Springer

KSME

Journal of Mechanical Science and Technology 24 (2010) 237~240
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-1175-9

Augmented reality-based training system for metal casting†

Keiichi Watanuki* and Lei Hou

Department of Mechanical Engineering, Graduate School of Science and Engineering, Saitama University
255 Shimo-okubo, Sakura-ku, Saitama-shi, Saitama 338-8570, Japan

(Manuscript Received May 2, 2009; Revised October 23, 2009; Accepted October 30, 2009)

Abstract

Products fabricated by metal casting are affected by casting design and pouring. In order to design products efficiently, engineers must consider the shape of the pouring gate and the fluidity of metal in the runner. Engineers must envision the shape of the product and the fluidity of the metal in three dimensions. However, this task is difficult, especially for beginners. Therefore, we developed an augmented reality-based training system for metal casting that allows visualization of fluidity. The proposed training system uses simple physical operations to compute and display fluidity in real-time. Visualization of three-dimensional images as well as training on this system is simple.

Keywords: Augmented reality; Skill transfer; Metal casting; Interactive interface

1. Introduction

In the Japanese manufacturing industry, recruiting the next generation of workers has become difficult due to population aging and avoidance of the manufacturing industry by young people. In addition, the transfer of production to overseas facilities has led to a decrease in Japan's industrial capacity. As a result, the future of the Japanese manufacturing industry is in crisis. In order to continue designing and manufacturing high-value-added products, the passing down of basic technology and skills, as well as the creation of knowledge, is essential. Developing suitable training systems is essential for meeting these goals [1].

Casting is an operation whereby metal is shaped by pouring it, in the liquid state, into a mold, followed by solidification. Pouring is an important step in the metal casting process. Since viscosity increases as temperature decreases, pouring too slowly causes misruns. On the other hand, since the molds are made of sand, pouring too quickly causes breakage of the mold and turbulence. Therefore, pouring metal at the right rate is critical [2]. In this paper, we present the development of an augmented reality-based training system for pouring. This system uses some simple physical operations to compute and show fluidity in real-time. Engineers can train pouring and study fluidity easily using our system.

† This paper was presented at the ICMDT 2009, Jeju, Korea, June 2009. This paper was recommended for publication in revised form by Guest Editors Sung-Lim Ko, Keiichi Watanuki.

*Corresponding author. Tel.: +81 48 858 3433, Fax.: +81 48 858 3433
E-mail address: watanuki@mech.saitama-u.ac.jp

2. Pouring

Casting is an operation whereby metal is shaped by pouring it, in the liquid state, into a mold, followed by solidification. Fig. 1 shows the metal casting process. Casting is also a method of detailing metal as a result of pouring the metal into a mold.

Fluidity is the ability of metals to flow through a gating system to fill the cavity of a casting mold and conform to the shape of the mold. Fluidity is determined by the solidification interval, viscosity, and surface tension. Metal is cooled by heat transfer upon contact with the mold and viscosity consequently increases. The metal solidifies upon further cooling, resulting in misruns [2]. To avoid misruns, engineers must pour the metal quickly. However, since the mold is made from

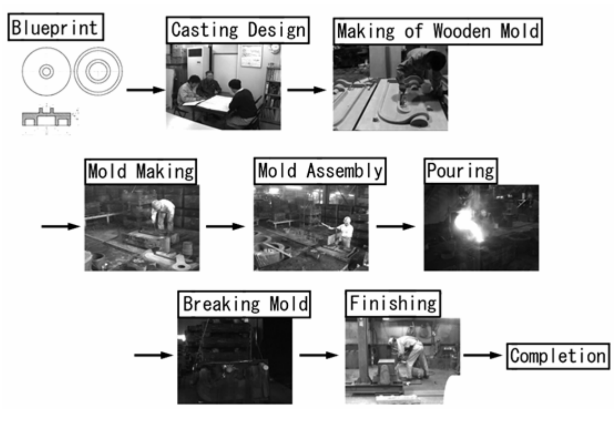


Fig. 1. Processes of metal casting.

sand, pouring too quickly can cause breakage or distortion in the shape of the mold. Therefore, it is critical to pour the metal at a proper rate. Engineers must consider the shape of the mold and the fluidity to determine the proper rate of pouring. However, this is a difficult task, especially for beginners. Therefore, engineers must study fluidity and be trained to pour metal properly.

