Whole Body Interaction with Geospatial Data

Florian Daiber, Johannes Schöning, and Antonio Krüger

Institute for Geoinformatics, University of Münster,
Weseler Str. 253, 48151 Münster, Germany
{flowdie,j.schoening,kruegera}@uni-muenster.de

Abstract. Common Geographic Information Systems (GIS) require a high degree of expertise from its users, making them difficult to be operated by laymen. This paper describes novel approaches to easily perform typical basic spatial tasks within a GIS: e.g. pan-, zoom- and selection-operations by using multi-touch gestures in combination with foot gestures. We are interested in understanding how non-expert users interact with such multi-touch surfaces. We provide a categorization and a framework of multi-touch hand gestures for interacting with a GIS. This framework is based on an initial evaluation. We present results of a more detailed in situ-study mainly focusing on multi-user multi-touch interaction with geospatial data. Furthermore we extend our framework using a combination of multi-touch gestures with a small set of foot gestures to solve geospatial tasks.

1 Introduction and Motivation

Multi-touch has great potential for exploring complex content in an easy and natural manner and multi-touch interaction with computationally enhanced surfaces has received considerable attention in the last few years. Some designers make use of the geospatial domain to highlight the viability of their approaches. This domain provides a rich testbed for multi-touch applications because the command and control of geographic space (at different scales) as well as the selection, modification and annotation of geospatial data are complicated tasks and have a high potential to benefit from novel interaction paradigms [1]. One important observation of previous studies [2] with multi-touch Geographic Information Systems (GIS) is that users initially preferred simple gestures, which they know from Windows-Icons-Menus-Pointer (WIMP) systems with mouse input. After experiencing the potential of multi-touch, users tended towards more advanced physical gestures [3] to solve spatial tasks, but these gestures were often single hand gestures or gestures, where the non-dominant hand just sets a frame of reference that determines the navigation mode, while the dominant hand specifies the amount of movement. So far the combination of hand and foot input has gained only little attention [4]. This combination has a couple of advantages and helps to rethink the use of the dominant and non-dominant hand. Foot gestures can be used to provide continues input for a spatial navigation task, which is more difficult to operate with the hands in a natural way.

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Hand gestures are good for precise input regarding punctual and regional information. It is however difficult to input continuous data with one or two hands for a longer period of time. For example, panning a map on a multi-touch wall is usually performed by a "wiping"-gesture. This can cause problems if the panning is required for larger distances, since the hand moves over the surface and when it reaches the physical border it has to be replaced and then moved again. In contrast foot interaction can provide continuous input by just pushing the body weight over the respective foot. Since the feet are used to navigate in real space such a foot gesture has the potential advantage of being more intuitive since it borrows from a striking metaphor.

In this paper, we present a framework for multi-touch interaction with GIS, an initial evaluation of that framework, a larger study with non-expert users and the extension of the multi-touch framework for the combination of foot and hand input. The following section places this paper in the context of the related work in the variety of fields that provide the basis for this research. In the third section the three key parts of a conceptual framework for multi-touch interaction with spatial data is proposed. Afterwards in section four, the framework is extended with foot gestures. A first evaluation of the multi-touch framework and a second study about multi-user interaction is presented in section five. Section six gives a short overview about the implementation of the system. The paper concludes with a discussion of the results and ideas for future work.

2 Related Work

Until today mice and keyboards are still used by most GIS users to navigate, explore and interact with a GIS even though they are not optimal devices for this purpose. Since 1999 several hardware solutions exist that allow for the realization of GIS with multi-touch input on surfaces of different sizes. The webpage[1] of Buxton is giving a good and complete overview on the current technologies as well as the history of multi-touch surfaces and interaction. With today's technology [5] it is now possible to apply the basic advantages of bi-manual interaction [6],[7] to the domain of spatial data interaction. Also the selection of relevant data, the configuration of adequate data presentation techniques, and the input or manipulation of data are central tasks in a GIS (as in any interactive system)[8]. For the study of our multi-touch GIS system with multiply users we installed an interactive surface in a pedestrian underway. Large interactive screens installed in public space are not so far from fiction [9]. Jeff Han's YouTube demonstration[2] captured the imagination of researchers and users alike. Technologies that allow the low-cost implementation of robust multi-touch interaction, such as Frustrated Total Internal Reflection (FTIR) [10] and Diffused Illumination (DI) [5], have allowed the low-cost development of such surfaces and have led to a number of technological and application innovations. From an HCI perspective it is interesting to investigate how these large interactive screens can support

