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Multiple Degrees-Of-Freedom Input Devices for Interactive Command and Control within Virtual Reality in Industrial Visualizations

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Abstract

The aim of this research is to present a new multimodal interaction mapping framework for 3D object manipulation within the virtual reality (VR) realm, by leveraging the advantages of having multiple DoF (Degrees of Freedom). In this new software engineering designed framework, interaction devices such as the keyboard, mouse, joystick, and specialist devices for 3D interactions; the Wing [Wor] [SO16] and the 3D connexion spacenavigator, can all be combined to provide a more intuitive and natural command system. This can be applied to many different specific systems including industrial applications within the petroleum, geology and materials sciences.

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI)**; **Visualization systems and tools**;

1. Introduction

With advances in technology, VR has become a powerful tool for interactive visualization and immersion of the user in 3D virtual spaces [Bry96] [BH97]. Despite having many 2D and 3D input devices for the exploration of large-scale 3D datasets, it is still difficult to navigate in unknown visual landscapes and access information [CMO*99] (simultaneously controlling a menu for example) and, not all combinations of input and display devices can work together in a suitable and useful manner, for example because they physically need complimentary setup [MHWM07].

The purpose of this short paper is to provide an overview of a new framework that allows users to switch between different modes of functions depending on the combination of the input devices. The development of this framework is an extension of a previous work on single high-degree of freedom input devices found in [TMS17]. In the industrial field, explorations of 3D environment reconstructions may involve observations at various positions and simultaneous setting of properties [AHBJ91]. These operations incorporate complex navigation that require more than six degrees-of-freedom user input [SO16] and multiple renderings of an object from various angles and viewpoints that may lead to new insights. Therefore, this framework offers multiple actions for monitoring

these 3D structures that best fit the reality allowing operators to perform multiple activities at once.

2. General overview

We define "virtual object" as a dynamic entity with multiple visual representations and functionalities in a Virtual Environment (VE) [GTV05]. This means that the user has the capability of dynamically scaling and adapting the object's geometry and functions to different scenarios. In this regard, we are focusing on defining a way to codify the dynamic adaptation of the multiple interaction techniques that can be used to communicate with it. The objective is to let the user access the available interaction input devices and customize them in real-time, personalizing the interaction technique through multiple combinations between these devices. We propose to complement this approach with an ontological overview that allows us to express the relationships between interactive devices and virtual objects in a VE.

According to Gruber [RG94], an ontology is "a formal specification of a shared conceptualization". In other words, it refers to the interpretation of a group of ideas within a specific domain that defines the interrelationship between those ideas. Taking this into consideration, the framework that we are building is composed of three main parts: **interaction through input devices**, **metadata ontology**, to identify components and map instructions to manipulate virtual objects, and the **virtual environment**, which is the space where 3D objects can be manipulated. The conceptualization shared by this framework consists of the abstraction of two main

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types of entities: input devices (mouse, keyboard, 2D devices, 3D devices, etc.) and virtual objects (3D datasets, images, etc.). The formal aspect of the specification refers to the fact that this framework can be both human and machine readable by means of an XML-based representation which introduces new elements to programming of VR that includes object-orientation and programming techniques [WC02].

Ontological principles are well recognised as effective design-ing rules for information systems [Gua98] based on the **ontology-driven information systems** [FM07], which covers both the structural and temporal dimensions of our multimodal framework [Gua98]: the **structural dimension** concerns a repository containing the information describing both interaction devices and virtual objects, while the **temporal dimension** is related to the interface or visualisation software that gives access to such information at run-time. The main focus of our formal representation is the conception of VEs as a set of objects with a semantic meaning. These objects can be represented and affected in a variety of ways, either through user interaction or autonomous processes.

The way these virtual objects are visualised, commanded and controlled depends on: the **application context**, the **interaction input devices available** and the **user preferences, experience and needs**. Our framework provides a flexible system that allows for adapting the interfaces to all those functions or semantics of the content. The functionality of a virtual object can be accessed in a variety of ways, by multiple modalities of the multiple combinations of the input devices. Users should be able to choose and configure the interaction technique and the different combinations between input devices that best adapts to their needs, translated into mapping the output of an interaction input device to a particular transfer function that manipulates virtual objects in the VE.

On one hand we have a range of interactive input devices that let the user express their intentions through multiple modalities. It can be by classical means (mouse, keyboard, etc.) or through more sophisticated multimodal devices (Spacenavigator, The Wing, etc.) or a combination of them. The essential attribute of an interactive device is the data that it delivers as it can be a 2D vector, particular movements in 3D (roll, pitch, yaw), etc.

