DEVELOPING A CORRECTING TOOL FOR INTERACTIVE FABRICATION PROCESS

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Abstract. This paper will propose the integration of multi-view stereo and time of flight technologies and components. Through the spatial point cloud sensor, the changes of objects in the space are converted into digital point clouds, which are feedback on the virtual interface. To make the virtual and physical will continuously communicate and feedback in space, which we established a correction tool for the integration of virtual and physical. The agent-based sensor computing method combines the fabrication process of visual sensors and behavior, from virtual object control to fabrication machines. In this tool, users can explain the reasons for design decisions by visualizing process and process-related information. It allows virtual and physical previews and feedback in real time, and finds out the differences between the two and makes real-time corrections. Solved the correction problem of coexistence.

Keywords. Digital fabrication; Digital Twin; Co-existing; Design process.

1. Introduction

The rapid development of digital fabrication tools has changed people's past creative modes, allowing machines to perform production and fabrication more quickly and conveniently. It is often pointed out that the interface bridging between the virtual and physical environment is useful for supporting personal fabrication design, but there are still differences between the virtual and the physical. Designers should continue to modify the process, increase the accuracy between the two and get closer to the appearance of both sides (Hsiao, Lee, Chen, & Chang, 2020). Currently, the real-virtual integration has attracted considerable attention in academic, industry and human-computer interaction. Many collaborative robots have been developed and integrated with these digital fabrication tools, such as automated operating systems using robotic arms and digital visual interfaces (W Huang, Williams, Luo, Wu, & Lin, 2018; WX Huang, Yan, Luo, & Li, 2016). The primary condition for human-machine collaboration is to integrate virtual and physical, as the preferred means of real-virtual integration. Digital twins (DT) have received extensive attention from industry researchers and

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 1, 653-662. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

practitioners through faster algorithms, enhanced computing power and available data (Dembski, Wössner, & Letzgus, 2019). It is a method of connecting virtual models and physical products. It is usually can be used in various physical assets, processes, personnel, places, digital replication systems and equipment for simulation. This method can also optimize the real-time control of products and production lines. The two can be integrated together so that the virtual object, and the physical product can be previewed in real time to find the differences and correct between them in time. It is effective Reduce fabrication errors and shorten production time (Caputo, Greco, Fera, & Macchiaroli, 2019).

During the experiment, we found that there is a difference in the presentation effect between the physical product in the real environment and the virtual model produced by the Mixed reality mobile, which leads to errors in the operation process(Okura, Kanbara, & Yokoya, 2015). Because the Multi-view Stereo (MVS) technology used it for environment establishment uses optical reflection to perform rapid multi-image overlay to obtain the calculation parameters of the environment model, and perform model establishment based on it (Chang et al., 2020). However, modeling through the difference in perspective will continue to deform the model in reverse due to the principle of perspective. When the deviation of the viewing angle is too large, the model level and the azimuth angle will be inaccurate. In this research, the digital twin will have a floating and uncertain state during execution. The time of flight (ToF) used by the Lidar point cloud sensor uses the principle of light wave reflection to detect reflected waves, and calculate the time difference to determine the location of the object as the basis for establishing the model (Sun, Zheng, Wang, Sun, & Ruiz, 2018). And computer-aided tools and digital fabrication are integrated to conduct research, and the problem of image errors caused by the implementation of virtual and physical integrated interactive tools is proposed, and solutions are found.

2. Literature Review

With the rapid development of digital technology, flat virtual images that originally existed only on computer screens have developed virtual environments, which can create more sensory experiences. This technology is changing the way people experience virtual and physical environments. The combination of virtual and physical requires the design of a human-machine interface, that can be sensed and controlled to establish a human-machine interactive operation method. Machines need to sense to identify the parameter information of the entity, and people need to use devices to understand the appearance of the virtual environment. By integrating the two, the barrier between human and machine can be crossed, so that the world of the machine can merge with the physical world to achieve completeness. Human-computer interaction model (Williams, Szafir, Chakraborti, & Ben Amor, 2018).

