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Development of Immersive Steel Tapping Training System

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Tapping is a dangerous job requiring a skilled operator. The operator controls the dumping angle of the furnace and the position of the ladle transfer cart at the same time, so that 250 tons of (1600°C) molten steel in the furnace can be poured into the ladle, smoothly. Sometimes, some abnormal situations arise (such as: a slag dart drop into ladle, steel leakage, out-of-control furnace operation, etc.) which can result poor quality of steel, production shutdown and/or personal injury. However, the operator cannot experience or deal with these abnormal situations in traditional training courses. Different from traditional training courses, immersive training allows users to train and learn in a realistic environment. Therefore, in 2019, CSC developed an immersive steel tapping training system, which includes the following six technologies: training stand, motion control module, steel simulation, 3D modeling, training engines, and scenario creation. Through this system, users can train skills of steel tapping and crisis handling of abnormal scenarios again and again in a safe and realistic environment, to shorten training time and achieve the purpose of experience inheritance.

Keywords: Steel Tapping, Immersive, Training System, Experience Inheritance

1. INTRODUCTION

Extended Reality (XR) is a development that combines computer graphics, simulation, artificial intelligence, sensing, display, and network parallel processing technologies. It can be divided into Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), etc... VR uses computer simulation to develop a 3D virtual world, providing users with a simulation of vision and other sensory organs, making users feel as if they are in this environment. Users can observe things in three dimensions instantly and without restriction. When the user moves position, the computer can immediately perform complex calculations and return accurate 3D world images to produce a sense of presence. Through the helmet, the field of vision is completely covered to produce a sense of immersion, and a complete virtual world is presented through the full virtual screen. AR is a technology derived from VR. It is an approach that instantly calculates the position and angle of the camera image and superimposes the corresponding image. The goal of this technology is to superimpose virtual objects on the real world. Through the “See Through” device, some digital information is displayed on these devices, and the digital information is generated visually and combined with reality. MR combines the real and virtual world, creates new environments and visualizations, where virtual objects can coexist with physical objects and can interact in the real world.

The development history of XR can be traced back to 1860. During its evolution, due to the digital motion sickness (Cybersickness), XR was silent for a while in the early 1990s. Until 2016, with the evolution of high-speed computing capabilities and the popularization of consumer electronics, XR has risen again. Today, XR is used in entertainment, education, military, medical and industrial fields(1). In industrial applications, most of them focus on training and simulation. For example, Purdue University established the Center for Innovation through Visualization and Simulation (CIVS) and cooperated with ArcelorMittal to build physical models and 3D visual virtual models of blast furnaces and continuous casting processes(2). Through the interaction of XR, operators can fully understand the impact of operating conditions of the process. At the same time, combined with the measurement data during actual operation, the predicted value of the process can be obtained through the physical model, and the predicted value is feedback to the actual system for control. POSCO develops a virtual reality operating system (VTS) that allows operators to simulate the rolling production process through the screen(3). JFE introduced MR technology in 2020 to simulate situations that may be encountered in the casting environment, such as blocked nozzles, so as to strengthen crisis management capabilities and allow experience to be inherited(4).

CSC has also cooperated with ITRI to develop virtual reality application technologies starting in 2019. The four features suitable for VR training applications are: the real environment is difficult to replicate, the operation is non-procedural, abnormal situations are difficult to reproduce, and in multi- perspective is needed. The process of steel tapping suits these features, exactly. The tapping operation room (Figure 1), which includes control joystick, control panels, furnace and ladle, etc., can not be replicated in the classroom for user training. Tapping is not a procedure operation, but depends on user control. The abnormal situation of steel leakage caused by a furnace with broken holes is an important training resource, but can not be reproduce. Moreover, limited by the view of the tapping-view window, operators can not observe the full view when tapping. Thus, "The Immersive Steel Tapping Training System" is the first VR training application in CSC.

Fig.1. Tapping Operation

2. EXPERIMENTAL METHOD

Tapping is a dangerous job. Requiring a skilled operator to control the dumping angle of furnace and the position of the ladle transfer cart at the same time, so that 250 tons of (1600°C) molten steel in the furnace can be poured into the ladle, smoothly. (Figure 2). Thus, CSC has developed "The Immersive Steel Tapping Training System" to train new operators. The immersive Steel Tapping Training System includes the following three layers: hardware, software and application. In the hardware layer, CSC has established a training stand (Figure 3) which all hardware: VR glasses, spatial locators, control joysticks, high-speed computing computer, etc. are mounted to. The size of this stand is less than $4m^2$, but it can simulate the tapping process space which is actually larger than $40m^2$.

