# Using the Body to Support Tangible Manipulations for Immersive Visualization

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## ABSTRACT

Recent technological advances in immersive devices open up many opportunities for users to visualize data in their environments. However, current interactive solutions fail at providing a convenient approach to manipulate such complex immersive visualizations. We present a new approach to interact in these environments, that we call On-Body Tangible interaction (OBT): using the body to physically support the manipulation of an input device.

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## KEYWORDS

Immersive environment; on-body interaction; tangible interaction.

This paper introduces the design space for OBT interactions, focusing on the forearm as input surface. We also illustrate its benefits through a sample application where OBT interaction is used to manipulate air traffic data.

## INTRODUCTION

The 3D capabilities of immersive systems make them a compelling candidate to visualize multidimensional data on 2D displays. However, data exploration involves many tasks, such as filtering, selecting, adjusting or annotating the dataset, which require a large interaction vocabulary. While often used to manipulate immersive visualizations, previous approaches based on touch and mid-air interaction [6, 14, 18] fail to offer enough degrees of freedom (DoF) to cover such a large set of tasks. Other solutions are often ambiguous and tiring (especially mid-air gestures [2, 14, 15]). Finally many input device (3D mouse or similar [12]) restrict the user's interaction to a well-defined place, usually a desktop. Alternatively, on-body interactions have been scarcely used in immersive environments. Serrano et al. [20] explored hand-to-face gestures arguing that they are well suited for HWDs. Dobbelstein et al. [6] proposed the use of the belt as a tactile surface to interact with HWDs. Wang et al. [23] proposed PalmType, an interaction technique that enables users to type with their fingers on the palm to input text in smart-glasses. These works illustrate that on-body interaction techniques allow eyes-free interactions by exploiting the proprioception capabilities of users and do not divert their attention from the task at hand. However, the explored approaches offer a limited set of possible gestures, making them unsuitable for complex data visualization. The challenge then is to provide an interactive solution for immersive visualizations that preserves the benefits of on-body interaction and the DoFs of tangible interaction.

To this end, we propose to explore On-Body Tangible (OBT) interaction, i.e. a new approach using the body as a physical support for manipulating a tangible object to interact with immersive visualizations. This approach combines: 1) the use of a connected tangible object, that offers multiple degrees of freedom and, 2) the use of the body to guide the physical manipulations of the tangible object and exploit the user’s proprioception (i.e. sensing its own body parts). While the first aspect offers the multi-DoFs of tangibles, the second aspect ensures that the solution can be used anywhere and can potentially contribute to reduce muscle fatigue.

## ON-BODY TANGIBLE INTERACTIONS

There are different types of immersive visualizations according to the data to visualize, which ranges from simple 3D objects to complex multidimensional data. All these immersive visualizations share a set of basic interaction requirements: 1) it has been demonstrated that the spatial exploration of data allows for a better spatial understanding of the visualization [10].

It is thus important that the interaction techniques do not constrain the mobility of the user; 2) the multidimensional nature of data in an immersive systems requires enough degrees of freedom (R2) to tackle the manipulation of the information space [1]: 3) the interaction techniques should not occult the data visualization (R3); 4) the interaction techniques should offer enough stability to properly tackle data visualization tasks in mobility (R4).

The On-Body Tangible interaction approach proposed in this paper aims to fulfil the full set of requirements described above. Below, we describe and justify the properties of the approach: the tangible object used in the interaction, the body part used to support it and their combination.