2.1. DIGITAL TWINS: DIGITAL MAPPING OF VIRTUAL AND PHYSICAL COEXISTENCE

The augmented reality (AR) in which the computer creates virtual objects or characters in reality combines people's perception of the physical world with the virtual objects generated by the computer to develop a digital model of digital twins. The two-way connection between the environment and the physical world generates a more reasonable virtual and physical integrated fabrication process and precise production control methods to help realize intelligent fabrication (Qi, Tao, Zuo, & Zhao, 2018).

This technology brings unprecedented visual effects. In the past, the instructions can only be transmitted to the execution end through the tablet. And through the actual fabrication process to find the error, and then return to the input terminal for correction. Forcing the operator to repeat the alternate operation between the instruction and the assembly process, which greatly reduces the efficiency of the work process (Figure 1). However, virtual reality (VR) head-mounted displays have opened the door to these limitations, and the operation of performing system functions in a wearable manner overcomes these limitations. Head-mounted displays incorporating augmented reality technology have gradually appeared on the market, which can create virtual images in mixed reality (MR).

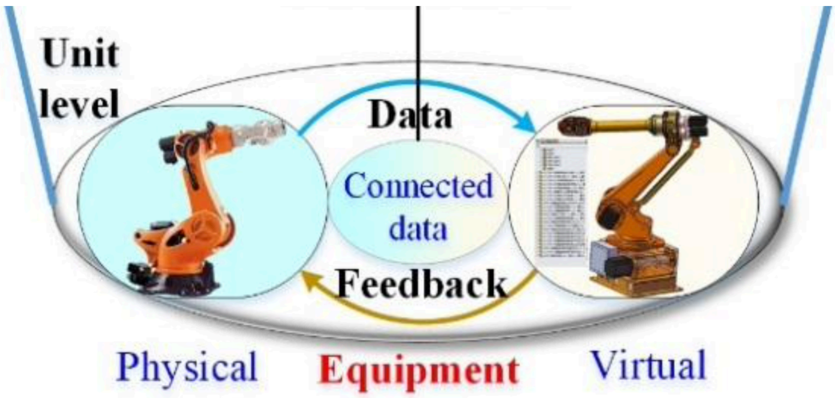

Figure 1. Digital twin in the virtual and real integration method of intelligent fabrication (Qi, Tao, Zuo, & Zhao, 2018).

2.2. DIGITAL FABRICATION TOOLS WITH VIRTUAL AND PHYSICAL COEXISTENCE

Mixed Reality is a technology application that allows users to experience navigation content. Through this technology, users can experience virtual visual effects in a real environment. Mixed reality creates new environments and visualizations through the integration of the physical world and the virtual world, in which physical and digital objects coexist and interact in real time. Mixed reality not only occurs in the physical or virtual world, it includes augmented reality technology that combines reality with virtual reality, and virtual reality real-time interaction technology. Today's mixed reality technology and application range have been extended to entertainment, interactive art, engineering, and medicine are used in many applications (Tepper et al., 2017).

2.3. MULTI-VIEW STEREO OF MIXED REALITY MOBILE (MVS)

The MVS technology uses optical reflection images obtained from different viewing angles to quickly superimpose multiple images to calculate the image difference of the reference object, thereby performing 3D model creation. The multi-view manifestation technology originated from the human visual system. The brain builds a three-dimensional space through several high-frame-number images obtained by the eyes (Figure2). The MVS technology is to operate in this way, using lenses separated by a certain distance to obtain multiple images, by comparing the distance between each lens, and then calculating the distance of the object seen by each lens from the lens focal length to determine position of the object in space (Furukawa & Hernández, 2015).

