were informed about the goals and the structure of the study and signed an informed consent form before its start.

The experimental setup was based on a laptop connected to an external big screen and to the input devices. Aside from the initial briefing where each child was given an explanation of the goal of the game and of the experiment, the core of the experience were the sessions with the three input devices. We used a within-subjects design, considering the device as the main independent variable. For all these sessions we used the same 3D world, with the objects and the bins placed in the same place, in order to avoid differences related to the difficulty of retrieving or manipulating them. For counterbalancing the learning effect, we divided the 30 children in 6 groups, using for each group a sequence of sessions derived by one of the possibile permutations of the three input devices, as suggested in [12]. An additional care for diminishing the learning effect was the introduction of a practicing trial, performed before the main sessions, for all the devices. Each trial was introduced by a short video tutorial. The miniatures on the right part of Fig. 1 are taken from the video related to the mouse-keyboard set and display the relation between the manipulation of the input device and a number of actions in the 3D world (i.e. go forward, turn left, collect and release the waste). We dedicated about 1 h and half to test each child. We took advantage of questionnaires for collecting qualitative data related to usability, engagement and physical fatigue. Quantitative data, among which the time for completing the sessions and the type and number of errors, were collected through direct observation and video recording. We asked the children fo fill in a preliminary questionnaire before the initial briefing, for collecting demographical data and information about their prior experience related to gaming and input devices. Then we asked the children to fill in an intermediate questionnaire after the session with each device. This questionnaire was organized as a set of closed questions focused on the 6 parameters of the engagement and on the physical fatigue. We formulated the questions related to each parameter in plain terms, suitable to che children's age, and we checked them with the teachers before the study. The children where asked to select among 5 values ranging from *Not at all* to *Extremely*. The answers were then converted in numerical values from 1 to 5 for the following analysis. At the end of the three sessions we asked the children to fill in a final questionnaire that included a set of open questions, for giving them the opportunity to highlight the positive and negative features of the experience and to propose modifications to the mappings as well. Both the user interaction and the output interface were recorded with a digital camera and a video capture software (see Fig. 2). The two streams were then post-processed for obtaining a single synchronized video, useful for re-examining in detail the sessions.

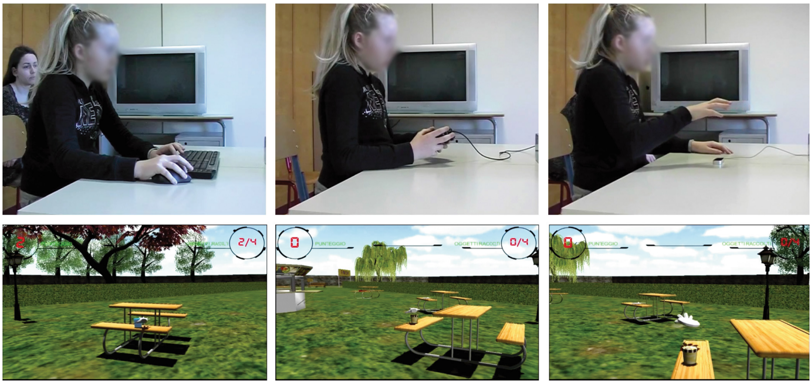

Fig. 2. Interacting with the mouse-keyboard, the gamepad and the Leap

4.1 Results

The exam of the initial questionnaire showed that only 1 child out of 30 didn't own a personal computer, a game console or a multitouch device. Coming to devices for capturing mid-air gestures, only 4 children declared to use them (i.e. 1 Kinect, 3 Wiimotes). Figure 3 resumes the results of the intermediate questionnaires related to the engagement and the physical fatigue. Please note that the question related to the usability was split into 4 sub-questions for getting better insights about the different types of actions. The box plot, which has been extensively used in this paper for visualizing the distribution of the scores (based on a 5 points scale), displays the limits of the first and the third quartile. A thick horizontal line inside the box and a dashed line are used for visualizing respectively the median and the mean. The single dots evidence the outliers

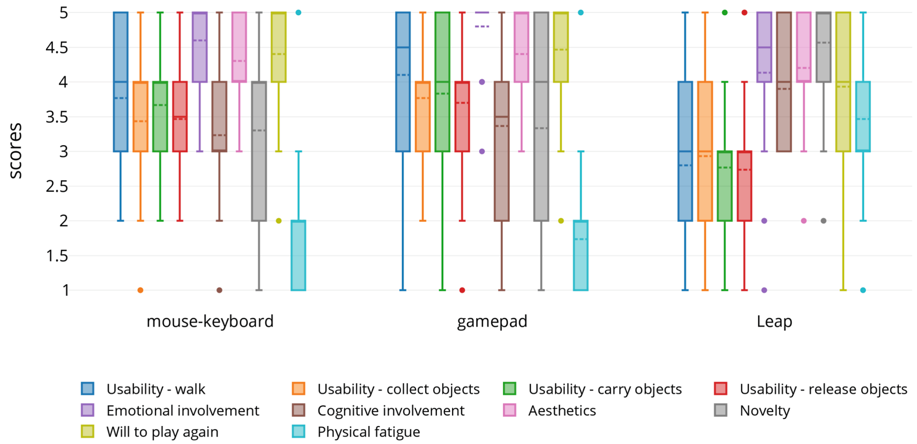

Fig. 3. Results of the intermediate questionnaire related to the engagement and the physical fatigue

as well. Figure 3 shows that gesture-based interaction gained the lowest scores for what concerned the usability, and that some actions were more difficult to perform. It was clearly considered by the children also as the most physically demanding and required also additional cognitive involvement. On the other side, gesture-based interaction was perceived as the most novel. For all the other parameters differences are less evident. The gamepad and the mouse-keyboard obtained generally similar scores, with a slight advantage of the gamepad for all the parameters.