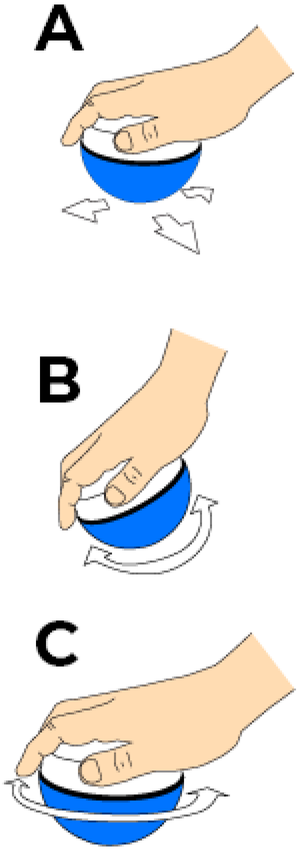

**Fig.1.** Manipulation of a semi-spherical tangible object: A) Translation; B) Roll; C) Rotation

### Tangible object

Among the plethora of existing tangible objects introduced in the literature, we propose to use a semi-spherical object. The rationale behind this choice is manifold. 1) It has been demonstrated [17] that such a form factor offers up to six degrees of freedom (R2), in the form of three types of manipulations (translations, rotations and rolls) (**Fig.1**), facilitating the manipulation of multidimensional data [17]. 2) As opposed to other forms (that have flat surfaces), the contact of a rounded object with the interaction surface is minimal (i.e. a point), which will easily adapt to the outline of any part of the body. Other small sharp objects (such as a pen) have also a minimal contact point, but their sharpness is detrimental as they may hang onto the clothes or hurt on the skin. 3) As opposed to objects that include flat surfaces, the manipulation of a round object remains continuous, does not interrupt the interaction flow and does not artificially promote the use of modes in the application. 4) The choice of a semi-spherical form rather than a full spherical one is motivated by the fact that it is easier to hold [17].

### Body-part used to support the interaction

Many research works have focused on interaction on or with the body [3, 7, 11, 22]. Arms and hands were the preferred body parts in most works. These body parts offer numerous advantages: they are easily accessible for interaction; they are in the user's field of vision and generate less social discomfort than other body parts [11, 21]. The non-dominant arm as well as the hip have been experimentally identified as the preferred body-parts for interaction in Karrer et al. work [11] while other parts, such as the stomach and legs, have been rejected for social or personal reasons.

We decided to focus on the forearm of the non-dominant arm to support the interaction for several reasons. It is an always-available physical support that favors physical exploration of data and it does not constrain the movement of the user (R1). Thanks to the body's natural capacity to sense its own body parts (proprioception), the user can perform tangible interactions on the body without having to switch his attention from the data visualization to the interaction tool (R3). Using the forearm offers a large surface on which the tangible object can be laid, and it is effortlessly accessible by the dominant hand as opposed to the upper arm which needs a consequent effort to be touched by the dominant hand (R1, R2). Furthermore, its combination with a tangible object (which use can be extended to mid-air manipulations, as suggested by the Lift-Up option in [19]) does not constrain the user's movement (R1). Finally, several stable poses can be adopted with the forearm (R4), which increases the range of possibilities (R2) (**Fig. 2**).

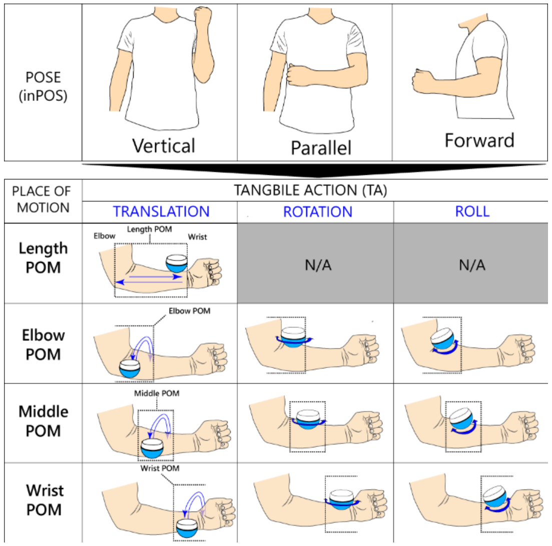

**Fig. 2.** Design Space for on-body tangible interaction on the forearm

### Mapping the input interaction space with the data visualization space

While the user's gestures are performed in a 3D physical environment, they trigger actions in a 3D virtual environment. It is therefore important to choose the right frame of reference for the interaction. The frame of reference can be allocentric (external: it can be world-centered, data centered...) or egocentric (relative to the body). In an egocentric frame of reference, the output of a given manipulation is determined by how it is performed with regards to the body, and will have the same effect regardless of the body position and orientation in the world. In our approach, we adopt an egocentric frame of reference to allow the user to interact anywhere with geographically anchored data in the physical world [13]. Indeed, previous research found that a lack of a logical relationship between the manipulated data's frame of reference and the user's frame of reference can affect performances negatively [16, 24].

## DESIGN SPACE FOR ON-BODY TANGIBLE INTERACTION

Based on the main design properties of OBT interactions introduced above, we now present a design space describing the use of the forearm as interaction support. Restricting interaction to the forearm –more socially acceptable, accessible and with a large interaction area– has the disadvantage of reducing the available interaction vocabulary. To address this limitation, we propose to consider the posture of the arm (Pose) as well as the use of sub-regions on the forearm (places of motion) and the tangible action (TA) that can be applied.

### Pose (inPOS)

The Pose describes the position of the forearm with respect to the user's body. We identified three main poses for the forearm. In the Vertical pose, the forearm is vertical, the hand points upwards. In the Forward pose, the forearm is perpendicular to the shoulders. In the Parallel pose, the forearm is parallel to the shoulders (**Fig. 2**). We chose these three poses because they are the most comfortable poses, the most accessible with the non-dominant hand and they are significantly different from each other, facilitating their distinction by the system and the user.