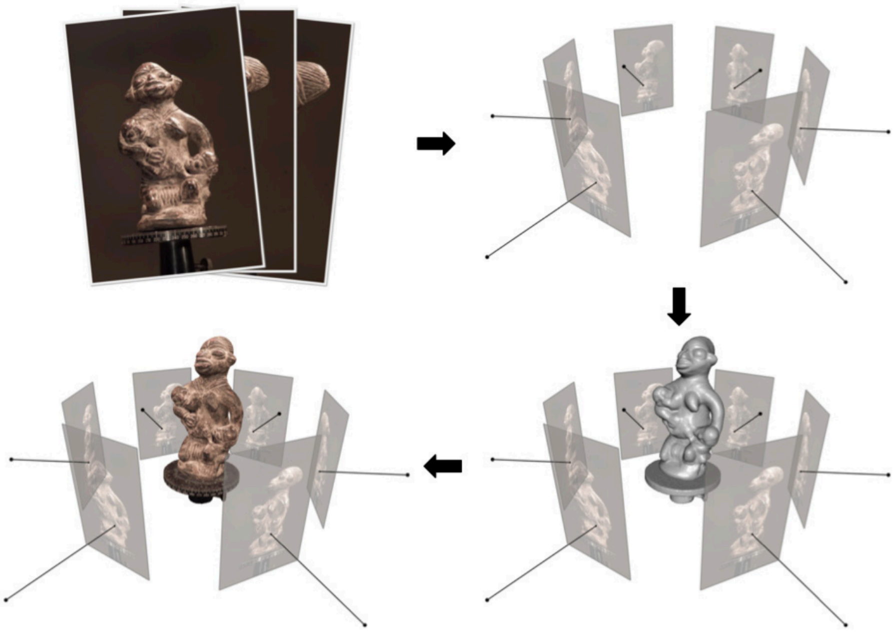

Figure 2. MVS image creation principle (Furukawa & Hernández, 2015).

2.4. TIME OF FLIGHT OF LIDAR SENSOR(TOF)

The space point cloud sensor technology can translate physical space objects into digital point clouds. The Lidar sensor uses this method to capture the parameter data of the physical space and is based on time of flight (ToF) Lightwave distance measurement, calculate the start and end signals of the flight time to get the distance, and then build the model (Li, Yang, Xie, Li, & Xu, 2018). Lidar uses a sonar-like optical reflection mechanism to locate the point cloud, and uses the time difference between light wave emission and reception to calculate the position parameters of the physical object. Therefore, when the object is blocked, the distance of the blocked object can be obtained through reflection (Figure3).

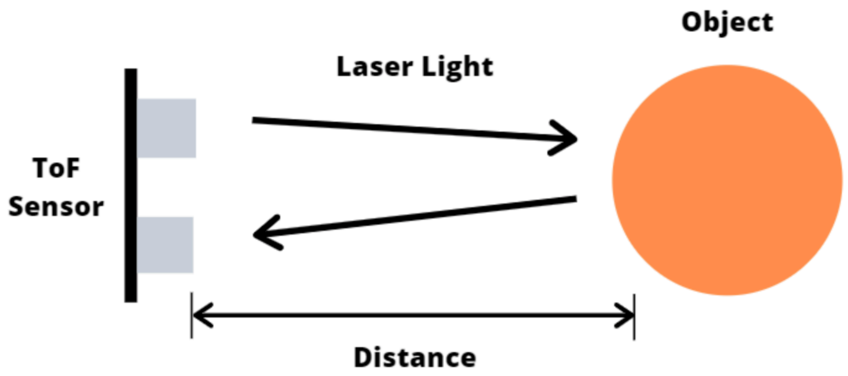

Figure 3. ToF lightwave ranging principle.

2.5. SUMMARY

Based on the above-mentioned literature discussion, the use of digital twin virtual and physical integrated fabrication tools requires the integration of that parameters. And virtual content needs to be presented to users with physical world devices, so that users can view the virtual environment from a realistic perspective. The physical environment also needs to be detected by the computer for identification by the sensor, so that the computer can know the appearance of the physical environment, so as to achieve the human-computer interaction where the virtual and physical coexist.

3. Materials and Methods

This experiment integrates the Lidar point cloud sensor time of flight (ToF) technology and the multi-view stereo (MVS) technology used by Mixed reality mobile in the establishment of the environment model. These two are different model results derived from sensing technology. In order to increase the accuracy between the virtual model and the physical environment, and apply it to the intuitive precision process control of the digital twin, so that the designer can more accurately view the fabrication process, so that the prototype can be corrected in real time when an error occurs (Chen, Chang, Hsiao, & Huang, 2019).