[1] `http://www.billbuxton.com/multitouchOverview.html`

[2] `http://www.youtube.com/watch?v=QKh1Rv0PlOQ`

different kinds of collaborative interactions. To our knowledge this is the second attempt to analyze the interaction at a large multi-touch display in (or in our case under) a city centre.

Peltonen et al. [11] presented detailed observations from their own large multi-touch display, called CityWall, in the city of Helsinki, Finland. On the DI multi-touch display a photo explorer was presented. They observed various interaction patterns relating to how people used the CityWall installation, and how they collaborated and interacted with each other at the display. Prante et al. [12] proposed different interaction zones (Cell Interaction Zone, Notification Zone, and Ambient Zone) for the interaction with a large public display. This work was followed up by Vogel et al. [13] with their work on an interaction framework for sharable, interactive public ambient displays. Vogel defined four interaction phases, facilitating transitions from implicit to explicit interaction and from public to personal interaction (personal interaction zone, subtle interaction zone, implicit interaction zone and ambient zone). In a former study [2] the focus lies on investigating the usage and user needs of virtual globes. The main result of that study was that the main motivation of around half of the users (53.4% - 11.6%) was to use a virtual globe for either looking at their own house or other individual places (e.g. a neighbor's house, their hotel from their last vacation, the city center). Even though multi-touch interaction gained a lot of attention in the last few years the interaction possibilities of feet were not considered as much, not even in the geospatial domain.

Various researchers did relevant work in the area of foot input for interactive systems. Pearson and Weiser identify appropriate topologies for foot movement and present several designs for realising them in [14]. In an exploratory study [15] they assessed a foot-operated device against a mouse in a target-selection task. The study showed that novices could learn to select fairly small targets using a mole. Pakkanen and Raisamo [16] highlight alternative methods for manipulating graphical user interfaces with a foot and show the appropriateness of foot interaction for non-accurate spatial tasks. In his research on 3D-input devices Zhai established the distinction in rate controlled and position controlled forms of input. While position controlled input depends on where the user directly maps to, rate controlled input means that the user's input is related to the speed of the cursor movement [17]. Following Zhai's classification the multi-touch input is predominantly position controlled while foot input is rate controlled.

3 Multi-touch Interaction with Spatial Data

In contrast to the more general work of Wu [18], a conceptual framework for interaction with spatial data on a multi-touch enabled surface using physical gestures is presented in the following section. This section describes the three key parts of our conceptual framework. Starting by deriving a set of physical interactions, followed by describing the interaction that is needed to manipulate spatial data. Finally, the commands and controls that are needed to manipulate the geographic interaction space (at different scales) are discussed.

3.1 Physical Multi-touch Interactions

As a first step towards developing a framework for multi-touch and foot interaction, a set of simple physical interaction patterns for multi-touch input is derived (see figure 1 inspired by [3] and [18]). For multi-touch input there are three classes of these patterns: simple fingertip, palm-of-the-hand and edge-of-the-hand input. Gestures with the suffix "1" and "2" are simple one hand gestures, whereas "3"–"5" are bimanual gestures. "1"s and "2"s can be combined to make more complex two-handed gestures. Gestures "F1"–"F5" are based on one or two single-finger touches. These gestures are derived from pointing motions. Interacting via one or two whole hands is described with gestures "H1"–"H5". The main idea behind the "F" and "H" interaction classes is the direct manipulation of region shaped objects. To interact with line-like objects and to frame or cut objects, the edge of the hand provides another class of gestures. These are the gestures with the prefix "EH". Each interaction class contains the following gestures: Single pointing touch (1), Single moving touch (2) (not only limited to linear movement), Two touches moving in the same direction (3), Two touches moving in opposite directions (4), Moving of two touches in a rotational manner (5) (Physical multi-touch interactions are highlighted with orange in Table 1).