On the other hand, there are the virtual objects to be controlled. They can be for example 3D volume datasets used widely in industrial fields such as seismic data, structural data such as zones and layers, planned well deviation surveys, logs, reservoir data, and so on. From the interaction point of view the most important attribute are the user modifiable functionalities. The virtual objects can be fully manipulable by the user, while others could display some behavior as reaction to user input. As a result, this allows the user to interact with the elements of that environment creating sensory experience. Now that we have explained the principles of the formal representation, we describe in the next section the multimodal framework layers in detail as well as the ontologies applied.

3. Multimodal interface framework

The elements of the ontology presented in the previous section are translated into XML descriptors. This simplifies the code of vir-

tual scene models, allows retrieval of data, and efficient coding of elements that have repetitive structure.

However, our novel component will implement a visual programming language (VPL) and it will consider the current user context and an ontology of the 3D input devices, with semantic integration component, to create an interaction matrix of functions, as seen in Figure 1. These map object-oriented specific functions will manipulate input values to an application. Thus, the system can understand the user intention and assist him in achieving his goal in the handling process.

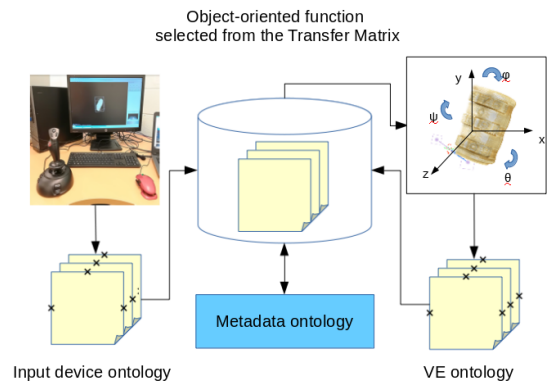


Figure 1: Architecture of our new multimodal framework based on the ontology-driven information systems.

Our new framework is split into five layers and based upon the Open Systems Interconnection project (International Organization for Standardization ISO), identification IEC 7498-1 as seen in Figure 2.

3.1. Input device ontology: physical and driver layer

The physical layer is concerned with the transmission and reception of the unstructured raw bit stream of the input devices connected to the system, while the driver layer first calibrates the components to examine each input request for certain qualifying criteria, for example, to eliminate noise and then it sets all the attributes of each input device based on the USB HID class to map it into a format readable for the system.

These two first layers of our framework describe an input device ontology that consists of a **behavioral model** and a **functional model**. The behavioral level describes the existence of devices or components, topological connections among them, and micro or macro hierarchies among components and systems (including sub-systems), whereas the functional level describes all base-functions of each input device that are defined as a result of the interpretations of the behavior of the components under the intended goal of the user.

The behavioral model of components represents all the changes in attribute values used to identify each component in the system, whereas the functional model maps the functional concepts with

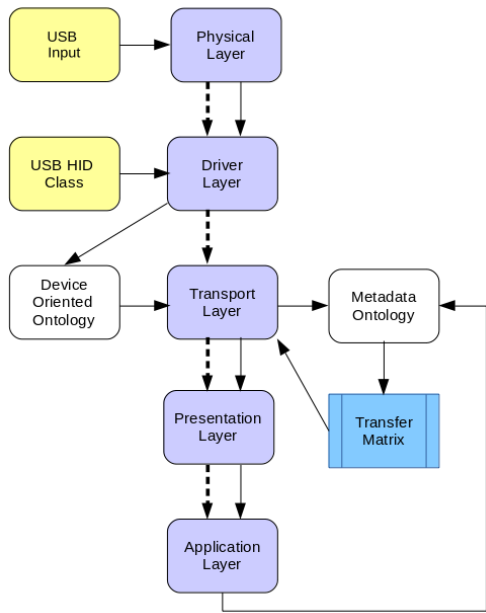


Figure 2: Pipeline representing the five layers of this new framework for multimodal interaction; where the Transfer Matrix stores links to object oriented functions switchable depending on application need and type of input device, defined by the ontologies.

the behavior of the component to identify all possible movements that can be performed by each input device. As a result, we will be able to create XML files that will be used in the next layers to map this input information to the transfer functions in the VE.

3.2. Metadata ontology: transport layer

In the previous section, we mentioned the creation of XML files with all the attributes of the input device(s) connected to the system. In this layer, all communications will be done through TCP sockets, allowing the implementation of a distributed system by connecting I/O ports through **modulators**. These modulators will save all information of the input devices in a repository (see Figure 3) where all the transfer functions available for each device will be defined and then mapped enabling simultaneous instructions for the manipulation of the virtual objects in the VE.

To achieve this, we have selected the XML-based syntaxes RDF/XML contain elements such as a subject, predicate, and object as the elementary representation of units for each component. Also, this will allow us to detect semantics in XML instance documents and map them to RDF documents, but with a simplified syntax.

