Terrain Mapping for Telepresence Applications

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***Abstract*— Technological breakthroughs in the VR industry have opened a wide range of possibilities in different sectors such as defence, healthcare, education, etc. It is a milestone in the history of telepresence whose goal is to completely immerse a person in a virtual world. However, complete user immersion hasn't been achieved due to several limitations such as lack of graphical fidelity, desynchronization with the user environment, limited workspace etc. This paper deals with the synchronization of the ground plane of the user with the virtual plane using 3D mapping in an effort to improve immersion the use of telepresence robots in order to achieve this goal. Different robotic mapping methods and their subsequent conversion to 3D have been used.**

***Index Terms*— Telepresence, Immersion, Telepresence robots, Virtual Reality, Ground plane synchronization, SLAM, Mapping, Navigation**

I. INTRODUCTION

While telepresence with robots have been achieved with a considerable degree of success there are still problems that haven't been addressed satisfactorily. When it comes to creating VR worlds using robots, the amount of immersion that the current methods provide are either less or the pipelines used are not efficient enough as they use costly sensors or photogrammetry methods that require high computing power and doesn't always give instantaneous or accurate results when it comes to textures and LODs of the world. One of the major limitations of VR is movement. While some headsets use state of the art technology such as eye-tracking, precision tracking using external cameras etc., these are limited to a certain amount of space. As a result, most VR applications doesn't encourage unlimited user movement. Applications such as beat saber encourage the user to stay at the same location or limit movement to a few strides while other semi-virtual reality applications such as airplane simulator restricts user movement to a certain space. Another method VR apps use for movement is teleportation. This restriction of movement impacts user immersion adversely. Most VR applications don't emulate the user's ground plane. As a result, the user experiences desynchronization with the real world and the virtual world and subsequently, their immersion breaks. This also creates the possibility of accidents and therefore restricts the use of such apps to safe contained environments. By emulating the ground plane of the user, VR apps could provide the user with limitless movement and game designers and app developers can change their applications to adapt to the user's ground plane so as to ensures that no part of the application is inaccessible to the user through natural movement methods. By allowing users the possibility to locomote using natural methods, their level of immersion ultimately increases.

II. LITERATURE REVIEW

Immersion has been a topic of research in a wide variety of telepresence applications for many years. Many strategies have been developed to improve immersion and use of robots in the field of telepresence over the years. Patrick Björnfot Victor Kaptelinin in their paper "Probing the Design Space of a Telepresence Robot Gesture Arm with Low Fidelity Prototypes" [1], suggests that design explorations of telepresence robot arms as an initial step while exploring design spaces is a fast and cheap way in determining the direction of future designs. Studies employing this method could provide definitive answers to design questions efficiently. Nandagopal Harikrishnan, Sneha Ann Soni, Ann Mary Alex, Vishnupriya Menon, Vishnu C Nair in their paper "Virtual Interactive Reality Robot" [2] demonstrates the use of magnetometer sensors in order to manipulate the rotation of robots using telepresence. This method is extremely useful to manipulate robots while the user is provided with limited space for movement. Jacob Young, Tobias Langlotz, Matthew Cook, Steven Mills, Holger Regenbrecht in their paper “Immersive Telepresence and Remote Collaboration using Mobile and Wearable Devices” [3] suggests the use of spherical panoramic representations of user environment. This accommodates independent views withing the environment and easier coordination of multiple viewpoints. This would ultimately help in providing collaborative social experiences in unprepared outdoor environments. Yeonseo Lee, Hyeonjung Lim, Yeunhee Kim, Youngsu Cha in their paper “Thermal Feedback System From Robot Hand for Telepresence” [4] suggest the use of piezoelectric sensors to detect hand postures of the users and use them to operate the robot while temperature sensors on the robot provide thermal feedback to the user thereby increasing their level of immersion. Kai Zhu Tao Zhang in their paper “Deep reinforcement learning based mobile robot navigation: A review” [5] provides a systemic comprehensive review of DRL-based mobile robot navigation research using DRL methods and navigation frameworks and compare and analyze the relationship and differences between different application scenarios. The use of deep reinforcement learning is being considered for navigation [6] however there are several hurdles to be overcome such as noisy data pointed out in [9] and [10]. Besides reinforcement learning, other methods such as semantic segmentation [11], RDC-SLAM [12], HectorSLAM LagoSLAM [13] have been proposed. However, before deploying such cyber-physical systems, a variety of conditions must be met as stated in [7] and [8]. ROS other such open source programs mentioned in [18] greatly help in testing environments virtually before physical deployment. Although there the applications being developed in the field of VR is growing with each day [14], the creation of immersive control environments remains as its major objective [16]. The ability to interact in 3D [19] along with the use of digital avatars make data interpretation highly intuitive as stated in [20].