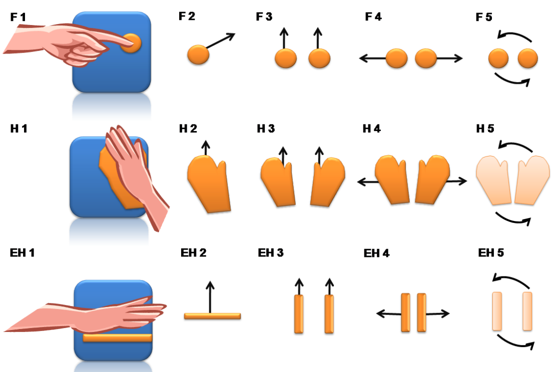


Fig. 1. Set of physical multi-touch gestures

Table 1. Framework for multi-touch interaction with geospatial objects (derived physical gestures)

	World		(Geo-) Objects			Symbols		
	Globe	Plain	Point	Line	Polygon	Point-Symbols	Labels	Layer
POINT	F1	F1	F1	EH1	H1	F1	F1	F1
ZOOM	F4	F4	-	F4	F4	F4	F4	(F4)
PAN	H2	F2	F2	EH2	H2	F2	F2	-
ROTATE	F5	F5	-	F5	F5	F5	F5	-
TILT	H1+F2, H1+H2	H1+H2	-	-	-	F6	-	-
CUT				EH1, EH3	EH1, EH3			-

3.2 Interaction Primitives

In addition to the aforementioned physical multi-touch and foot gestures classes, a set of interaction primitives for interaction with geospatial data is proposed (see Table 1 yellow sidebar). These primitives allow interaction tasks for basic geospatial data, such as pointing or zooming [1], and are commands and controls that are needed to manipulate the geographic interaction space (at different scales) as well as to select, modify and annotate geo-objects. The tasks are point, zoom, pan, rotate, tilt and cut as described in [1].

3.3 Interaction Space

The interaction space is a simple set of graphical views and representations for spatial objects. Interaction primitives are used to modify the (graphical) view, e.g. zooming, panning, and rotating the globe (sphere) or plain (map view). It also contains feature manipulation, feature symbolization (simple symbol changes), feature filtering (hide a layer or feature, show another) and management of background images (see Table 1 green header).

3.4 Multi-touch Gestures for Spatial Tasks

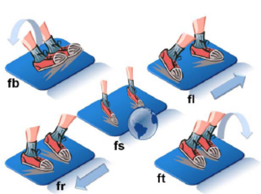
To understand the relationship between gestures and geospatial operations, we have asked 12 participants (five female and seven male) to fill out the matrix with one or more physical interaction primitives or combination of primitives of their choice. All eight participants assigned physical gestures for the interaction primitives in the spatial interaction space at different scales. If three participants agreed on the same interaction primitive, we inserted the proposed interaction styles for various selection and manipulation tasks in Table 1. This table is organized as follows: The rows represent the most common commands that are needed for geospatial tasks: point, zoom, pan, rotate, tilt (i.e. to control the parameters of a geographical view), and cut (as a representative for a topological operation such as dividing an area). We are aware that there might be other commands which could be explored but at this stage of the work we wanted to concentrate on some of the most common ones. The columns of the table represent the geographic space and objects that can be subjects of the various commands. The interaction (selection and manipulation) with geo-objects can be distinguished according to their geometric properties: point, line, and polygon. Finally, in geospatial applications one often finds interaction patterns with symbolic representations (such as a point-of-interest, in the table denoted as point-symbols), or their annotations, which we refer to as labels. Similar symbols are often organized in layers, which can themselves be subject of manipulation. Interestingly, the geometric property of the interaction is reflected in the physical nature of the proposed multi-touch interaction. For example, single point-like objects are referred to with a single pointing gesture (F1), while rotation of a globe or panning of a 2D map is more likely to be performed by a wiping-style gesture (H2). The selection of geo-objects can be improved by referencing their geometric properties. For example, the selection of a street on a map could be more precisely performed by moving a finger along that street (F2) instead of just pointing to it. This helps to reduce the ambiguity of the gesture as pointed out in [19]. Please note that not all of the primitive gestures of Fig. 1 are listed in Table 1. For example the two-hand gesture (EH4 and H4) seems of no use. However we believe that if we look at more complex operations, such as intersecting two polygons, these operations will be useful. Of course, this has to be investigated further in future work.