The answers to the open questions brought additional insights. The mouse-keyboard set was appreciated for the familiarity of the devices, although for some children the same familiarity appeared as boring. This input solution received many appreciations for its usability as well, although some children were confused by the use of the keys and suggested to simplify interaction using only the mouse. Some children suggested also to use the more common WASD set of keys for locomotion, as an alternative to the use of the arrows. Also the gamepad was appreciated for its familiarity and usability. A lot of children stated that the gamepad was very engaging. While many children appreciated how we mapped the gamepad buttons and sticks to the actions in the 3D world, some of them suggested alternatives for locomotion (e.g., arrows instead of the stick) and for the hand motion (e.g., using different keys or a stick for changing the hand's vertical position). The Leap was appreciated by the users for its novelty and the possibility to use their hands for controlling the interaction, giving a feeling of direct connection with the 3D world. Different children however emphasized the physical fatigue, due to the need of keeping the arm in a straight position for long periods of time. Children evidenced also the difficulty to interact and perceived a lack of precision or an excessive sensitiveness during the use of the device. On the other side, children were engaged by the challenge of controlling it properly.

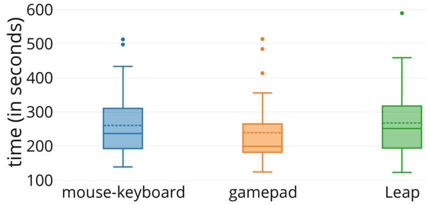

Fig. 4. Time of completion

Fig. 5. Errors

The children's suggestions were mainly related to the locomotion actions: some of them suggested to associate them to the act of pointing a finger. One of the children considered the gesture of moving the fist as a combat action and stated that he would have preferred an alternative mapping. Another child suggested to mimic the legs' movement with the fingers.

The analysis of the time needed for completing the session (Fig. 4) shows that the gamepad permitted to obtain the best results in terms of mean, median and quartiles, while the use of the keyboard/mouse and of the Leap obtained similar but worse results. The analysis of errors shows that a much higher number of errors characterized the experience with the Leap (see Fig. 5). The most evident differences are related to the act of collecting the objects. The exam of the errors during the transportation and the placement of the collected object confirms a difficulty in using the Leap, although differences are less evident. Finally, while the mouse-keyboard set and the gamepad required more assistance during the practicing phase (there were respectively 20 and 23 requests of assistance, vs. 16 requests for the Leap), things radically changed during the main sessions. There was only one request of assistance for the mouse-keyboard set and the gamepad, while there were 9 requests for the Leap.

5 Discussion and Conclusion

The result of this study showed that the Leap and gesture-based interaction was perceived as an interesting novelty (Fig. 3), in a context characterized, as shown by the first questionnaire, by the familiarity with gaming platforms and desktop environments, but scarce acquaintance with this type of device and interaction. Children were engaged by gesture-based interaction and by those gestures that mimicked the manipulation in the real world [2,5], as evidenced from the answers to the open questions. All the requests of modifying the mappings of the Leap were referred to the locomotion, which unfortunately was not possible to mimic. A number of issues emerged from this study, related in particular to the physical fatigue and the usability (Fig. 3). Both issues were evidenced also by the answers to the open questions. Besides, the quantitative data suggest that what contributed to originate the children's judgement, rather than an increase in the time needed for completing the task, was the high number of errors performed during the interaction, due to the lack of precision evidenced in the open questions. The direct observation evidenced also that a part of the errors (e.g., the involuntary ungrabbing of the object during locomotion) were due to the fact that the children moved their hand outside the scanning boundaries of the device. The analysis of the assistance given to children evidenced also that the difficulties were due, rather than to a conceptual comprehension of the interaction mechanism, to its practical utilization.

Resuming, in this work we identified some major problems in gesture-based interaction whose resolution could led to a wider use of this technology, that it is interesting for a number of factors. We can infer from the results of the study that the issues related to physical fatigue seems to be related to the nature of gesture-based interaction, while the usability problems seem more related to technological difficulties. Solutions for the first issue can be related to the design of gestures less physically demanding and that don't require a continuous action by the user. These solutions however should take into account the preference for gestures that mimic reality, as confirmed also from this study. In this respect, additional benefits might come from considering, during the design, the posture of the whole body during interaction, in order to define a more satisfying solution from the ergonomic point of view. The availability of a library with a wider number of gestures of course would bring great benefits for further experimentation. Solutions for the second issue can come from different factors, including the tuning of the mapping used in this study, but also the availability of more advanced libraries for the precise management of the input. The results of this study suggest also that there are a number of potential domains for the application of gesture-based interaction, where the impact of physical fatigue would be minor, because the interaction with the system would be limited or more distributed in time. Smart home applications seem good candidates on this respect. Additional insights might come from long term studies, for eliminating completely the novelty effect and give the user more time for improving the control of the device. Finally, concerning the educational potential of this new technology, the study gave mixed results. Only a part of the factors that define the engagement received higher scores (novelty). For other parameters the Leap didn't gave a competitive advantage over the other devices. Some results, such as the cognitive involvement requested by the Leap, might be read as positive in an educational context. As a matter of fact, part of the children declared that they appreciated the challenge of mastering this device. However the prolonged use of the device and the precision problems might hamper the use of gesture-based interaction and discourage the users after the end of the novelty effect. Therefore usability and physical fatigue are critical factors that should be taken in serious account in the future development of this technology. At the current state gesture-based interaction seems to be a great solution for educational experiences that don't require a prolonged use and high levels of precision; in this sense, it appears as a useful integration rather than a replacement of the existing technologies.

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