GeoTUI: A Tangible User Interface for Geoscience

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ABSTRACT

GeoTUI is a system designed for geophysicists that provides props as tangible user interface on a tabletop vision-projection system for the selection of cutting planes on a geographical map of a subsoil model. Our GeoTUI system allows the geophysicists to manipulate in the same action and perception space since the movement of the physical artifacts is done on the tabletop and thus constrained to two dimensions. Consequently, it combines the advantages of the spontaneous conditions of user interaction that the geophysicists are commonly used to in their classical paper/pen/ruler environment with the advantages of the use of powerful geological simulation software. We conducted an extensive user study in the workplace of the geophysicists that clearly revealed that using a tangible interaction performs better than using the standard mouse/keyboard GUI for the cutting line selection task on a geographical subsoil map. Consequently, it increases the efficiency for the real-world trade task of hypothesis validation on a subsoil model. Moreover, this geological user case is complex enough to confirm the hypothesis that in space-multiplex conditions, specialized devices perform better than generic ones.

Author Keywords

TUI; two-handed interaction, tabletop, user study, geoscience.

ACM Classification Keywords

H5.2 [**Information interfaces and presentation**]: User Interfaces—user-centered design, interaction styles, evaluation/methodology, input devices and strategies.

INTRODUCTION

In the field of energy, a strategic domain activity is the search of hydrocarbons by geoscientists. The geophysicists are in charge to reconstitute a three-dimensional (3D) model of the deep basement by interpreting seismic 3D data (see Figure 1) based on their expertise and rule-trades, and assisted by powerful geological simulation software. In order to integrate the human factors in the design of the involved computer human interface, it is obvious to take into account the end user of the interface during the design. It is also important to take into account the experiment and the know-how of the concerned user in order to develop tools that are adapted to the targeted tasks.

In this paper, we present GeoTUI, a system designed for geophysicists that provides props as tangible user interface (TUI) on a tabletop vision-projection system for the selection of cutting planes on a geographical map of a subsoil model.

The remainder of this paper is organized as follows. In the following section, we present the two major concerns of the geophysicists that are at the origin of their need of a new kind of interaction. Then, we discuss some solutions from previous work. After that, we describe our GeoTUI system in detail and propose some possible physical interfaces, or props, that can be used for the specific task of cutting line selection on a tabletop. We also describe the user studies that we conducted in order to evaluate the possible props. Then, we outline the contribution of these studies for both the geological domain and the domain of tangible user interfaces. Finally, we conclude and give directions for future work.

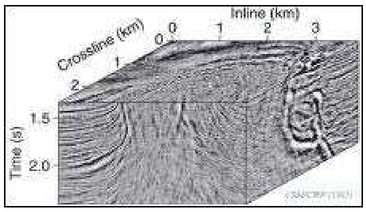

Figure 1. Seismic 3D volumetric data.

THE NEED OF A NEW KIND OF INTERACTION

Before deciding the construction of an oil well, the geophysicists must answer various kinds of questions. Of course, they must be able to locate an oilfield and specify the optimal drilling site that will make it possible to exploit the greatest quantity of oil. Therefore, the geophysicists need to know the exact composition of the subsoil. They study, for example, the pressures that are exerted. Thus, a model of the subsoil must be computed (in a mathematical sense). Usually, the first model is a sample of points in the 3D space that is initially obtained by seismic acquisitions. The geologists and geophysicists interpret this rough model and reiterate assumptions on the nature of the rocks, until they obtain a mathematical model that is as close as possible to reality.

To our knowledge, all geological simulation software use graphical user interfaces (GUI) and increase the efficiency of the geophysicists. For example, in order to interactively explore geographical subsoil models, new cutting planes can be visualized efficiently after the selection of new cutting lines on the map. Consequently, the hypothesis validation on a subsoil model can be done very efficiently. As a consequence, the performance of the cutting line selection task accurately reflects the overall performance of the system. However, the success of the geological software is still limited. In an on-site study at the French Institute of Petroleum (IFP), we identified two major concerns of the geophysicists that could be at the origin of this limitation. A first concern is the difficulty to interact via the graphical user interface. This is due to the strict interaction protocol when using the mouse or the keyboard that makes it difficult to concentrate on the intrinsic task. For example, the geophysicists have difficulties to position cutting lines with the graphical user interface, because they are accustomed to interact with pens and rulers on classical paper maps. A second concern of the geophysicists is the difficulty to collaborate by using the keyboard or the mouse in front of a screen (even in front of large dual screens). They find it impractical and exhausting. Indeed, geologists and geophysicists are accustomed to long working sessions with paper maps and printed seismic records around a desk.