III. METHODOLOGY

In this paper, a pipeline has been created in order to achieve ground synchronization of the real world and the virtual world so as to improve user immersion. The result can be used in real-time VR applications to mirror user movement in the real world so as to make the virtual world fully traversable and thereby removing current restrictions placed on locomotion of users using such applications.

A. Proposed Framework

1) Capturing the real-world ground plane: The first step in synchronizing the real-world ground plane with the virtual world ground plane is to map the user environment. This is achieved using a robot that autonomously maps the room. The ground data can be captured using sensors such as LIDAR sensors which use IR rays to determine coordinates using the principles of relativity. In order to map the entire environment autonomously, mapping algorithms such as SLAM can be used. This ensures that the robot creates a map of the entire environment without any redundancy in ground data. Using slam over other methods also ensures easy localization, additional sensor handling as well as object tracking. The Lidar SLAM method has been used instead of the Visual SLAM method as the result is a point cloud. The point cloud data is much easier to handle in the later steps. The robot then uses autonomous navigation to track the movement of any obstacles if necessary. Manual mapping methods such as capturing LIDAR data during tele-operation of the robot is also a viable option as it gives the user complete freedom in defining the terrain data that is captured.

2) Creating the virtual ground plane: In the second step, the ground plane is emulated in the virtual world. Several considerations were made in this step. The primary consideration is the type of application being used. In the case of VR games quite often the game designer would want to modify the ground plane and add elements such as puzzles, other NPC characters or enemies. All these cases can be handled using procedural content generation in real-time and therefore can be done in-engine. In this paper, a standalone application has been developed for the emulation of ground plane which can be used in game engines such as Unreal Engine Unity as well as 3D modelling software such as Blender Maya. However, in certain applications, the developer would want to use a modified version of the original ground plane. This might not always be possible in real-time. Therefore, the software produces height map as well as a base 3D model as outputs that can be easily edited in order to enable the developer to create custom terrains based on the original ground plane.

IV. RESULTS DISCUSSION

A. Tools Techniques

In order to capture the real-world ground plane, ROS has been used to operate the robot and capture the LIDAR sensor data using subscribers. Turtlebot simulations were performed in Gazebo as it supports accurate sensor actuator simulations. The results were visualized, tested and compared using Rviz.

In order to create the virtual ground plane, a standalone application that generates height maps as well as 3D models based on the mapping data was built using Python. The resulting height map or 3D model can be directly used in the terrain system of game engines such as Unreal or Unity and in 3D modelling software such as Blender or Maya.

B. Dataset Experiment Environment

In order to test the real-world data capture of the robot, a basic terrain with some obstacles have been modelled and placed in Gazebo. The robot then maps the environment and the data is captured and visualized in Rviz. This is then superimposed on the original environment to ensure the accuracy of the mapping.

In order to test the virtual ground plane creation tools developed in this paper, the USGS 3D Elevation Program data set has bee used. As these are high-quality lidar images that was produced using the SRTM elevation data they accurately model the data captured by the robot. The elevation of the