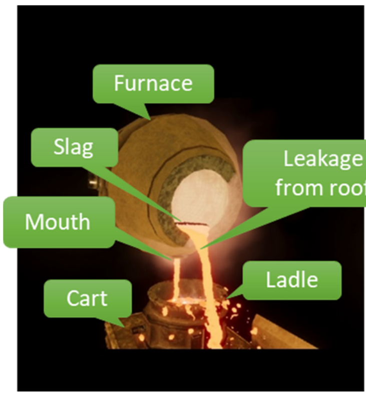

Fig.2. Tapping Process

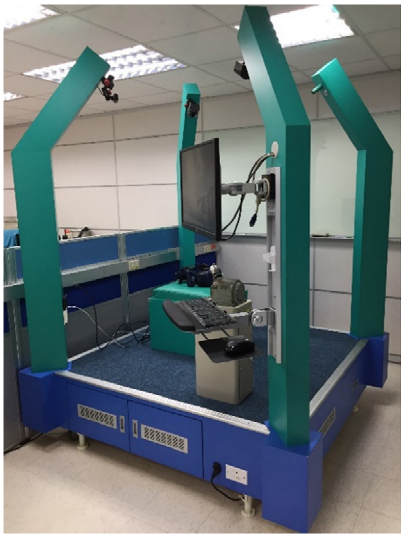

Fig.3. Training Stand

In the software layer, the motion control module and steel simulation were developed. The motion control module (Figure 4), is embedded in system and works in the background. It captures the control signals of the two control joysticks (furnace and ladle cart), then calculates and simulates the dumping angle of the furnace and the position of the ladle cart to the corresponding virtual objects. A motion control module acts as a bridge between the real and virtual worlds to capture the signal and control the virtual object. Allowing the tapping process to be controlled by the users and not by a fixed procedure.

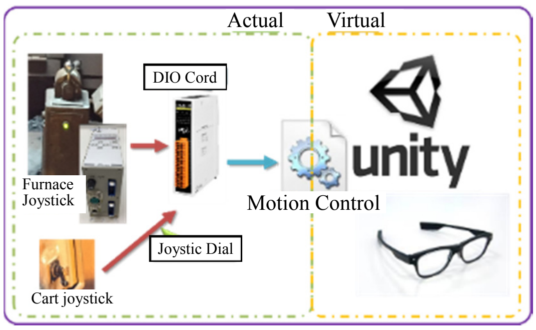

Fig.4. Motion Control Module

Steel is the main element in the tapping process, and will be simulated via a particle system (Figure 5). Commonly, particle generators have two systems, Obi and Flex. The same approach is used to generate a particle pool, and then take out some of the particles from it. The particle solver will simulate a fluid and its physical properties, such as gravity, vorticity, viscosity, cohesion, density, etc. Finally, the surface rendering such as light and shadow is added to simulate steel. The advantage of Obi(5) is that it can trace the position of each particle, which is conducive to tracking the height of the simulated steel. But, it is impossible for Obi to simulate 250 tons of steel due to the restrictions of the huge amount of calculation as well as the upper limit of 4,500 particles. In contrast, Nvidia's Flex(6) uses GPU to compute the particle solver. The disadvantage is that all particles are treated as the same object. The advantage is that it can generate a large number of particles. According to an actual test, with a 3.5GHz CPU, it can generate 50,000 particles to simulate 250 tons of steel and computing performance to maintain 25FPS (Frames per Second).