The goal of our work is twofold: simplify the interaction, and facilitate the collaboration. Our on-site study at the Institute of Petroleum initiated us to design the GeoTUI system that overcomes these two concerns. The major idea is to use a tabletop vision-projection system and props as tangible user interfaces that can be manipulated directly on any suitable table (see Figure 2). In this way, we combine the horizontal working conditions (that the geophysicists are used to when working on a desk) with the use of powerful geological simulation software. Moreover, by using the props directly on the table, the geophysicists interact in the same way as in the classical paper map environment.

PREVIOUS WORK

The first tabletop approach can be attributed to Wellner in 1993 [21] with the DigitalDesk, and the formalization of graspable user interfaces or tangible user interfaces can be attributed to Fitzmaurice, Buxton, Ullmer and Ishii [3][9]. There is some prior work on combining these two ideas, i.e. using TUIs in combination with a tabletop, like for example Audiopad [16], the IP Design Workbench [12] (a great source of inspiration for us), and Built-IT [5]. Several technologies are used in these systems, such as video-projectors to display the data, and electromagnetic sensors, or optical tracking in order to acquire the physical properties of the objects. In this regard, we can cite recent issues: the framework ReacTIVision [11] or the commercially available system Microsoft Surface [23]. Both use IR cameras and rear capture through a glass table.

According to the targeted task, we are interested in using props for selecting a cutting plane in 3D volumetric data. Probably the most related previous work is the idea of Hinckley et al. [7] where props are used for selecting a cutting plane in 3D volumetric brain data for neurosurgical visualization. The tangible representation of the manipulated data is a head viewing prop and a cutting-plane prop that helps to easily control the position and the angle of the slice to visualize. Note that there is no tabletop in this seminal work. The Visual Interaction Platform [1] proposes that the manipulated 3D data is not at all represented, neither tangible nor intangible. The 3D data is virtually present on top of the table, and the user manipulates the RISP (Rigid Intersection Selection Prop) above a "3to2D window", a delimited zone on the table where the resulting visualization is displayed. In the field of interacting with geographical data, let us notice the Illuminating Clay [19] system that allows the user to define and to position a more general two-manifold surface for digital terrain modeling. The user specifies the surface by modeling clay or plasticine with his hands. The modeling of clay is also used in the Phoxel-Space system [20] to specify cutting surfaces of a 3D volumetric brain model.

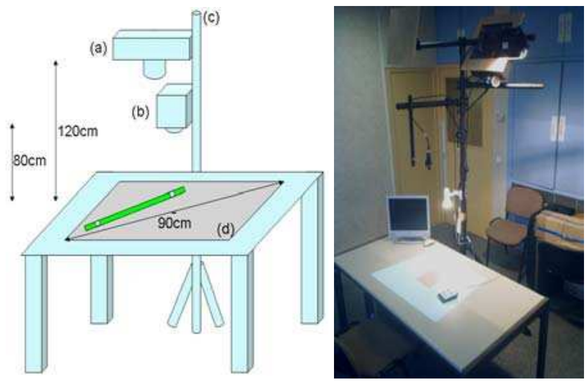

Figure 2. (left) the schematic view, and (right) the setup of our GeoTUI system at the Petroleum Institute.

In the Illuminating Clay system, the Phoxel-Space system, the IP Design Workbench, ReacTiVision and Microsoft Surface, the perception and action space coincide. This is not the case in the work of Hinckley et al. [7] and in the Visual Interaction Platform, where the resulting visualization is separately displayed on a screen, and thus the perception and action space do not always coincide.

THE GEOTUI SYSTEM

In this paper, we focus on the specific task of cutting plane selection on geographical subsoil maps that is the key task in geological applications. The cutting planes that we define are always perpendicular to the map. In the context of a geographical subsoil model, to the best of our knowledge, the GeoTUI system is the first work that uses props as TUIs on a tabletop for the specific task of selecting cutting planes that are perpendicular to the tabletop. Following the recommendations of Norman [14], the GeoTUI system has a perfectly coinciding action and perception space. Consequently, the geophysicists can be concentrated as much as possible on the actual working task. The major goal is to integrate virtual elements within the real world that the geophysicists physically inhabit.