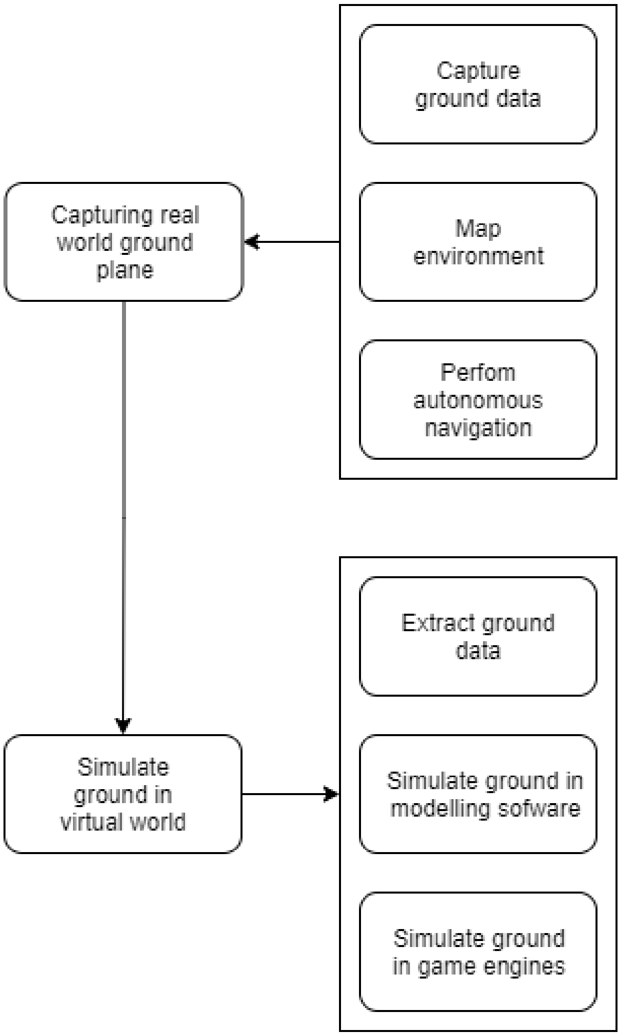

Fig. 1. Proposed pipeline for ground plane synchronization

created terrain is then compared to the actual elevation in order to check the accuracy of the tools.

C. Evaluation Metrics

In order to the accuracy of the real-world data captured by the robot, each data point in the point cloud captured by the LIDAR sensors of the robot is compared with the LIDAR ground truth data. The offset from each point indicates the accuracy of the results. The final result is then compared to the overall layout of the terrain to verify whether the boundaries and obstacles have been mapped successfully.

The accuracy of the virtual ground plane creation tools has been ensured by comparing the input height map data with the ground truth. Any loss in elevation is taken into account while determining the accuracy of the tools.

D. Experiments Results

1) Real-world mapping: To capture the real-world terrain data a variety of techniques such as image processing, satellite imagery etc. can be used. However, the paper proposes the use of telepresence robots for mapping as they enable both indoor outdoor data capture. The robot could be operated manually or autonomously to capture the data.

For autonomous mapping, Simultaneous Localization and Mapping (SLAM) has been used as it performs simultaneous localization and mapping easily. It easily accommodates various sensors such as cameras, LIDAR, ultrasonic sensors etc. LIDAR sensor data has been used as the conversion of real-world co-ordinates into virtual 3D space co-ordinates can be performed easily and efficiently. Besides, they offer better precision than cameras and are optimal for constructing maps.

From the data collected, the pose of the robot is determined from a posterior probability distribution which is approximated through the use of filters such as Kalman particle filters. As the data captured is based on distance, the resulting observation would be geometrically accurate thereby making it suitable for simulation in virtual worlds.