3. Augmented reality-based training system

3.1 Augmented reality

Augmented reality (AR) is the overlay of computer graphics onto the real world. AR has many potential applications in industrial and academic research. One of the most difficult parts of developing an AR application is precisely calculating the location of the camera in real-time so that the virtual image is exactly aligned with real world objects. ARToolKit allows this to be done easily. ARToolKit tracking is shown in Fig. 2.

ARToolKit is a software library for building AR applications. The ARToolKit video tracking libraries calculate the real camera position and orientation relative to physical markers in real-time, enabling the development of a wide range of AR applications. Some of the features of the ARToolKit include single-camera position/orientation tracking, tracking code that uses simple black squares, the ability to use any square marker pattern, simple camera calibration code, and sufficient speed for real-time AR applications. ARToolKit is a C/C++ language software library that allows programmers to easily develop AR applications. ARToolKit uses computer vision techniques to calculate the real camera position and orientation relative to marked cards, allowing the programmer to overlay virtual objects onto these cards [3]. The fast precise tracking provided by ARToolKit is expected to enable the rapid development of many new and interesting AR applications.

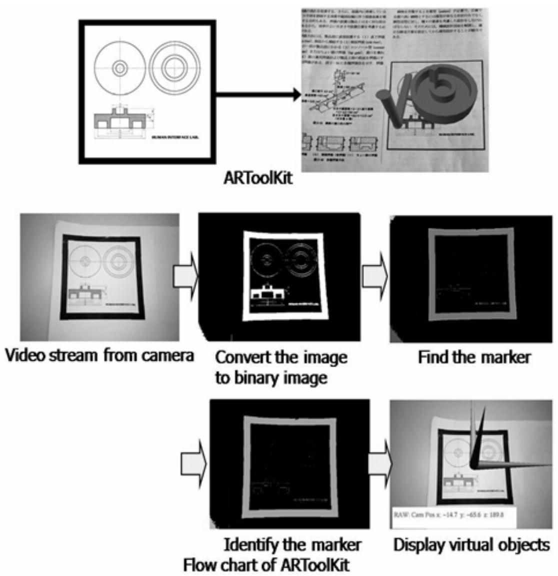


Fig. 2. ARToolKit.

3.2 Training system for pouring

Fig. 3 shows the AR-based training system for pouring built using ARToolKit. The system displays fluidity that is simulated by simple physical models in real-time.

The ARToolKit tracking works as follows: (1) The camera captures video of the real world and sends it to the computer. (2) The software on the computer searches through each video frame for any square shapes. (3) If a square is found, the software calculates the position of the camera relative to the black square. (4) Once the position of the camera is known, a computer graphics model is drawn in the same position. Thus, users can see virtual objects from every angle by moving the camera. In the proposed system, a mold and ladle is displayed on the marker and users operate a keyboard to rotate the ladle and pour metal.

Particles that represent liquid are initialized by the state of the ladle. Generally, intermolecular force increases with the distance of the fluid particles. Here, we define the fluid particles as rigid bodies. As a result, intermolecular force is constant. Fig. 4 shows a flowchart for the calculations.

Our calculations take into account gravity, collisions between particles, and collisions with the mold. The angle between the directional vector of a particle and the vector perpendicular to the collision surface is constant. Thus, the directional vector of a particle after collision can be obtained from Eq. (1).

$$R = 2\times(-I\cdot N)\times N + I \quad (1)$$

Here, R is the directional vector of a particle after collision, I is the directional vector of a particle before collision, and $\boldsymbol{N}$ is the vector perpendicular to the collision surface.

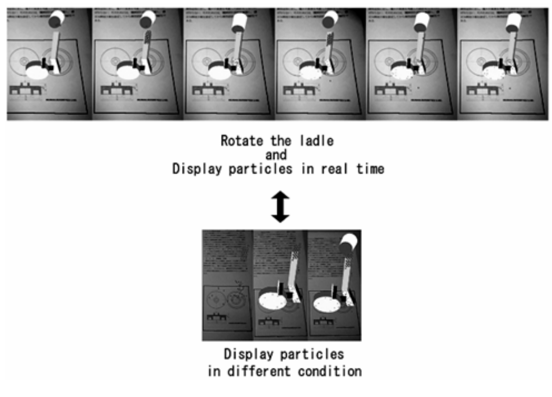


Fig. 3. Augmented reality-based training system.