4 Multi-touch and Foot Interaction with Spatial Data

Even though multi-touch interaction gained a lot of attention in the last few years the interaction possibilities of feet were not considered as much. In [4] we try to make a contribution in that direction of how physical multi-touch gestures in combination with other modalities can be used in spatial applications. What is still lacking is a better understanding of how physical multi-touch gestures in combination with other modalities can be used in spatial applications. This work tries to make a contribution in this respect. This section describes the extension of the multi-touch framework presented above. Multi-touch is now combined with foot interaction to improve the overall interaction with spatial data.

4.1 Physical Foot Interactions

A set of simple physical foot interaction patterns that can be performed by the user standing on a Wii Balance Board (see Figure 2 (a)) are derived. Up to now five different patterns (named with lower case letters) can be investigated: “fb” = “stand on ball of feet”, “ft” = “stand on tippy-toes”, “fr” = “balance center on the right”, “fl” = “balance center on the left”, “fs” = “stand on sides of feet”. Most of the gestures are self-explaining. For example “ft” means that the user is moving the balance point forward and just stands on tiptoes. “fs” denotes an action (user standing on sidefeets) people often perform while they are waiting (the physical foot interactions are highlighted with blue in Fig. 2 (b)).



	World		(Geo-) Objects			Symbols		
	Globe	Plain	Point	Line	Polygon	Point-Symbols	Labels	Layer
POINT	F1	F1	F1	EH1	H1	F1	F1	F1
ZOOM	F4	F4	-	F4	F4	F4	F4	(F4)
PAN	H2 , fr, fl	H2 , fr, fl	F2, fr, fl	EH2, fr, fl	H2, fr, fl	F2	F2	-
ROTATE	F5	F5	-	F5	F5	F5	F5	-
TILT	ft, fb	ft, fb	-	-	-	-	-	-
CUT				EH1, EH3	EH1, EH3			-

Fig. 2. Set of physical foot gestures (a) and framework of multi-touch and foot interaction for geospatial objects (b)

4.2 Interaction Primitives and Interaction Space

The interaction primitives and the interaction space are nearly the same. Some interaction primitive are now controlled by the feet (see Fig. 2 (b) yellow sidebar). The proposed interaction styles for various selection and manipulation tasks are summarized in a table (see Fig. 2 (b)). The table is organized as described in section 3.4 but now filled up with physical hand and/or foot gestures to interact with-geo-objects. For example “panning” can be accomplished by using the physical multi-touch interaction “H2” or the foot interactions “fr”, “fl”.

5 Results and Evaluation

The presented framework was evaluated in different stages and in different studies. The results of an initial user study and a broader study in an exhibition are presented in the following.

5.1 Multi-touch Interaction

An initial user study was carried out to test the multi-touch interaction framework. The study was conducted with 9 participants, 3 female and 6 male, with a mean age of 26.8 years (ages 23–38). The test setup was the following: The subjects had to solve simple geospatial tasks to get information about certain places in the world. For example, they had to navigate (with pan, zoom, rotate and tilt) to Washington, D.C., find the Washington Monument and gather information about the monument, the Lincoln Memorial and the Capitol. Another task was to measure distances on the globe. During the test the users were asked to “think aloud”. After the actual test users rated the map navigation techniques by filling out a questionnaire based on ISO 9241-110 (five-point rating; lower scores denote a better rating) and inspired by [20]. The total time of the experiment took about 60 minutes for each participant. In general users gave good rates (between 1 and 2) with small confidence intervalls (see Fig. 3). The only outlier was the error tolerance because the tilting gestures caused problems for some users.