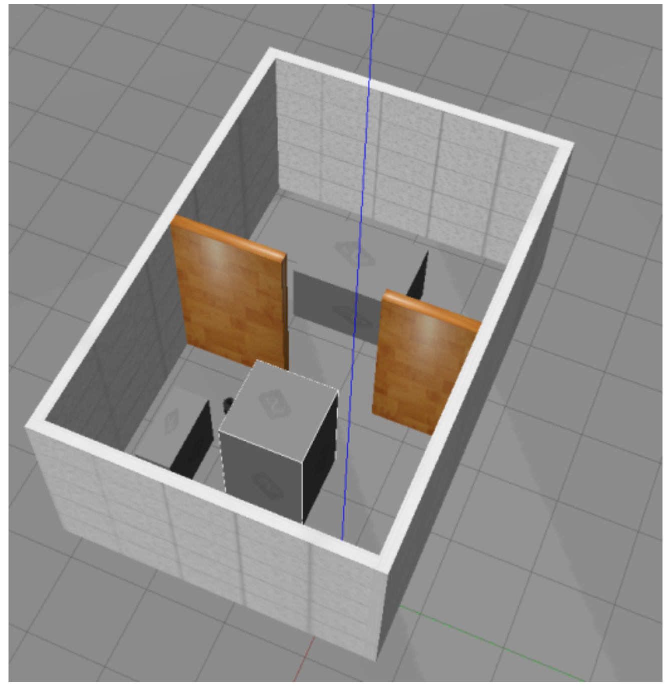

Fig. 2. Sample environment constructed in Gazebo

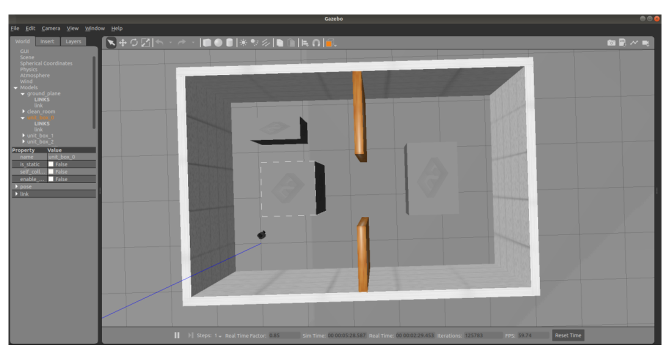

Fig. 3. Bot begins mapping the environment

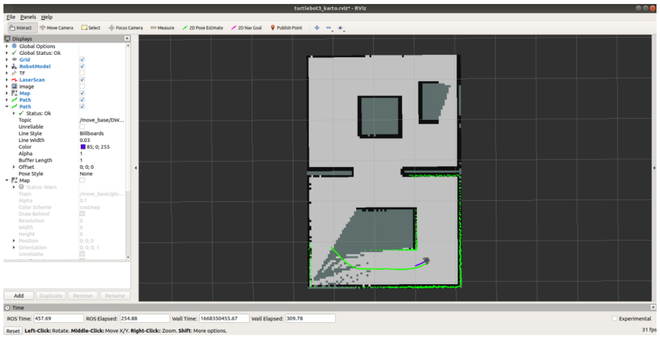

Fig. 4. Visualization of mapping data

In the experiments conducted in this paper, the robot was expected to map a room full of obstacles. It was able to do so successfully with the point cloud corresponding to the ground truth accurately and the margin of error was low. The robot could successfully map the entire room including the obstacles placed in them without entering into redundant loops or leaving areas un-mapped.

Instead of using the data in real-time the end result of the mapping is taken as developers might need to access and modify them beforehand in order to suit their purposes. For example, an environment designer might need to edit parts of the terrain and add foliage and other assets. This can not always be done using procedural content generation.

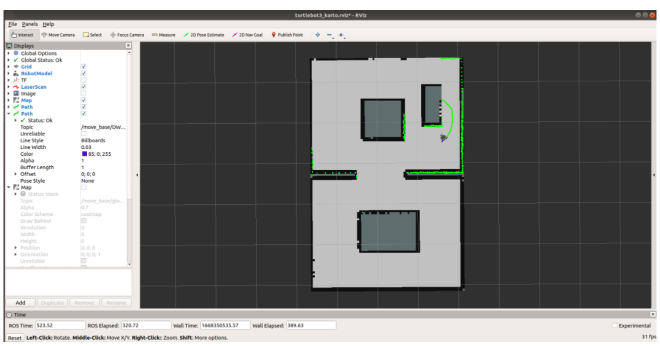

Fig. 5. Completely mapped environment

Manual mapping was also implemented. It provides the user more freedom in deciding which part of the terrain to map. It also enables faster mapping in certain cases as where the user has more information about the area to capture than an autonomous system could have.

2) Simulation of captured data: Instead of using the data in real-time, developers might need to access and modify them beforehand in order to suit their purposes. For example, an environment designer might need to edit parts of the terrain and add foliage and other assets. This can not always be done using procedural content generation.

Moreover, the initial data isn't developer friendly as it is just a huge data set comprising of 3D co-ordinates and is hard to visualize. In order to make the data easily comprehensible, the original dataset is converted into a hight map. This allows the developers to easily visualize the real world terrain before

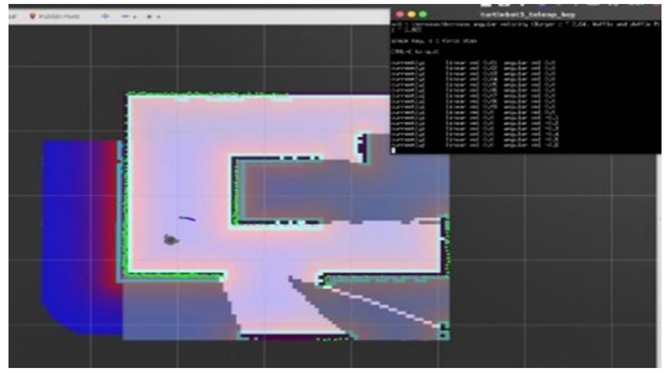

Fig. 6. Manual Mapping

hand and make adjustments using a simple image editor if needed. This step also helps in removing a lot of noise, that might be captured by the lidar sensors, using thresholding.