3.1. TOF AND MVS ENVIRONMENT MODELING

This technology first uses the ToF sensor Lidar to translate objects in space into digital point clouds, and feeds them back to the mixed reality mobile interface using the MVS module. In response to different sensing technologies in the process, ToF and MVS will individually produce different digital models. This technical process is to examine the differences between these two virtual models to increase the accuracy of the virtual model and optimize it. Interactive workflow of the virtual and physical integration platform. In addition, this technology also expects to shorten the time for designers to fabrication and test prototypes by allowing designers to view and correct digital models more accurately and in real time, and to reduce problems that need to be corrected again after fabrication. First, we set up the ToF point cloud sensor in the space for sensing, and transmit the signal to the surroundings in a divergent manner. After sensing the physical object in the space, it will bounce back to the sensor to obtain the position information of each physical object, then convert it into a point cloud, and rearrange it in the software (Ouster Studio) to be in the virtual environment produced physical sensing model world (Figure4).

Figure 4. Use fixed ToF for environmental modeling pre-test.

When an object in physical space changes, the position of the bounced signal also changes. The signal is updated at 655,360 points per second to detect the change of the physical object in real time (Figure5).

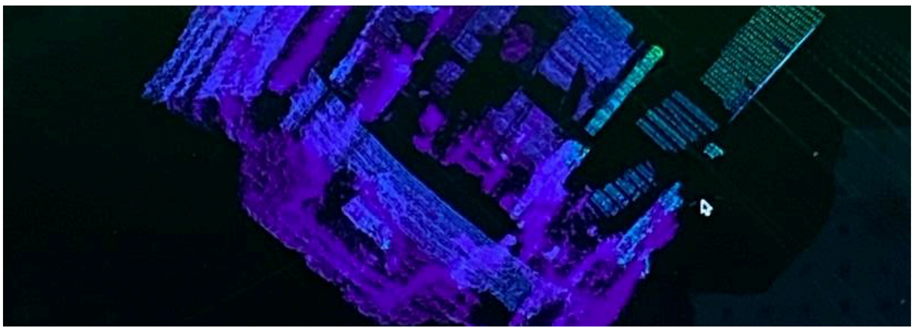

Figure 5. ToF point cloud model.

Then we set the initial origin in the MVS device, and use this origin as the base point of the virtual world and the origin in the computer-aided design software. The origin setting assists us in locating the space, fabrication equipment, and the relative position of the material (Figure6).

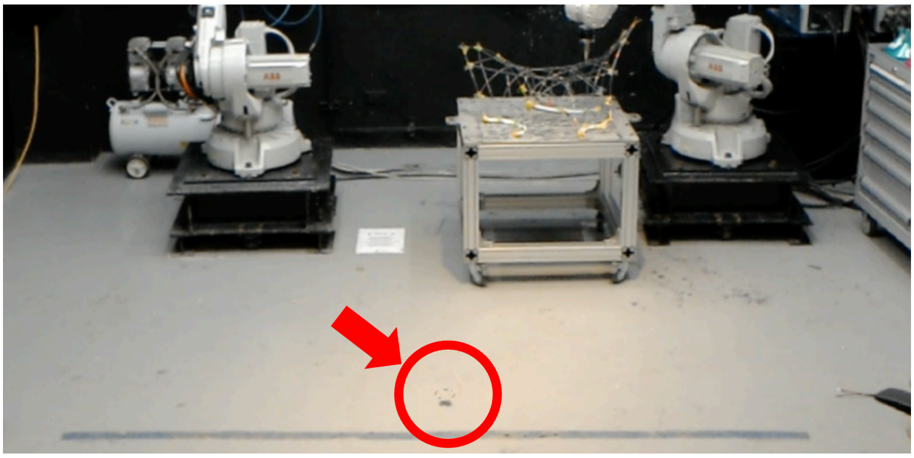

Figure 6. MVS positioning mechanism.