Fig.5. Steel Simulation

This system uses Flex to simulate steel. Since the simulated steel has physical properties, the flow rate of tapping will depend on the dumping angle, and the steel leakage can also be simulated realistically. The overflow from the roof of the furnace (Figure 2) can be detected via beam, but the amount of steel outside of the ladle or the height of the steel in the ladle can not be detected via beam, since all particles are treaded as the same object (Figure 6). Therefore, some different approaches are proposed to detect this. A transparent spheres with a lower density than the steel can be created to float on the surface to detect the height of the steel in the ladle. In the same way, the floating sphere can simulate slag on the surface of the steel (Figure 2). The steel outside of ladle can be collected via a funnel positioned under the ladle track, and the amount of steel collected can be calculated. Therefore, in addition to the dumping angle of furnace and the position of the ladle, the amount of steel in or outside of ladle can be digitized and feedback to the user, via this approach. Moreover, the particle system can simulate not only fluid, but also smoke, dust and fire, creating a real world tapping environment.

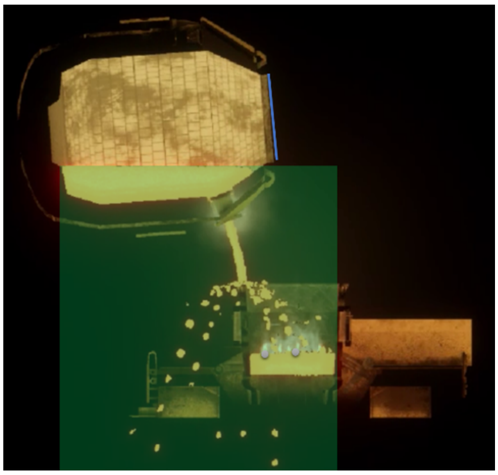

Fig.6. Green Box as seen as one object

The application layer includes 3D modeling, training engine and scenario creation. The 3D modeling method is to capture the contours or point cloud information of the real object, after stitching, reshaping, and finally rendering the surface material to achieve a realistic effect (Figure 7). The training engine that integrates the digital information feedback and the scoring mechanism can identify the user's learning ability and have a deeper understanding of the principles of tapping (Figure 8). During the tapping process, the standard operating procedures can allow steel to be smoothly poured into the ladle, but some abnormal situations (such as: the furnace or the ladle having a broken hole causing steel leakage, the furnace losing control, etc.), which can cause production shutdown or personal injury. However, these abnormal situations cannot be taught in traditional training, and the first time the operator encounters the abnormal situation is often after going online. Therefore, in the virtual world, scripts are written to create abnormal scenarios (Figure 9) that have occurred in the past, so that users can repeat the exercises and cultivate the ability to deal with crises. In this system, in addition to the normal operating procedures, five historical scenarios (such as: steel leakage and out-of-control furnace operation) are created for users to experience and learn from.

3. RESULTS AND DISCUSSION

The Steel Tapping Training System runs via 3.6GHz CPU, RTX 2080 GPU and HTC VIVE hardware, with a performance of 20-25 FPS. The system has standard and abnormal training situations. The standard training simulation includes the following steps: let the