5.2 Multi-user Interaction

The multi-touch framework proposed in Sect. 3 was also evaluated in a multi-user scenario. A sample application on a large-scale multi-touch screen based on the framework was installed during a technology exhibit called “Germany ‘Land of ideas’ ” in a pedestrian underway in the city of Münster for one week. In the following first insights gained from this deployment are provided. The focus of this study lies on the observation of spontaneous and group interaction patterns. The video[3] presents the short impression of the installation. The ambient nature

[3] Hightech-Underground on youtube:
`http://www.youtube.com/watch?v=27oSoDdU2fk`

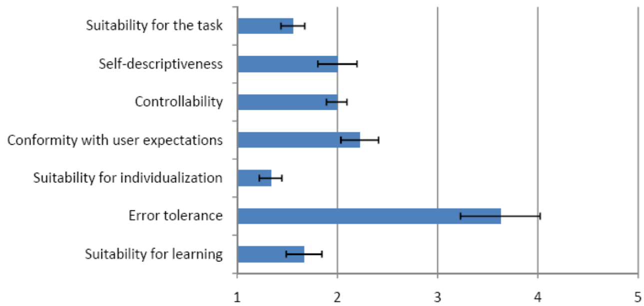


Fig. 3. Results of the user interface evaluation questionnaire

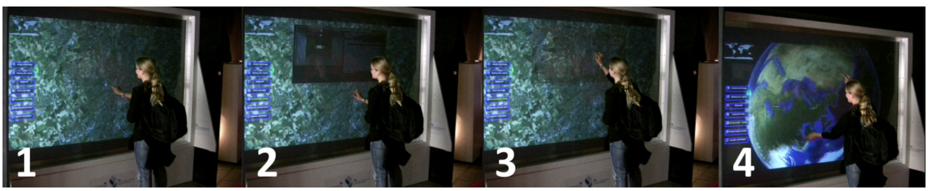


Fig. 4. User interacting at a large-scale multi-touch displays in a pedestrian underway in the city of Münster, Germany, during a hightech exhibition in Oct. 08

of this wall setup does not attract users by itself. Users watching other people interacting with the application before they interact seem to be less shy and more experimental [21]. Users rarely performed the proposed interaction scheme as depicted in Fig. 4:1–3. Instead of navigating to a POI (see Fig. 4:1) and open the detailed information (see Fig. 4:2) and closing it again (see Fig. 4:3). Users had fun performing various gestures: rotating, flipping, scaling the digital globe. This "fun-factor" played an important role. Most users were not so interested in the presented information that was intended for this exhibition but rather interacting with the globe in order to look for their house, vacation houses and tennis court (see Fig. 5:7). Although designed for single users, the application was mainly used by groups of 2–8 people. An exemplary group of elderly men reveal this highly interactive group communication in Figs. 5:5–5:8. After reaching the wall the first user (with a cap) starts to interact with the globe (see Fig. 5:5). Immediately a discussion about the map begins ("Where is our tennis court?"). A second user (with a red jacket) looks over the shoulder of the first one (see Figs. 5:6 and 5:7), leans forward and takes over the interaction part (see Fig. 5:8) [22]. Thus, user groups of different sizes are able to collaboratively interact with the single-user application. The formerly described "Teacher-apprentice setting" [11] also plays a role in this study. Examples for this are shown in Fig. 6. In many cases one person (teacher) shows or explains something to "the student" (see Figue 5:8). Another collaborative interaction is shown in Fig. 6:12. A team of users performs parallel zoom-gestures. Our preliminary investigation of the

Fig. 5. User interacting at a large-scale multi-touch displays in a pedestrian underway in the city of Münster, Germany

Fig. 6. User interacting at a large-scale multi-touch displays in a pedestrian underway in the city of Münster, Germany

data we have collected, largely verifies findings from literature. We could find similar interaction patterns as Peltonen [11] namely: "huge amount of team-work" (consider Figs.5:5–7), "Pondering grip vs. grandiose gestures" (consider Figs.5:8), "Leaving a mark" and "Teacher-apprentice setting" (consider Fig.5:8).