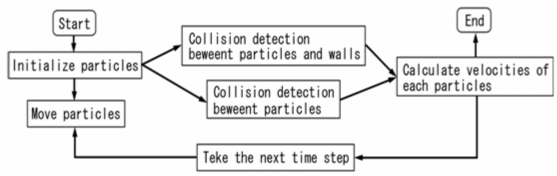


Fig. 4. Flowchart of simulation.

In the present system, we define particles as rigid bodies; thus, conservation of energy applies to the particles. We also define the mass of each particle as 1. For collisions between particles, the velocity of each particle after collision is obtained from Eq. (6) and Eq. (7), which are derived below.

$$V1_x = U1_x + U2_x - e(U1_x - U2_x) \tag{2}$$

$$V1_y = U1_y \tag{3}$$

$$V2_x = U1_x + U2_x - e(U2_x - U1_x) \tag{4}$$

$$V2_y = U2_y \tag{5}$$

$$V1 = V1_x + V1_y \tag{6}$$

$$V2 = V2_x + V2_y \tag{7}$$

Here, *U1* and *U2* are the velocity of each particle before collision, *e* is the elastic coefficient, and *V1* and *V2* are the velocity of each particle after collision. We use these equations to calculate the direction of each particle and the velocity of each particle in a predetermined time step. A random value is assigned as the velocity of each particle to avoid alignment.

We used an acrylic model ladle to pour colored water in order to compare real-world results with the proposed simulation. We also used the commercial fluid simulation software RealFlow4 to evaluate the simulation. Fig. 5 shows the shape of the mold used in the experiment. The results of pouring water in the model mold are shown in Fig. 6(a). We set the number of particles in our simulation at 1000, obtaining the results shown in Fig. 6(c). Fig. 6(b) shows the result of the RealFlow4 simulations. With RealFlow4, the viscosity, pressure, density, and velocity are used to calculate fluidity. The simulation is similar to actual fluidity. However, particles are modeled as rigid bodies in the proposed simulation; thus, collisions between particles, as well as between particles and the mold, are calculated as elastic collisions without considering viscosity, pressure, and density. The results of our simulation agreed qualitatively with the result of RealFlow4 at the pouring gate and in the runner. However, the results of our simulation differed from the results of RealFlow4 in the cylinder that represents the product. The particles in the proposed simulation spread faster than the particles in RealFlow4. Next, we put particles in the cylinder directly, the results of which are shown in Fig. 7. When water was poured into the model mold, water flowed and spread from the runner. Particles in the RealFlow4 calculations flowed with a small spread. On the other hand, particles in the proposed simulation flowed without spread because pressure was not taken into account. After collisions between the particles and the walls of cylinder, water spread along the walls of the cylinder and filled the cylinder in the real world. The results obtained with RealFlow4 and our simulation are similar. Even though the proposed simulation differed from real flow to a certain extent, this simulation agreed qualitatively with real flow. The proposed system displays the fluidity in the mold for training purposes. It is important to display fluidity in real-time; however considerable detail is unnecessary, since the system is not for fluid analysis.

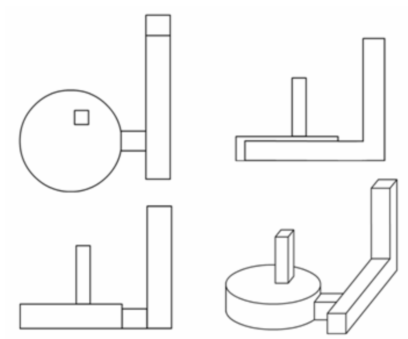
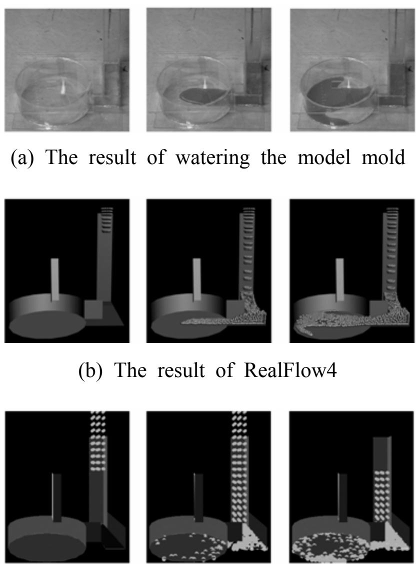


Fig. 5. The shape of the mold.