In the GeoTUI system, the cutting planes are constrained to being perpendicular to the top of the map displayed on the table, since it is too difficult for the geophysicists to create a mental 3D representation of the subsoil starting from arbitrarily oriented cutting planes. Consequently, the GeoTUI system also facilitates collaboration. Once a first user proposes a cutting line, another user can modify the proposition easily since the props stay at their position. The first and most important question is the following:

What is the best interaction?

To answer this question, we implemented four means of interaction for the manipulation of the subsoil model. "The best interaction" has to be understood in terms of speed, and, more importantly, in terms of reliability. One is with the mouse on the screen (classical GUI), and three are with tangible props as input, and the tabletop as output. A key problem in interface design is to choose an adequate physical form for representing the control of the digital information. We chose the props so that they recall the everyday working conditions, either the classical paper map environment or the selection of a cutting line with the mouse in the GUI. The four different props that we chose are denoted in the following by *(M)* for mouse, *(1P)* for one-puck, *(2P)* for two-pucks and *(R)* for ruler. Since the 2D cutting plane of the selected cutting line cannot be calculated on the fly, we provide an additional device, the physical button box, that offers buttons to engage the calculation of the 2D cutting plane (see Figure 3 (BB)).

The mouse (M)

Selecting the cutting line in a GUI with the mouse pointer is done by specifying two points of the line, as in common vector graphics applications. The resulting cutting line can be changed by moving the handles of the two points, or replaced by creating a new line.

The one-puck prop (1P)

One puck, made of wood with a diameter of 35mm, a thickness of 10mm, and a green coloured marker on top, is used as a physical handle for the cutting line. The dialog with the system is similar to the one with the mouse pointer *(M)*.

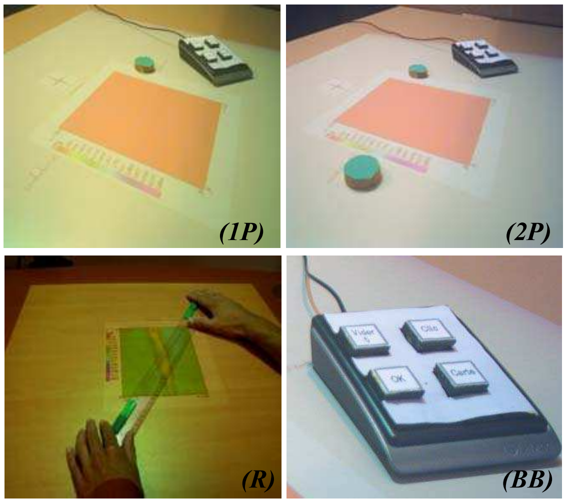

Figure 3. ***(1P)*** **the one-puck prop,** ***(2P)*** **the two-puck prop,** ***(R)*** **the ruler prop and** ***(BB)*** **the button box.**

The two-puck prop (2P)

Two pucks, the same ones as in *(1P)*, physically represent the two cutting line handles. In order to create a cutting line, the user puts the two pucks on the table, and the line is displayed directly. To select another cutting line, the user moves the pucks to the desired position. There is no stage of grabbing activation of the line because the physical handles continuously control the line.

The ruler prop (R)

A ruler prop, a flat 30cm long and 4cm wide ruler made of translucent plastic with two green markers glued on each extremity, is used as a physical representation and control of the cutting line. Once the ruler is on the map, the line along the graded border of the ruler is displayed, as if the user would have drawn the line by himself. To select another cutting line, the user moves the position or the orientation of the ruler, and the cutting line is modified accordingly. There is no stage of grabbing because the ruler continuously controls the line.

The button box (BB)

We built a button box consisting of physical buttons in spirit of Norman [15]. The four buttons are labelled exactly the same as the button widgets in the GUI interface that the geophysicists usually manipulate. The first button validates the selected cutting line on the map, and the 2D cutting plane is displayed instead of the map. The second button allows the user to get back to the map display. The third button erases the last 5 displayed cutting lines on the map, and the fourth button connects or disconnects a puck to the handles of the cutting line.

We preferred to provide a physical button box instead of putting buttons on the props, because we wanted to propose objects that the geophysicists are familiar with – and those do not have buttons as well. Nevertheless, we believe that it would be useful to put a button when manipulating *(1P)*, since it has to be pressed frequently because it is part of the manipulation task. However, it is not that easy to find the correct size and position of the button so that it is easily accessible but not pressed unintentionally. Still, it would be interesting to compare the button box to the buttons on the props in a formal user study for all four different interactions.

