Motion and Interaction Tracking Tool for Virtual Reality Environments

Marcelo de Paiva Guimarães[1,2(✉)], Diego Roberto Colombo Dias[3], Leonardo Chaves Dutra da Rocha[3], Elvis Hernandes Ribeiro[3], Rogério Luiz Iope[4,5], and José Remo Brega[4,5]

[1] Rectory, Federal University of São Paulo (UNESP), São Paulo, Brazil
marcelo.paiva@unifesp.br
[2] Computer Science Master Program (Unifaccamp), Campo Limpo, Paulista, Brazil
[3] Computer Science, Federal University of São João del Rei (UFSJ), São João del Rei, Brazil
{diegodias,lcrocha}@ufsj.edu.br, elvishribeiro@aluno.ufsj.edu.br
[4] São Paulo State University (UNESP), São Paulo, Brazil
{rogerio.iope,remo.brega}@unesp.br
[5] Computer Science Department, São Paulo State University (UNESP), Bauru, Brazil

Abstract. Evaluating user behavior in virtual reality environments is a challenging task, requiring leading with spatial user freedom and with non-conventional visualization and interaction devices. By gathering and analyzing user movements and interactions, researchers and even game designers can notice important behavioral patterns and correlations. This paper aims to present an automatic motion and interaction tracking tool for virtual reality environments that allows researchers and game developers to move from the pure observational paradigm, such as video recording and questionnaires, to one that considers quantitative data. After gathering users' data, the tool automatically generates charts to assist the analysis process and also allows the replaying of all user behavior executed in the application. A case study case is shown in which a user navigates and interacts in a virtual reality city performing instrumental activities of daily living (IADL). Using the tool presented here, we conclude that tracking user behavior automatically in a virtual reality environment is possible. To facilitate the software development process, we have developed a Unity Asset, allowing developers to use the tool easily by importing our asset into their projects.

Keywords: User behavior · Tracking · Virtual reality

1 Introduction

Virtual reality environments in which users are inserted into 3D worlds with a high degree of freedom of movement and interaction now have new ways to evaluate user behavior. Moreover, these virtual environments can deliver stimulus and create situations in a controlled mode that are nearly impossible with any other means, building a large and practical data source of user behavior. As such, new approaches to test and verify hypotheses in a realistic and scalable manner can be executed in virtual environments that were previously infeasible. Understanding user behavior in these virtual environments is

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fundamental to scaling up this technology's use and identifying correlations and patterns in user movements and interactions.

User behavior analysis evaluates how users move and interact with the virtual reality environment and what obstacles they experience during the navigation, which requires to collect, combine, and analyze user data. Behavioral analysis of users has already been investigated in several applications, including virtual reality applications [1–4]. The results of these analysis are fundamental, such as to verify whether the user is performing a similar behavior as demonstrated previously during skills training.

Considering virtual reality applications, which use non-conventional devices (e.g., a head-mounted display and data gloves), behavioral analysis is more complex than in common applications like web applications. Notably, users' degree of freedom and interaction levels in a virtual environment are immense, as they can walk and look freely in any direction. Recently, the possibilities for tracking users using devices such as Oculus, PlayStation VR, HTC Vive, and Kinect Azure have considerably increased. These devices have been used for behavioral observation of users in virtual reality environments.

In this paper, we present an automated tool to gather information about user behavior during virtual reality application use. The collected data can be utilized to improve virtual environment design and to identify points where users have difficulty performing a task, allowing, for example, an instructor to identify a user's difficulties and to investigate the user's attitudes. This tool logs [5, 6] users' movements and interactions while they are interacting with the virtual environment. The data are combined, and charts are generated automatically. These charts provide valuable insight, such as how long a user spent going from one place to another and how long a user stayed in one place. Moreover, this tool allows the researcher/user to replay user behavior in the virtual environment. Furthermore, via such replay, recreating the user's playing experience in detail is possible. To facilitate the software development process, we developed a Unity Asset, allowing developers to use the tool easily by importing our asset into their projects.

Several areas tend to benefit from using our approach, such as the activities employed in virtual neuromotor rehabilitation applications [7], when a patient must perform several tasks during a physical therapy session. Currently, health professionals write down everything that occurs during the virtual session, depending purely on their cognitive senses; however, using this paper's proposed solution, this annotation will be done automatically, employing milestones defined in the application. Another benefit of using this type of automated annotation is the metadata creation that enriches the data generated and stored in a medical database, facilitating the data pre-processing phase, usually necessary when using machine learning techniques.

This study is structured as follows. Section 2 discusses work related to this research. Section 3 presents the motion and interaction tracking tool developed. Section 4 offers a case study of our motion and interaction tracking. Finally, Sect. 5 presents our conclusion and suggests future work.