### Place of motion (POM)

The Place of motion represents the surface of the forearm on which the tangible object can be used. We identified two types of places: the first one extends over the length of the forearm, from the elbow to the wrist (length POM); the second one, called width POM, divides the forearm into several sub-regions. The number of sub-regions was defined according to the following criteria: 1) the sub-regions have to be large enough to accommodate interaction with the tangible object (diameter = 8 cm); 2) the sub-regions have to be easily distinguishable. Applying these criteria, we divided the forearm in three sub-regions: close to the Elbow (Elbow POM), in the Middle of the forearm (Middle POM) or close to the Wrist (Wrist POM) (**Fig. 2**). This results into 12 different interaction areas (3 poses x 4 places), increasing the interaction possibilities.

### Tangible Action (TA)

The TA stands for the physical actions than can be performed with the tangible object. The round shape of the tangible object offers three physical manipulations: translation, roll and rotate. Rotations and rolls along the length of the forearm (Length POM) were not considered. Indeed, they are performed with the tangible object motionless, in the same spot, rendering them too similar to rotations and rolls on one of the other three places of motion.

## USAGE SCENARIO: Data exploration

**Fig.3.** Using on-body tangible interactions to manipulate air traffic data

We illustrate our approach through a scenario detailing a possible use of on-body tangible interactions to manipulate multidimensional data.

Emily is an air traffic controller. Part of her work consists of improving traffic management in the control tower [5](analyzing past conflicts, improving the ecological footprint, increasing the profit by improving the trajectories of aircraft...). To this end, Emily must analyze large quantities of air traffic data (time, position, altitude, speed...) on a regular basis [5]. The manipulated data represents complete aircraft journeys, from takeoffs to landings, containing multiple dimensions. Visualizing this data in an immersive context helps Emily having an optimal understanding of it. Indeed, by anchoring the volume of data to a wall for example, she can move around it and analyze it from different angles. She can have an overview of the data by moving away from it, or a more detailed view by getting closer. For instance, when Emily, facing the wall, observes a high concentration of points, she knows it probably represents an airport. A side view of data allows her to observe the most used altitudes by the aircraft. Standing with her back to the wall and looking at the data, Emily can observe the main airways.

Emily uses a mixed reality headset (Hololens) to visualize the data and the tangible object to interact with it (**Fig.3**). The tasks Emily performs on the data are [5, 4] selecting data using range-sliders; applying a command on the selected data (e.g. data subsampling); changing colors; scaling, etc. Emily has configured her system so that:

- The forward pose carries the departure time (Elbow) and Arrival time (Wrist) of the aircraft: Adjusting the earliest and latest Departure time can be specified through rolls around the Elbow POM.
- The Parallel pose is associated to the altitude of the aircraft. Elbow and Wrist POM can similarly be used to adjust the lowest and highest considered altitude
- The Vertical Pose is associated to Companies. A Length translation allows to scroll from A to Z among company names. While rolls on the Middle POM allows to select a country of origin of the company.

Range sliders are controllers that allow the user to select values included in a range (an interval). The range sliders are composed of two cursors, one defines the minimum value and the second defines the maximum value. To control the range slider and select data, Emily uses translation over the length of the forearm (on the Length POM). The cursor to manipulate is automatically selected according to the starting position of the tangible object on the forearm: if the object is placed on the Wrist POM, the cursor defining the maximum value is manipulated; if it is placed on the Elbow POM, the cursor defining the minimum value is manipulated; and finally, if it is placed in the Middle POM of the forearm, the two cursors are moved simultaneously while maintaining the range length initially defined.

## CONCLUSION

In this paper, we proposed a new approach for interaction with immersive visualization: On-Body Tangible interactions. This approach is based on the use of the forearm to support tangible interactions using a rounded object that offers multiple degrees of freedom. It takes advantage of the body's natural capacity to sense its own body parts (proprioception) without switching user's attention from the data and minimizing the fatigue. We proposed a design space describing the Pose and the Place of Motion of interaction where a tangible action can be applied. Finally, we illustrated possible usages of this approach through a concrete scenario exploring interaction with multidimensional data related to Air traffic management.

The next steps of this project consists in carrying a longitudinal study of this approach, particularly to see how users map actions to task. Another relevant research question concerns the memorization of on-body tangible gestures, which could benefit from the semantic and spatial aids of the places of motion [7]. Finally, it will be interesting to explore the usage of this approach under different frames of reference: while the egocentric approach seems to better fit this type of interaction, the effects of using a world-centric reference should be evaluated in a controlled study.

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