Implementation

We designed a prototype, the GeoTUI system, by using a video-projector for the output of the data and a camera for the optical tracking of the props. Both the projector and the camera are fixed on a moveable tripod in order to provide a horizontal flat working surface like a table or a desk (see Figure 2). Our setup was motivated by the strong design constraints of our partner to obtain an economic and mobile system that can be installed in every office. The GeoTUI system controls a geological application called JOHN (Jerry On tHe Net) [10], that was developed by the Institute of Petroleum. JOHN is an interactive software for the manipulation of 3D volumetric geographical subsoil models. In the following, we provide a detailed description of the physical setup of our prototype, the involved optical tracking procedure, and the interface substitutions of JOHN that have to be done.

Physical setup

Our hardware architecture is illustrated in Figure 2. For the display (a), we use an EPSON EMP7200 video projector with 1000 ANSI lumens luminosity at a resolution of 1280 x 1024 pixels. The tracking of the physical objects is done by using a SONY XC-555P firewire video camera (b) that captures images of the projection area at a resolution of 720 x 540 pixels. Both the projector and the camera are fixed on a SHOWTEC 70128 Aluminium double T-Bar (c) at the height of 120cm and 80cm, respectively, above an ordinary table. The resulting projection area (d) is about 90cm in diagonal. A small angle is applied to the video projector to avoid shadows under the user's fingers and hands. We decided to fix our installation on the aluminium tripod stand instead of hanging it on the ceiling in order to obtain a mobile system that can be moved from one office to another (inspired by PlayAnywhere [22]).

The optical tracking procedure

We use optical tracking in order to locate the props on the table. The green plastic markers glued on the props are tracked on the images captured by the video camera (see Figure 4).

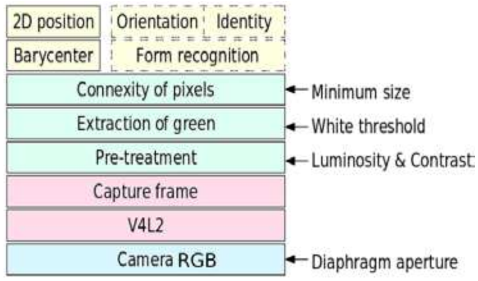

Figure 4. The tracking of the markers.

The interface substitutions

The software for the GeoTUI system was developed in C++ using the GTKmm 2.0 graphics library for creating the images. We built a communication protocol through a UNIX socket with JOHN. GeoTUI sends instructions resulting from the user manipulations, and JOHN sends back calculated images. Note that the GeoTUI system only substitutes the GUI of JOHN while the trade tasks remain the same - only the interaction is modified. On the surface of the table, only maps and cutting planes are displayed as if they were sheets of paper, and all the WIMP components are removed (the borders of the windows, the mouse pointer, and the menus). The screen, the mouse and the keyboard are also removed. Consequently, the users only dispose of the tangible props and the button box for the interaction.

EXPERIMENTATIONS

We conducted two user studies for evaluating the GeoTUI system. The first study was an explorative user study to see whether the users accept such a new kind of interface, and which props they choose spontaneously. The second study was a more formal user study to evaluate and compare the four different interactions *(1P)*, *(2P)*, *(R)*, and *(M)*. During a one year period, the GeoTUI prototype was transported twice from our laboratory to the Institute of Petroleum in order to conduct the studies on-site in the workplace of the geophysists. In order to efficiently collect and exploit the results of the user studies, we were three persons to organize it. A first person explained the task and conducted the experiments, a second person observed how the users were handling the props, and a third person was collecting the oral remarks of the subjects when they filled in a questionnaire. This questionnaire was designed to get a qualitative and subjective feedback of the GeoTUI user interface. In addition to our observations, we recorded the important user actions of the GeoTUI software into a logfile. All participants performed both exercises with all the different interactions (within-subject design). The order of using the GUI and TUI is counterbalanced, and when testing several props in the second user study, the interaction order is counterbalanced as well.

First user study

The first explorative study was organised as a day expert evaluation. The participants were ten persons from the IFP. Two of the volunteers were female and eight were male, aged from 23 to 59 years (41 years in average). The participants were geophysicists or were familiar to the field of geophysics. All participants had a high skill in general computer usage. Two participants were left-handed, five were right-handed, and three were ambidextrous with a preference for the right hand.