2 Related Work

Users' data behavior in space is a valuable source of information about their activities. Moreover, such data allows identification of correlations and patterns in user movements

and interactions, corresponding with their activity patterns. Simkovic, Hajtmanek, and Zajicek [4] tracked users of Barcelona Pavilion by Mies van der Rohe from Expo 1929 using an HTC Vive. They compared the user's heatmap with photoshoot positions, concluding that users' movements influence their activity in space and vice versa. Hurst [5] examined user behavior when they interacted with websites. Ivory [8] showed automatic data logging to analyze web application users. Mellon [9] evaluated user behavior in digital games. Drachen and Canossa [10] discussed spatial analysis methods for user behavior and presented case studies involving data from thousands of users. Southgate [11] captured videos to analyze a student learning environment. Kim et al. [3] examined game users by combining behaviors recorded in logs with visualizations and hierarchically organized reports.

Behavior analyses have usually been made based on tools such as questionnaires [12], direct interviews [13], and screen recorders [11]. For example, Deb et al. [14] used a questionnaire to measure the general attitudes of people while crossing in front of autonomous vehicles. Additionally, Tussyadiah, Wang, and Jia [15] also used a questionnaire to understand how the virtual environment influences users' travel decision-making. These analysis tools are powerful, but they create difficulties in use because they are time-consuming and laborious, requiring extended research time to ensure proper collection and data interpretation.

Research methods have tailored and combined techniques for each context to overcome their limitations [16, 17]. Therefore, relatively few solutions exist for integrating user behavior with the virtual environment in an automatic way. Although the idea of automatically tracking what users are doing while interacting with the environment seems simple, this task is complicated regarding virtual reality applications that use non-conventional devices, where the quantity of movement and interaction is immense. Our tool is integrated with the game engine Unity in that it was not originally designed to grab information about user behavior [18].

3 Motion and Interaction Tracking Tool

Depending on the research field, several interpretations exist when discussing human interaction. According to Edwin Hutchins [19], from the artificial intelligence viewpoint, interaction with humans is performed through the strings exchanged with an artificially intelligent agent. From the conversational analyst perspective, interaction is performed through speech. In ethnography, interaction can be characterized by face-to-face interplay, highlighting facial interactions and verbal behavior. However, human interaction goes beyond the social interaction between people and also includes user interaction with a virtual environment. With immersive virtual environments interaction can happen in several ways if we consider the interaction form and time between actions. User´s interaction is different for each individual. Thus, ways to identify and represent user environmental interactions are of great value to understanding user behavior within virtual environments.

Figure 1 depicts the workflow of our solution. Initially, the virtual environment is developed using the Unity game engine. Subsequently, a specific script is added to the main camera, and the hotspots are defined. User movements and interactions are

recorded via triggers with colliders that were added on hotspots spread over the virtual environment. When the application is running, the log files are recorded. Finally, charts are generated, and the application can be replayed according to data registered in the log files.

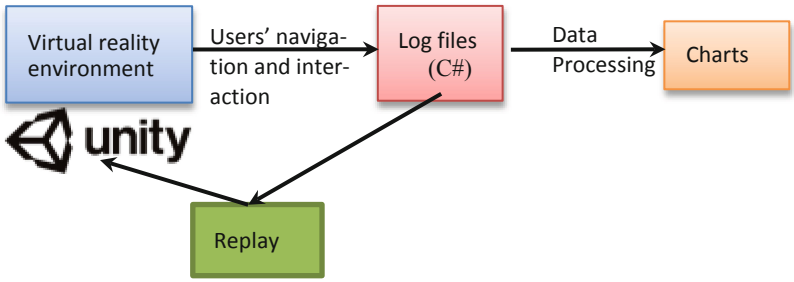


Fig. 1. Tracking tool workflow

Colliders are meant to represent the hotspot's physical properties. We register data about the user's camera, hotspots name, timestamp, and interaction with the environment while the application is running. Collecting this data enables monitoring of the time spent in each spot, how many times the user goes through each location, and the user's head movements, allowing a complete replaying of user behavior.

The tool was designed to be easy to use, without writing code. Developers simply must do the following:

- **Create hotspots:** When the user goes through a hotspot, the tool saves users' behavior data (e.g., timestamp and hotspot name) about the event. The quantity of hotspots depends on the research/user interest and is unlimited.
- **Add the script TrackingTool:** Developers must add this script to the main camera to gather all information. During interaction with the virtual environment, users are free to move and interact.

Figure 2 presents a code snippet showing the TrackingTool script created to gather information about user behavior. When running, this script records (1) when a user collides with a hotspot; (2) when a user stops touching a hotspot; (3) quaternions that represent the camera rotation; and (4) vector3, which represents camera position. TrackingTool script has functions to generate chart images on-the-fly[1] and to replay user behavior. Furthermore, TrackingTool script also maps physical keys on the keyboard to functions, such as "S" to call the function to save data in a file. TrackingTool script can be extended easily to monitor any conventional or non-conventional input device (e.g., data glove, biomechanics sensor nodes, mouse, and keyboard).