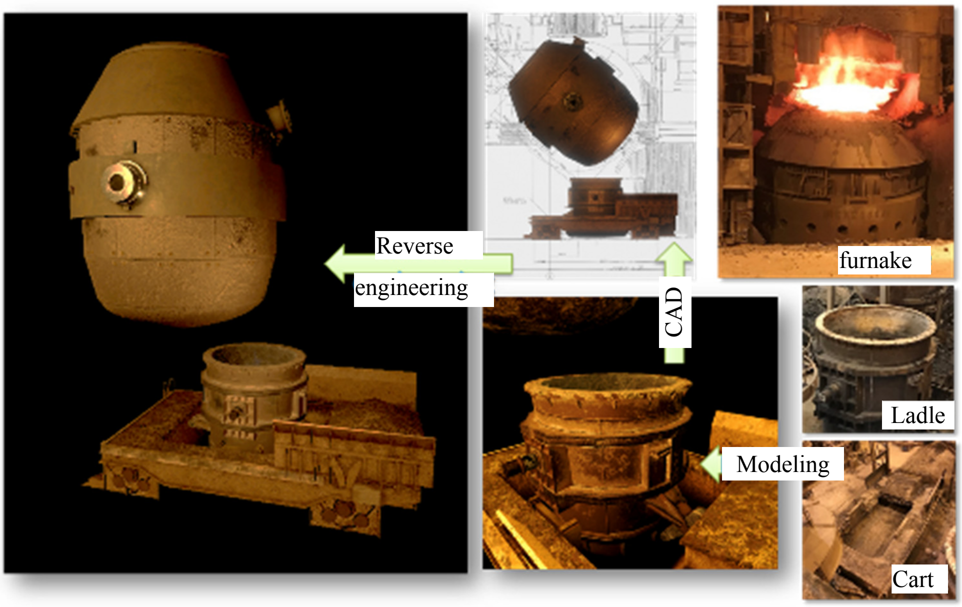

Fig.7. 3D Model

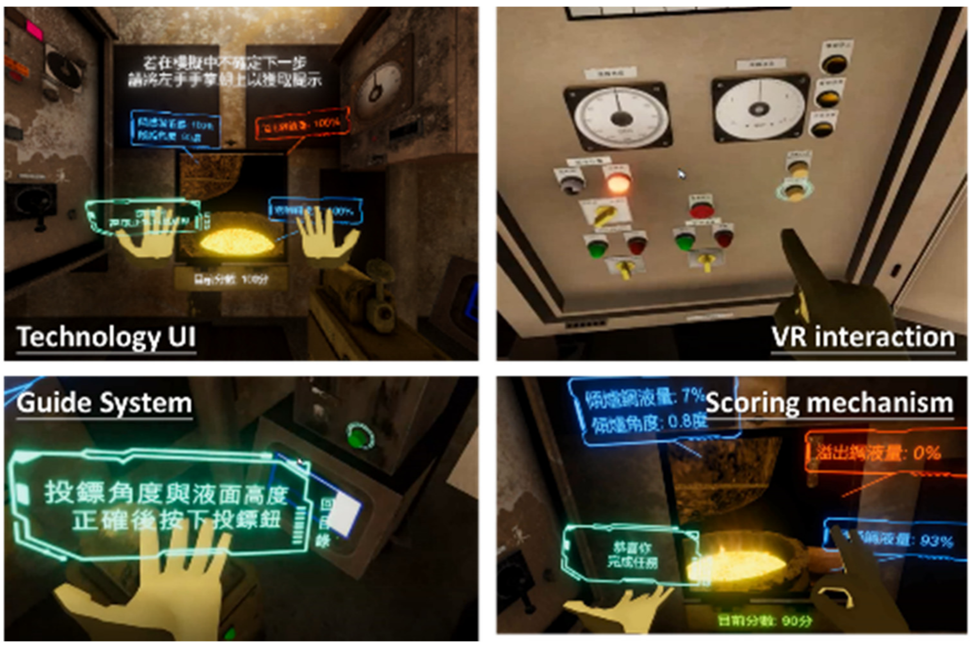

Fig.8. Training Engine

ladle move to the predetermined position, waits for ready-to-tap signal light (RTS), responds to start-to-tap (ST), dumps the furnace at a predetermined angle, starts tapping, avoids steel condensation, throws dart into furnace, and ends tapping. At the beginning of tapping, the central monitoring room will send out a RTS request. The VR glasses will detect whether the user is focused on the RTS. And recognizes whether the user responses by ST, which is a virtual button, through finger gesture via Leap Motion. During tapping, the user must correctly pour the steel into the ladle within a limited time, and throw overflowing from the roof of the furnace, or the steel flowing out side of the ladle, which will be detected. When the remaining steel in the furnace is less than 30%, the user must press the virtual button to throw a slag dart. The dart is a plug (with a density between the slag and the steel) used to block the tapping mouth to prevent slag pouring into the ladle, while allowing a reduced flow of steel, since steel is attached with real-physical properties. At the end of tapping, the user must take the steel stream close to the wall of the ladle, and finally, upright the furnace to complete the tapping.

Abnormal situations can occur during tapping, unexpectedly. Common abnormal situations include: a broken hole on the wall of the furnace or the ladle, joystick control and brake failure of the furnace resulting in the loss of operational control. These situations result in steel leakage and can result in major industrial safety accidents. In this system, five abnormal scenarios are created: broken hole on the bottom of furnace, broken hole above the tapping mouth, broken hole on the side of ladle, joystick control and brake failure of the furnace resulting in the loss of operational control. The emergency procedure steps, that need to be trained, include: ensuring that the ladle is no longer under the furnace, pressing the emergency stop button, and turning the furnace to stop tapping. By abnormal scenarios created, users can practice again and again in a safety classroom (Figure 10.).