Two kinds of exercises were required: the first one was to perform five precise cutting planes at given coordinates, and the second one was to navigate through a model in order to find marks. A mark is an impact of a ray tracing obtained by seismic acquisition. Those marks were hidden in the subsoil at random locations. The second exercise was limited to 10 minutes, and the users had to write down the number of marks they found on a sheet of paper. The data was available in 20 exercises, and 320 cutting lines were done during 8 hours.

This first experimentation had two important results. First, 100% of the subjects chose the ruler to perform the task of selecting a cutting line on a map in order to obtain a perpendicular cutting plane. We believe that this is due to the affordance of the ruler to control a cutting line. The second result is the adhesion of the geophysicists to use GeoTUI.

Second user study

The second experimentation was organised as an all day long expert evaluation. This second experimentation was designed to qualify the four different kind of interactions *(1P)*, *(2P)*, *(R)*, and *(M)* for the selection of a cutting line in order to navigate in the seismic 3D data. We were interested to know which interaction is the best in terms of manipulation and to determine which one allows the most rapid realization of the tasks, and, before all, which interaction conducts to the best result.

The participants were 12 geophysicists from the IFP. Three of the volunteers were female and nine were male, aged from 23 to 66 years (41 years in average). They were all familiar to the geologic application field and with computer usage. They were all right-handed. Together with the IFP, we determined two kinds of exercises that only require navigation tools.

The first exercise consists in the selection of a series of six cutting planes at various given coordinates on the map. According to Payne [17], these tasks are called *simple tasks* (see Figure 5 (left)).

The second exercise is based on the exploration of the subsoil. Imagine a 3D geometric form, shaped as a letter of the alphabet and hidden in a cube, and you can only view the 2D planes of this cube. By specifying cutting planes, the user must locate and identify this letter. In this exercise, the former cutting planes that were selected helped the user to mentally solve the global problem. Then, the user's observations have a direct impact on the selection of the next cutting planes. Those tasks are called *composed tasks* because each of them is a combination of sub-tasks (see Figure 5 (right)).

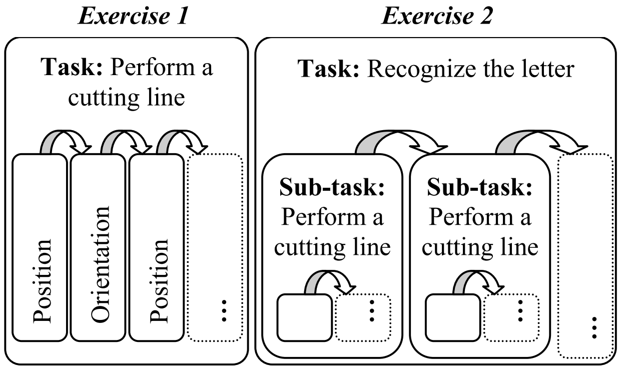

Figure 5. (left) a simple task, (right) a composed task.

The recorded log file was 5.000 lines long after 9 hours of experiments. The data was available for 96 exercises and 620 cutting planes.

As we will see below in the results section, this second experimentation shows quantitative and convincing values to argue that tangible interaction is useful in geosciences, and provides a user case which validates a hypothesis of Fitzmaurice [2] of general scope.

RESULTS OF THE USER STUDIES AND DISCUSSION

Benefits for geoscience

As a first result, we proved the acceptance of the geophysists of the tangible user interaction. Indeed, in the first exercise of the first experimentation, in all 50 exercises (5 exercises for each of the 10 subjects), nobody refused to use the TUI, but 2 subjects refused to use the GUI (20%). The essential reason was that the exercise was too difficult. We have to admit that the TUI had the advantage to be innovative, and that the subjects were very curious to test it.

The contradiction between the significant difference in the special layout task and the non-significant result of the subjective reports of [6] was not encouraging. The second result is that, in our case, both the quantitative results (see Table 1) and the qualitative results were in favour of the TUI. The specific subjective comments of the subjects about the four interactions are synthesized in Tables 2 and 3. Note also the following general comments and suggestions: *"Very interesting."*, *"Interesting in combination with a classical interface."*, and *"Plan buttons on the ruler."*

After these experiments on the subsoil model, the superiority of the tangible interfaces on a tabletop compared to the standard GUI is pointed out in this specific experimental context. This is not surprising when taking into account the well-known results of the benefit of direct manipulation techniques versus indirect manipulation techniques. But the experimentation enabled us to convince our partner institute and their geophysicists about the interest to use a TUI.