[1] We use QuickChart (https://quickchart.io/) service to generate chart images on-the-fly. Charts are rendered by Chart.js on web browsers.

```
...
public class TrackingTool : Monobehavior{
   private Vector3 obj_pos;
   private Quaternion obj_rot;
   ...
   // Users collided with a hotspot
   private void OnTriggerEnter(Collider col)
   //Replay users' behavior
   private IEnumerator Replay()
   // Save  users' behavior
   public void WriteToLogFile(string message)
   // chart to show time period in each hotspot
   private void Chart_period()
   // chart to show how many times crossed the hotspot
    private void Chart_crossed()
      ...
}
```

Fig. 2. Code snippet of the TrackingTool script added to the camera

4 Case Study

The activities of daily living (ADL) are extremely important for a person's daily life. ADL includes feeding, using the toilet, choosing clothes, dressing, personal hygiene, and keeping continent, among others. ADL activities are learned during childhood. Instrumental activities of daily living (IADL) also exist, which are more complex than ADL because they also include actions performed outside and activities necessary for a person's autonomy. Unlike ADL, IADL activities are learned during adolescence. Examples of IADL are managing finances, dealing with traffic, handling public transportation, shopping, preparing meals, managing medications, and maintaining household chores, among others. We can simulate most of these activities in virtual environments, allowing users to perform training in controlled and safe environments.

In this work, we defined as a use case the activities of a user's interaction with city artifacts. The user interacts with streets, sidewalks, and crosswalks. Our solution allows all the user's activities to be described regarding chronological order and duration, allowing a better understanding because of the visual metaphor employed (graph).

The purpose of the virtual reality environment presented is to simulate user behavior while walking in a city. Then, we are interested if the user utilizes the pedestrian crossings properly when navigating to some place, such as the gas station or bus stop. We added motion and tracking functionalities to the 3D city model called "City package."[2]. Figure 3 (a) depicts the 3D city, and Fig. 3(b) depicts the 3D city with the hotspots visible on the crosswalks and over the gas station.

[2] https://assetstore.unity.com/packages/3d/environments/urban/city-package-10722.



(a) 3D city

(b) Hotspots are visible on crosswalks and over the gas station

Fig. 3. 3D city model

Figure 4 depicts the hotspots created in the chosen 3D city. The colliders of each hotspot are enabled and set as a trigger, then the hotspots detect external interaction from the user's camera and execute code that is within the OnTriggerEnter and OnTriggerExit from the TrackingTool script. Then, the application can monitor when users collide or stop touching a hotspot.



Fig. 4. Hotspots

To evaluate our tool, a user navigated in the 3D city. We gave him the task of going to a variety store and returning to the starting point. He had unlimited time to accomplish the task. Once all data were recorded, we transformed, analyzed, and interpreted the results. All charts were created automatically. Figure 5(a) depicts how long the experience took, and Fig. 5(b) illustrates how many times the experiment was executed.

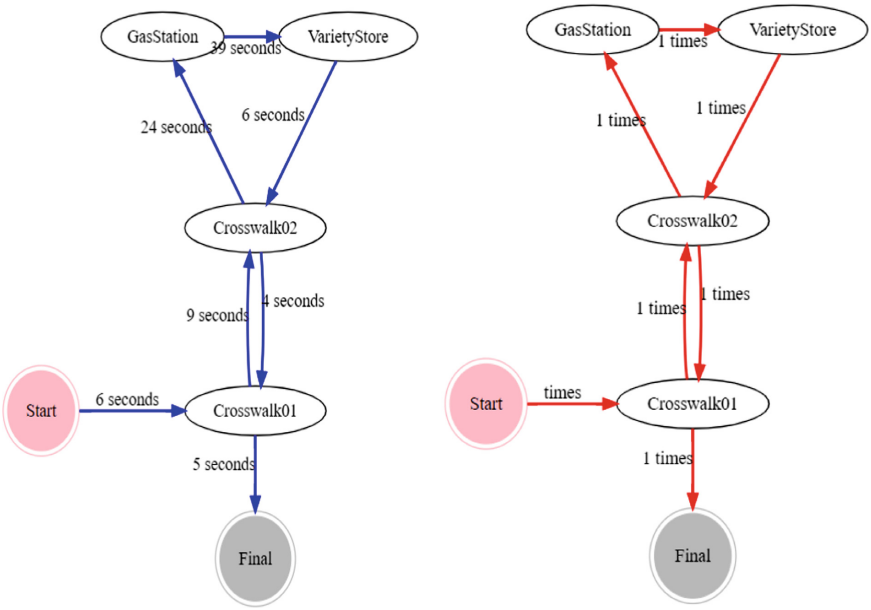


(a) Period of time

(b) How many times

Fig. 5. Period of time and quantity

Figure 6 depicts the user's routes during navigation represented by a graph. Each node is a hotspot, and the edge label shows how long the user took to move from one hotspot to another (a) and how many times the user traveled between two hotspots (b).