3.2. MVS AND TOF DIFFERENCE COMPARISON

In order to be able to analyze the point cloud, we will capture part of the point cloud and output it as a CSV, and then read the file by Grasshopper to generate the point cloud information in the computer-aided design software. However, after displaying the space model scanned by the mixed reality device (green) and the point cloud scanned by the sensor (red). We found a slight difference between the two. You can see the boundary of the space model scanned by the MVS, and the point cloud boundary of the ToF scan does not currently match in angle (Figure7).

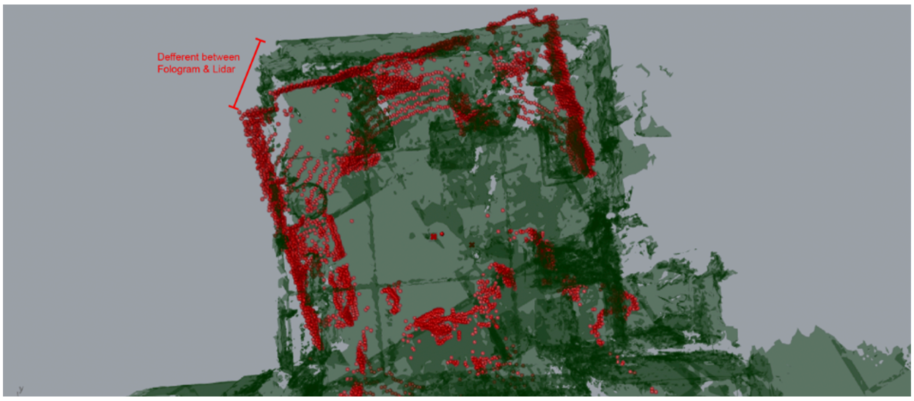

Figure 7. Differences in modeling results between MVS and ToF.

3.3. MVS AND TOF ERROR ADJUSTMENT

In order to make the two models match each other, we projected the origin of the MVS and the center of the ToF point cloud on the same reference center. The center point of the digital space formed by the point cloud is analyzed, and the center point is the position of the sensor. Since the sensor is mounted in the air, we connect the outermost point of the point cloud to form a frame, and use the center point of the bottom of the frame as the origin. Finally, the center point of the sensor and the origin of the mixed reality device are pasted together so that the spatial positions of the two are consistent (Figure8).

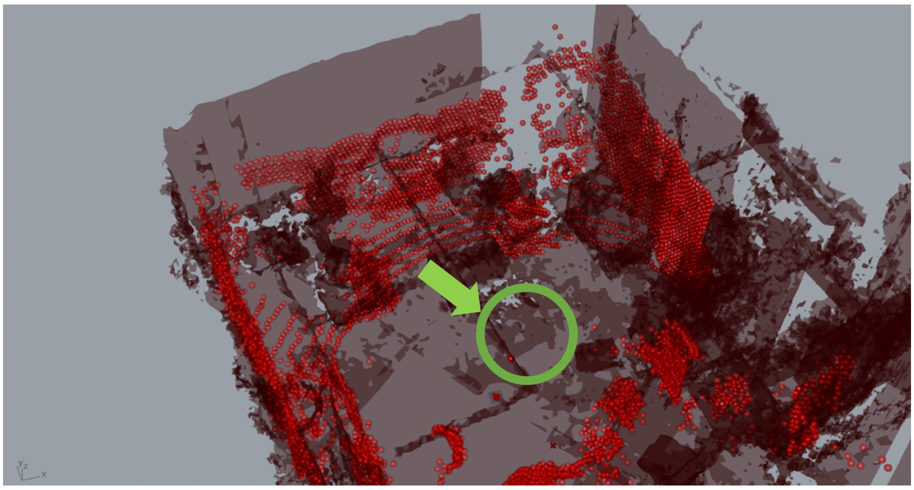

Figure 8. The MVS and ToF models are overlapped with a reference point and then the matrix transformation calculation is performed.