	M	*1P*	*2P*	*R*
Easiness to select a line	4.1	2.6	4.6	5.2
Most precise interaction	3.8	2.8	4.8	5.1
Most rapid interaction	3.8	2.5	4.6	5.3
Most simple interaction	4.2	2.7	4.6	5.2
User preference	3.5	2.7	4.5	5.0
Concentration on recognition	3.8	2.6	4.4	4.8

Table 1. Averages of the subjective ratings of the users scaled from 1 to 6 (6 is best).

M	*"Known manipulation." – "Habit of working with such a tool." – "There is only one tool." – "Lower motions." "Less tiring for eyes (less sweeping across)."*
1P	*"Each hand has its action (one hand on puck, one hand on button)." – "Only one puck."*
2P	*"Physical contact with extremities of the lines." "Materialization of the points." "The line is automatically created."*
R	*"Good mastering of space, of parallels, perpendiculars, handiness." – "Easiness of the moving translation plus rotation." "Intuitive for the selection of a line."*

Table 2. Strong points, self-reported by the users, in the written questionnaire, for the four interactions.

M	*"Slow for some manipulations." "Focus on the tool at some points."*
1P	*"Complexity of the manipulation." "Many motions to execute." – "The number of motions of the arm." – "Slow." "Always trying to click on the puck."*
2P	*"Too many elements to move and to manage." "Precision of results, the slope of the line varies too much for a small movement." "The pucks are too big."*
R	*"It is difficult to modify one point without modification of the other." – "When I adjust the coordinates of a point, the other point moves and loses its coordinates."*

Table 3. Weak points, self-reported by the users, in the written questionnaire, for the four interactions.

Benefits for general TUI design

The button box

The validation is still an important topic in TUIs and vision-projection systems. There are several solutions of projected buttons coupled with finger tracking, but there is a latency time that can be annoying with the discrete action of validation. Another solution is a validation puck labelled "*OK*" that can be presented anywhere in the projection zone for a validation action. Nevertheless, moving a puck is not always an appropriate representation for a discrete action. Our proposition is a physical button box (Figure 3 (BB)) consisting of real physical buttons, inspired by the dedicated button box work of Perlman [18]. In our GeoTUI system, the dedicated physical buttons are labelled exactly the same as in the GUI interface, and stick out of the box by half a centimetre. Norman explains the benefits of affordances ("physical affordances", not "perceived affordances") and that "people would be better served if we were to return to control through physical objects, to real knobs, sliders, buttons, to simpler, more concrete objects and actions."

Concerning the button box, we observed, for the two user studies, easiness and speed for all subjects. We detected notable mistakes on the button usage ("*Map*" button from the map or "*OK*" button from a cutting plane) in the log file for only one subject. We think that having space localised buttons in relief is efficiently exploited by kinesthesia and allows eyes free operations. Note that the subjects appreciated the bi-manual interaction offered by keeping one hand on the button box when using props (especially *1P* and *R)*.

Manipulation task

At this point, we want to focus on the second exercise of the second user study: the composed task "recognize a letter". Our case study takes place for a two dimensional task (e.g. translate and rotate, but not scale). Let us first remind the definitions of Fitzmaurice given in [2][4].

"With **space-multiplex** input each function is controlled with a dedicated transducer, each occupying its own space. Each transducer can be accessible independently but also simultaneously." "In contrast**, time-multiplex** input uses one device to control different functions at different points in time. The device is being repeatedly attached and unattached to the various logical functions." The **physical form** of an input device is considered **specialized** "when the physical shape of the device roughly matches the shape and manipulation characteristics of the virtual logical controller." The physical form is considered **generic** when it does not match. According to these criteria, in Table 4, we characterize the mouse *(M)* and the three props *(1P)*, *(2P)* and *(R)*.

		Multiplex	Form
GUI	*M*	Time	Generic
TUI	*1P*	Time	Generic
	2P	Space	Generic
	R	Space	Specialized

Table 4. Characterization of the input devices for the cutting line selection task.

Let us now remind the two hypothesis of Fitzmaurice given in [2][4].

Hypothesis 1. [2, chap 6.1] Space-multiplex performs better than time-multiplex.

Hypothesis 2. [2, chap 6.1] In space-multiplex conditions, specialized devices perform better than generic.

Both of these hypotheses have been proved by the experiment in [2, chap 6.2] and [4] that focuses on the issue of space multiplexed input and examined the inter-device transaction phase of interactions. The experimental results obtained for exercise 1 of the second user study show the same conclusions for *(2P)* and *(R)* against *(M)* and *(1P)*.