In accordance with a survey we conducted in previous work [2], we observed that in practice most people seem to use digital globes to answer simple questions, like: "where is my house?", "how does the vicinity of a particular area look like?","where is our tennis court?" and so on. We also recognized the interaction zones already identified by Prante and Vogel. However, here we have observed a much finer and dynamic distinction between different zones when multiple users are involved. Since the closest zone has enough space to accommodate multiple users, we could observe different types of interaction ranging from synchronous and asynchronous interaction in time and space. It often happened that users where switching zones, for example the user with the red coat in Fig. 5:5–7, first observes at a certain distance and then suddenly moves towards the wall to interact in the same space as the user in front of him at the same time. Synchronous interaction in time but not in space can be observed in Fig. 6:9: here both users have their "own" area of the wall were they interact. What is very interesting is that the size of the wall and the type of application seems to afford these different interaction patterns. Being designed with a single user in mind, the application would not support these types of interactions. Still our users naturally appropriated the application and tried to overcome the deficits of the interface design. This could point designers of user interfaces of large multi-touch surfaces in two directions, to take an expensive or a cheap approach: it could mean to carefully design interaction methods that take care of time and space and allow for both asynchronous and synchronous interaction in space and time, or to just ignore this and design a simple but useful single-user application that people enjoy (and then appropriate for group usage). Of course the latter case makes only sense in settings such as the one presented in this paper: a playful virtual globe application, which aims at interaction spans of minutes rather than hours.

6 Implementation

We used a low-cost, large-scale (1.8m x 2.2m) multi-touch surface that utilizes the principles of Frustrated Total Internal Reflection (FTIR) [10] as display and touch input device. The Wii Balance Board[4] as foot input device is wirelessly connected via Bluetooth and GlovePie[5] and is used to stream the sensor data from the Wii Balance Board to the application. The image processing and blob tracking is done by the Java multi-touch library[6], developed at the *Deutsche Telekom Laboratories*. The library provides the touches as a server using the TUIO-protocol [23]. The application is based on NASA World Wind[7] using the Java-based SDK. The exhibition setup was nearly the same, but without the Wii-Board and the associated components. The exhibition took place for one week in an old pedestrian underway in the city on Münster. This underway is normally closed due to construction defects, but was reopened for the event from 10 am to 6 pm every day. Nearly 1200 people attended the exhibit. We installed a video camera to record the user and group interactions and this was clearly identified by the visitors. In addition in the "semi-wild" exhibition environment there were many other technical challenges to tackle (lightning, seeping water, vandalism etc.).

7 Conclusion and Outlook

In this paper, two steps of a framework for geospatial operations are presented. In the first step multi-touch gestures to navigate and manipulate spatial data are derived from a usability inspection test. Based on the results of the multi-touch framework a first concept and implementation of the combination of multi-touch hand and foot interaction is provided. The combination of direct, position controlled (hand) with indirect, rate controlled (feet) input is proposed and evaluated in an initial user study. While hand gestures are well suited for rather precise input foot interactions have a couple of advantages over hand interactions on a surface: (a) it provides an intuitive means to input continuous input data for navigation purposes, such as panning or tilting the viewpoint, (b) foot gestures can be more economic in the sense that pushing once weight over from one foot to another is less exhausting than using one or both hands to directly manipulate the application on the surface, e.g. when trying to pan a map over a longer distances, (c) it provides additional mappings for iconic gestures, for

[4] e3nin.nintendo.com/wii_fit.html
[5] http://carl.kenner.googlepages.com/glovepie
[6] http://code.google.com/p/multitouch
[7] http://worldwind.arc.nasa.gov/java/

single commands. In a more general way foot interaction provides an orthogonal horizontal interaction plane to the vertical multi-touch hand service and can be useful to improve the interaction with large scale interaction multi-touch surfaces. In a second study the pure multi-touch approach was used to analyse multi-user interaction with geospatial data. The first results are that geospatial like virtual globes highly support group communication and interaction with the wall on one side and more hierarchical structure like the "Teacher-apprentice setting" on the other side. The different interactions have to be investigated more in detail.

In future there is a need for exploring the combination of interaction both planes for spatial tasks further, but this certainly has a huge potential for interaction with spatial data or even for more abstract visualization that uses a 3D-space to organize data. This paper presents first steps how additional modalities can overcome navigation problems with virtual globes and let users interact more intuitively and presumably even faster with virtual globes on multi-touch surfaces.

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