In order to let the developers access the ground terrain beforehand, a custom application was developed which converts the data captured by the robot into a height map which can then be used to generate a 3D model directly or be used in the terrain system of game engines such as UE Unity.

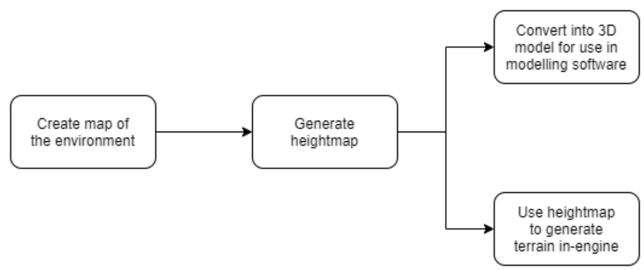

Fig. 7. Process flow for standalone application

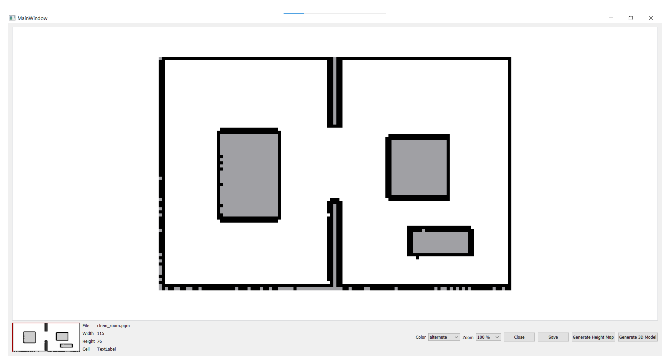

Fig. 8. GUI for standalone application

The subsequent 3D file generated is an accurate representation of the real-world terrain although a small amount of data is lost while compressing the entire dataset into a single heightmap. However, this loss in precision doesn't affect the user's immersion as it is too small to be noticed.

Fig. 9. Height map generated from map of the room

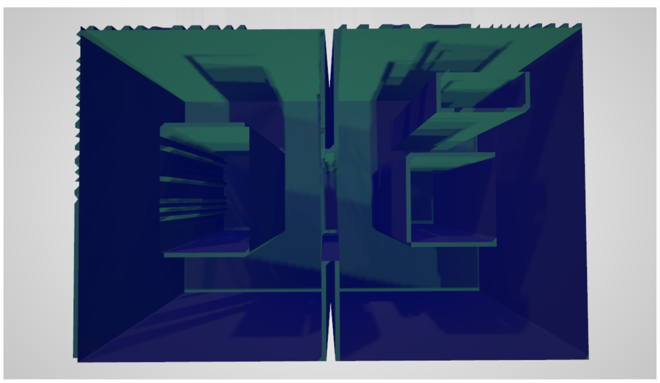

Fig. 10. 3D model generated from height map

V. Contributions and Limitations

The restriction of movement in VR applications is a problem that has adversely impacted user immersions. This paper's suggestion of synchronizing the virtual world's ground plane with the real-world using telepresence robots has never been attempted before. It gives the user the freedom to move naturally and thereby increases immersion.

The autonomous mapping technique used suffers from a few limitations in terms of computing speed and processing power. As the robots used for navigation usually have compact microchips, the processing power is limited. Point cloud matching, optimization calculations, etc. requires high computational power. However, this can be solved using parallel computing which can be achieved using multicore CPUs or GPUs to improve performance. The frequency of graph optimizations can also be varied so as to ensure optimal results both in terms of results as well as performance.

Estimation of sequential movement ultimately leads to some margin of error. This can be due to several factors such as sensor calibration, wheel movement of the robot, etc. However, if this error is large enough, it can accumulate and cause deviation from the actual co-ordinates which ultimately results in a distorted map. One counter measure is to determine the calibration errors of the robot beforehand and correct the measurement values.

VI. Conclusion

Synchronization of the real-world ground plane with the virtual world is a novel method to ensure natural movement while using VR applications. By avoiding traditions VR locomotion methods such as teleportation and embracing natural locomotion, the immersion of the user increases. It gives more freedom to VR users as they will be able to safely use their applications in any environment regardless of the obstacles present in them and would ultimately lead to an increased number of VR users. Moreover, it allows developers and game designers to make their application adapt to the user's environment opening the possibility for a new level of immersive interactions.

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Fig. 11. Signature of Guide