However, for a manipulating task, the second hypothesis H2 was not validated in [2, chap 6.1] even though the author is convinced about his hypothesis. Numerous works show results on bi-handed manipulation, but as far as we known no experimentations exist about this precise point addressed in hypothesis 2 for a manipulation task.

We observed the results of our experimentation for the specialized device, the ruler *(R)*, and for the generic device, the two pucks *(2P)*. A manipulation task has to be analysed concerning speed and accuracy. That is to say, the capacity of the device to increase the efficiency of the task has to be taken into account.

The results of the experimentation are as follows, for a same longer time:

With two-pucks *(2P)*: 119 cutting lines, 3 letters found and 3 well recognized. With the ruler *(R)*: 140 cutting lines, 8 letters found, and 7 well-recognized. Furthermore, *(R)* is faster than *(2P)*, and, more interesting, *(R)* is more efficient than *(2P)*. We then validate by convincing results the hypothesis H2 for a manipulation task (half a day evaluation with 12 experts): an 18 % speedup (from 119 to 140 cutting lines) and a 133 % performance gain (from 3 to 7 letters) with the specialized device ruler *(R)* compared to the generic device two-pucks *(2P)*.

The additional physical constraints of the specialized device help the users to physically maintain the relationships that exist between the dimensions of the virtual line and the real line being drawn. In our case study, the cognitive correspondence between the ruler and the control of a cutting line is highly intuitive. Remember that in the first experimentation, 100% of the 10 subjects chose the ruler to perform the task of selecting a cutting line on a map to obtain a perpendicular cutting plane. Hence, the specific physical form of the ruler helps the users to concentrate on the task of finding a letter. The subjects have a global working problem to solve and specify various cutting planes in order to achieve it. For each condition, Figure 5 shows the average manipulation times obtained for both exercises.

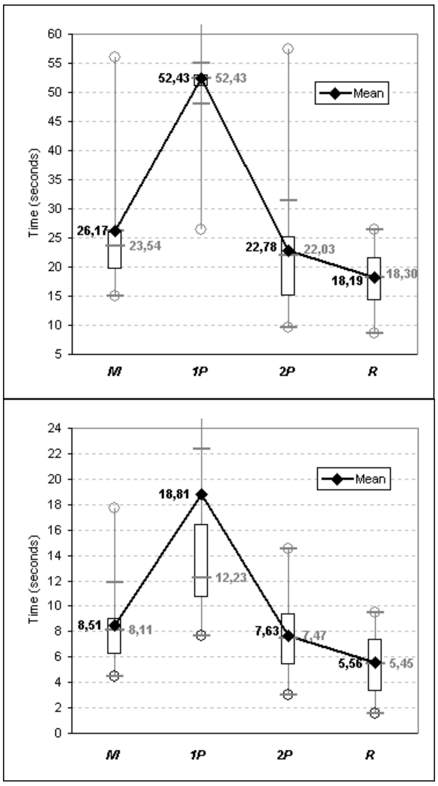

Figure 5. Means and box plots of the times to select a cutting line during the first exercise (top), and the second exercise (bottom), using each interaction.

CONCLUSION

Geoscience is a novel application area for tangible user interfaces, and we presented the GeoTUI system that was specifically designed for geophysicists. It provides props as tangible user interface on a tabletop vision-projection system for the selection of cutting planes on a geographical map of a subsoil model. Consequently, it combines the advantages of the spontaneous user interaction that the geophysicists are commonly used to in their classical paper/pen/ruler environment, with the advantages of the use of powerful geological simulation software.

We presented and discussed technical means to integrate a virtual geological map and virtual cutting planes with real and physical props for interaction and control. In the context of geological applications, we validate the hypothesis of Fitzmaurice [2, chap 6.1] by convincing quantitative results: the experiment showed that the specialized space-multiplexed conditions outperform the generic space-multiplexed conditions since the task implies a global working problem that has to be solved by means of the manipulation of input devices. Hence, the ruler will be a more appropriated input device for the geophysicists. It may help them to concentrate more on their actual complex working task. Certainly, the fact to work in a coinciding action and perception space, thanks to the tabletop, is also decisive.

As future work, promising research investigates tangible interaction for spline editing in our geological context. Integrating this work in order to interact on a tabletop could improve other tasks of the geoscientists.