(a) How many times the user spent in each travel

(b) How many times each route has been travelled

Fig. 6. The user's routes

Figure 7 depicts how long the user stayed inside the hotspot area during each crossing. For example, the user spent 6 s walking the pedestrian Crossing01 the first time, and 2 s the second time.

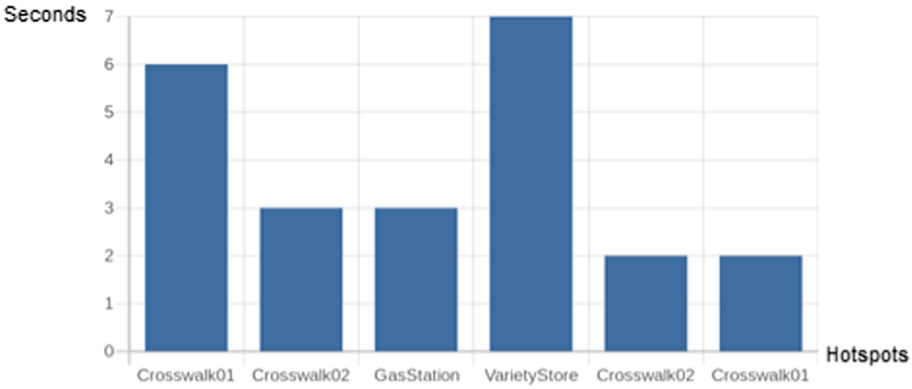


Fig. 7. How long the user stayed inside the hotspot area during each crossing.

After walking in the 3D city, the researcher/user also had the opportunity to replay users' movements and interactions, including the gazing behavior that can reflect the user's attention to spatial objects. Thus, a log file (Fig. 8) is generated while users' movements and interactions with the virtual environment. From the observed results, the performance of the application was not be considerably affected by the Tracking tool, being able to maintain the user experience in real time.

```
09/06/2021 13:48:17 Position: (-150.6, 71.2, 2.5) Rotation: (0.0, 0.0, 0.0, 1.0)
09/06/2021 13:48:17 Position: (-150.6, 71.2, 2.5) Rotation: (0.0, 0.0, 0.0, 1.0)
09/06/2021 13:48:17 Position: (-150.6, 71.2,2.5) Rotation: (0.0, 0.0, 0.0, 1.0)
09/06/2021 13:48:17 Position: (-150.6, 71.2, 2.5) Rotation: (0.0, 0.0, 0.0, 1.0)
...
```

Fig. 8. Log file snipped while a user moves and interacts with the virtual environment.

5 Conclusion

User behavior analysis is commonly employed to identify patterns related to individuals when they are using applications. Understanding user behavior in a virtual reality environment is not intuitive and depends on various factors, such as interaction and visualization devices used and world complexity. Even though there are several behavior studies available, automatic tools to gather user behavior in virtual reality environments remain an open issue.

This paper presented a tool that gathers information about user behavior, including motion and interaction in virtual reality worlds, and combines these data to generate charts. The tool also allows the researcher/user to replay all user behavior. This tool, integrated with virtual reality environments, tracks user behavior, allowing instructors, designers, developers, and researchers to reduce errors and save significant time. We also presented a case study that used our tool, where a user explored a virtual reality environment in several ways. The tool was added easily to the 3D city available in the asset store. The user then navigated, data were collected and combined, and charts were created, allowing investigation with quantitative data analysis of the user's behavior.

From the observed results, we conclude that our tracking tool has achieved its purpose, allowing us to gather information easily about users while they are navigating and interacting with a virtual world environment. As future work, we intend to use our tool in specific contexts, for example, to investigate patients' motor rehabilitation sessions in virtual reality environments (i.e., after Covid-19). We also aim to add new charts, such as a heatmap.

From the approach proposed in this work, we can extend and create several applications focused on simulation. Following the theme addressed in our case study, we intend to add new artifacts to the interaction performed by the user, such as traffic elements (cars and traffic lights) and other pedestrians (non-player characters—NPCs). Regarding ADL, we can also include a house with several activities defined to the user.

As for behavioral study applications, the data generated by our tool can be used to infer treatments and training aimed at ADL and AIDL. Going further, the tool can help health professionals understand the actions performed in virtual environments and generate data for use in the automatic inference of information by machine learning approaches.

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