The system was completed in 2020, and related departments such as W3, Y1, A1, H2, dragon steel, etc. have been invited to operate and experience.

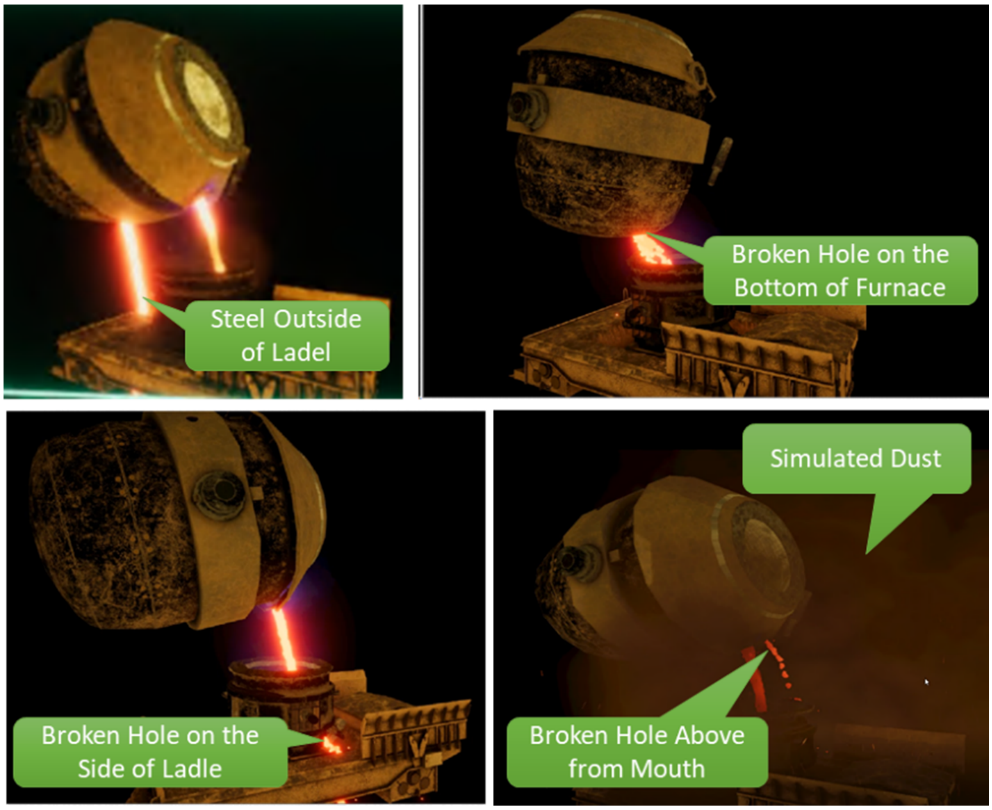

Fig.9. Some Abnormal Scenarios

Fig.10. Immersive Tapping Training

4. CONCLUSIONS

Most of the processes in CSC require proficient skills and experienced operators. Thus, better methods are needed to improve the effectiveness of training. Taking the steel tapping process as an example, the operator must operate 85 rounds (250 tons of (1600°C) molten steel) a day, which is skilled work. But new operators could only learn by observing the actions of their predecessors.

Different from traditional training methods, the feature of virtual reality training is to create an immersive experience. Thus, CSC used the steel tapping process to demonstrate and developed an immersive steel tapping training system. The system includes hardware, software and application layers. In the hardware layer, CSC built a training stand where actual-joysticks and VR glasses are mounted to. The motion control module was developed to cascade the real-and virtual world, and steel is simulated via a large amount of particles, in the software layer. The application layer is composed of 3D models, training engines and scenario creation. The 3D model creates an immersive environment and provides interaction with virtual buttons. The training engine provides digital information feedback to the user and evaluates the user's learning ability through a scoring mechanism. Finally, five abnormal scenarios are created in the virtual world for users to practice again and again.

Via this system, new operators can train steel tapping skills and crisis handling of abnormal scenarios again and again in a safe and realistic environment. The training time has been shortened from the original one month to one week to improve the effectiveness of training. In the future, CSC will continue to develop the application of XR technology in issues such as manufacturing, training, simulation, patrol, navigation, and remote cooperation.

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