The tabletop has also been chosen because of its capacity to support collaborative work. We plan to follow the ideas of Hornecker [8], as well as Maher and Kim [13] in order to lead experimentations and to explore results on the benefits of TUIs on tabletops at a cooperative and collaborative point of view for our concrete application field.

REFERENCES

1. Aliakseyeu, D., Subramanian, S., Martens, J.B. and Rauterberg, M. Interaction Techniques for Navigation through and Manipulation of 2D and 3D Data. In *Proc. EGVE'02*, Eurographics Association (2002), 179-188.
2. Fitzmaurice, G. *Graspable User Interfaces*. PhD Thesis, University of Toronto, Canada, 1996.
3. Fitzmaurice, G., Ishii, H. and Buxton, W. Bricks: Laying the Foundations for Graspable User Interfaces. In *Proc. CHI'95*, ACM Press/Addison-Wesley (1995), 442-449.
4. Fitzmaurice, G. and Buxton, W. An empirical evaluation of graspable user interfaces: Towards specialized space-multiplexed input. In *Proc. CHI'97*, ACM Press (1997), 43-50.
5. Fjeld, M., Bichsel, M. and Rauterberg, M. BUILD-IT: An Intuitive Design Tool Based on Direct Object Manipulation. In *Proc. GW'97*, Springer-Verlag (1997), 297-308.
6. Hang, C, Not Just Intuitive: Examining the Basic Manipulation of Tangible User Interfaces. In *Proc. CHI'04*, ACM Press (2004), 1387-1390.
7. Hinckley, K., Pausch, R., Goble, J.C. and Kassel, N.F. Passive Real-World Interface Props for Neurosurgical Visualization. In *Proc. CHI '94*, ACM Press (1994), 452-458.
8. Hornecker, E. Understanding the Benefits of Graspable Interfaces for Cooperative Use. In *Proc. Coop'2002*, IOS Press (2002), 71-87.
9. Ishii, H. and Ullmer, B. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms, In *Proc. CHI '97*, ACM Press (1997), 234-241.
10. Jurado, F., Sinoquet, D. and Lailly, P. Jerry: a 3D reflection tomography designed for complex structures. *KIM 1996 Annual Report*, Institut Français du Pétrole, Pau, France, 1996.
11. Kaltenbrunner, M. and Bencina, R. reacTIVision: a computer-vision framework for table-based tangible interaction. In *Proc. TEI'07*, ACM Press (2007), 69-74.
12. Kobayashi, K., Hirano, M., Narita, A. and Ishii, H. A Tangible Interface for IP Network Simulation. In *Proc. CHI 2003*, ACM Press (2003), 800-801.
13. Maher, M.L. and Kim, M.J. Studying Designers Using A Tabletop System For 3D Design. In *Proc. Tabletop 2006*, IEEE Computer Society (2006), 105-112.
14. Norman, D.A. *The Psychology of Everyday Things*. Basic Books, NY, USA, 1988.
15. Norman, D.A. Affordance, conventions, and design. *Journal Interaction 6,* 3 (1999), 38-43.
16. Patten, J., Recht, B. and Ishii, H. Audiopad: A Tag-based Interface for Musical Performance. In *Proc. NIME02*, National University of Singapore (2002), 11-16.
17. Payne, S.J. and Green, T.R.G. Task-Action Grammars: A Model of the Mental Representation of Task Languages. *Human-Computer Interaction 2*, 2 (1986), 93-133.
18. Perlman, R. Using computer technology to provide a creative learning environment for preschool children. *MIT AI Lab Memo No. 360/Logo Memo No. 24*, (1976).
19. Piper, B., Ratti, C. and Ishii, H. Illuminating Clay: A 3-D Tangible Interface for Landscape Analysis. In *Proc. CHI 2002*, ACM Press (2002), 355-362.
20. Ratti, C., Wang, Y., Piper, B., Ishii, H. and Biderman, A. PHOXEL-SPACE: an Interface for Exploring Volumetric Data with Physical Voxels, In *Proc. DIS '04*, ACM Press (2004), 289-296.
21. Wellner, P. Interacting with paper on the DigitalDesk, *Communications of the ACM 36,* 7 (1993), 86-96.
22. Wilson, A.D. PlayAnywhere: A Compact Interactive Tabletop Projection-Vision System, In *Proc. UIST'05*, ACM Press (2005), 83-92.
23. Microsoft Surface. http://www.microsoft.com/surface/