4. Result and Discussion

To enable the coexisting interactive fabrication tools to realize the physical and virtual interconnection, through the spatial point cloud sensor, the change of the object in the space is converted into a digital point cloud and feedback to the virtual interface. The two spaces of virtual and physical are constantly communicating and giving feedback, and the differences between virtual models and physical products are tested to optimize interactive design tools. We used two different sensing technologies to model the environment at different stages of the workflow, combined the advantages and disadvantages of MVS and ToF, and applied the two models derived from the algorithm for correction. According to the results of this experiment, it is recommended to digitally model the environment through the positioning ToF mechanism at the beginning of the work, and use it be a reference benchmark. And then continuously obtain it through the MVS of Mixed Reality Mobile Buffer model. The original reference object is calculated through digital reference and matrix transformation, and the comparison effect between the mixed reality mobile device and the point cloud sensor is further optimized.

After that, we also tried to use this interactive fabrication tool for the application of weaving structure. The weaving structure is widely used in the field of architecture, and the use of digital technology to construct a complex spatial curve model (Chang et al., 2020; Huang, Yan, Luo, & Li, 2016).We imported the physical data into the virtual system, and the environment construction used the optical correction tool of this experiment. It can be found that after this correction tool, the virtual image seen in Mixed Reality Mobile is close to the actual state, achieving a more complete digital twin effect (Figure 9). After the fabrication calibration system, the computer can obtain the environmental parameter values more completely and instantly. This system can help users greatly reduce errors when performing digital twinning, and more accurately view and operate the fabrication process. In the future, this system will be able to combine image recognition and machine learning to fully automate the operation of digital fabrication tools. This calibration mechanism provides rapid establishment of environment and object parameters, which helps the computer to establish an environment on the virtual side when performing automated settings later. And more importantly, users can accurately view the process through this system and can make real-time corrections.

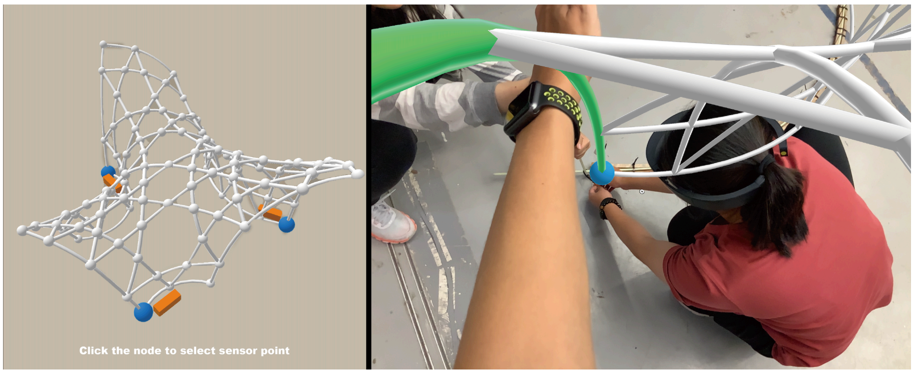

Figure 9. Use mixed reality mobile to manipulate the weaving structure of virtual models.

5. Conclusion

The ToF and MVS technologies are integrated to increase the accuracy of the digital tools that coexist with virtual and physical. In the process, it was discovered that the two technologies can be used to complement each other. ToF space point cloud technology Obtain the real space environment parameters to compensate for the errors caused by MVS in using different viewing angles to present images. In the experiment, we found that the models established through those technologies can be interactively compared and corrected, which can solve the inconsistency between the virtual space model and the physical space environment, when using the digital fabrication tools of Mixed reality mobile for work.

This technology can be applied to the building fabrication process, so that the virtual 3D model corresponds to the physical mechanical operation and can be observed alternately at the same time. However, through experimental results, we believe that more automated calibration is needed to eliminate the need for manual adjustment during calibration. Therefore, a system to solve this problem can be established in the future. The system allows designers to execute directly on the device while viewing the virtual and physical environment. The virtual execution side can control and observe physical equipment to facilitate the fabrication process of digital buildings.

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