3.3. Mapping interaction behavior: presentation and application layer

In the final layers of our framework, input devices, modulators and virtual objects are represented as boxes containing the corresponding attributes. Interaction data between the presentation and the ap-

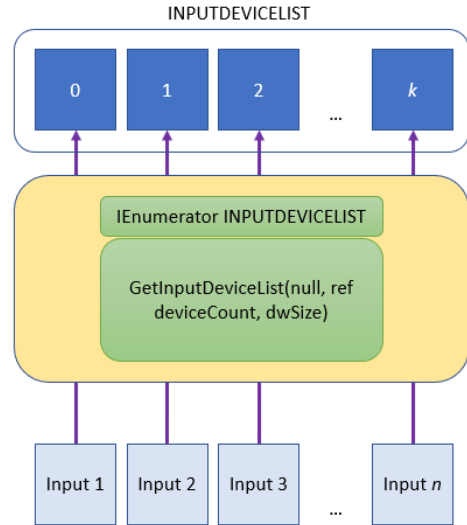


Figure 3: Framework's repository called "INPUTDEVICELIST" that saves the attributes for each input device detected.

plication layers will be of two types: by tokens or by numeric normalized values.

We will use tokens when output is coming from the VE, this is from the application layer to the metadata ontology. This process will remap the existing transfer functions to a different device or add new functions to the current one. The selected device is determined by the user. We will use numeric values in a normal flow, from presentation to application layer, as ontologies for VE will manage the input data by the defined functions established in the previous layer. In addition, VEs definitions should be saved in a repository for consistency and users or application will be able to specify the output interval (minimum and/or maximum values) and modulate the output with polynomial functions.

4. Implementation example within a VE

As an example of this new framework in action, Figure 4 shows an X-ray CT (Computed Tomography) dataset of a metal locking mechanism. Employing the new layered framework the system can use multiple input devices to switch via the Transfer Matrix between two modes of operation. A viewing mode that can change the rendered view position which requires six degrees of freedom – translation with three degrees; x , y and z - and rotation with three degrees; θ , ϕ and ψ . And a clipping plane mode of manipulation to slice the dataset into two halves which requiring four degrees of freedom – a normal vector x' , y' and z' with a distance value d . So ten degrees of freedom need to be mapped via object-oriented functions within the Transfer Matrix.

In practice the user can either seamlessly switch between these two modes, using various input devices; say the 6DOF wing and a mouse, and the input data values are filtered through the layered architecture as appropriate. So a user can view and then probe the 3D

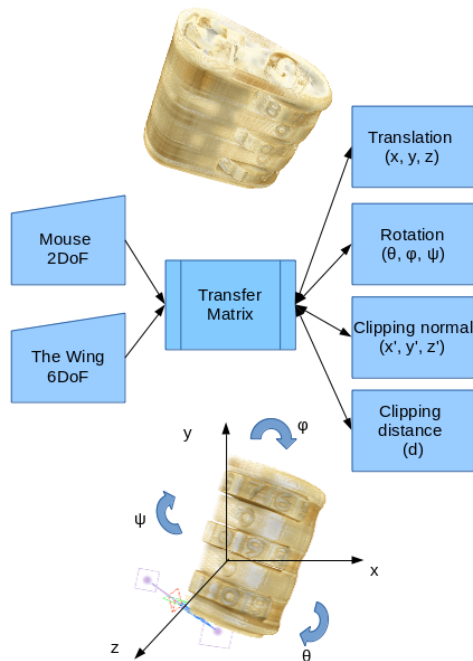


Figure 4: Application of the transfer matrix in a VE.

volume dataset to spot say Materials Science defects in the metal of the locking mechanism deep (requiring precise clipping) that is best viewed from a certain direction. If there are enough input devices then both modes of operation can be simultaneous, otherwise a keyboard or button switch is required to be mapped to select the mode for certain input values. This is also processed through the ontology and the functions available within the Transfer Matrix.

5. Conclusion

To deepen our understanding of input devices, particularly those with high degrees of freedom, this short paper has proposed a new framework consisting of an input device ontology, metadata ontology, an object oriented switchable Transfer Matrix of reusable functions and the graphical representation, where the metadata ontology is the main handler that is aware of the input devices connected to the system and how the input data will be displayed in the graphical representation.

We will apply this approach to the evaluation of various 2D and 3D interaction paradigms and their utility in analysing the 3D scanned structure, such as those used by the petrochemical industry that generates tessellated surfaces from point clouds [LXG10]. This specific task is chosen as it incorporates complex navigation that require more than six degrees-of-freedom user input.

6. Acknowledgement

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framework, will be within the UAV control environment, 3D volume analysis for Materials Scientists and data analytics for the petrochemical communities. We acknowledge continual discussion and support from Worthington Sharpe Ltd. [Wor]

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