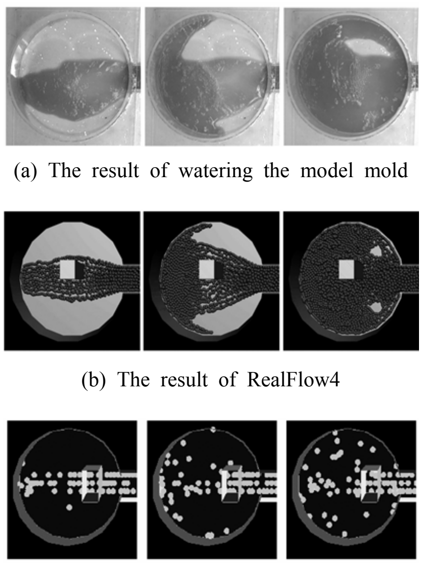


(a) The result of watering the model mold

(b) The result of RealFlow4

(c) The result of our simulation

Fig. 6. The results of the experiment



(a) The result of watering the model mold

(b) The result of RealFlow4

(c) The result of our simulation

Fig. 7. The results of the experiment.

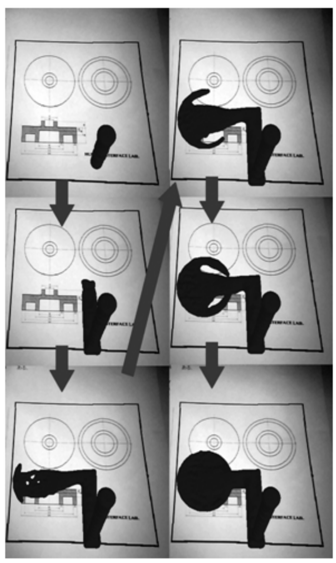


Fig. 8. Display the result of fluid analysis.

The proposed system can also display the results of the fluid analysis that is preliminarily calculated, in considerable detail, if necessary. Fig. 8 shows these detailed results. The proposed simulation, which uses simple physical laws, is considered to be useful for training.

3.3 Interactive interface

In training, it is necessary to use an interactive interface; controlling the ladle with a keyboard is not highly useful. Therefore, we apply an algorithm to detect the marker in ARToolKit to implement an interactive interface. First, we measure the rotation of the marker in small time increments and calculate the rate of rotation. We then initialize the direction and velocity of particles, based on the calculated rate of rotation. We also monitor the remaining particles to simulate reduced flow and velocity. Fig. 9 shows a flowchart of this process. We attach the marker to the cup so that users can interactively control the flow. Users can control the number and velocity of poured particles by tipping the cup, as shown in Fig. 10. The number and velocity of the poured particles increase with the extent to which the cup is tipped, thus decreasing the number of particles remaining in the cup. In other words, flow is controlled by the rate of rotation of the cup and the remaining number of particles, as in the real world.

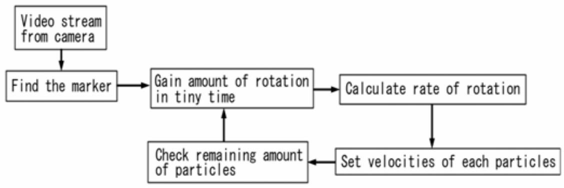


Fig. 9. Flowchart of pouring.

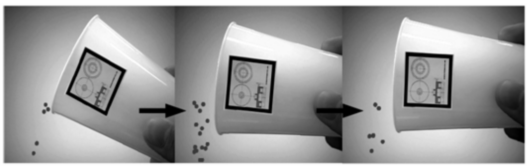
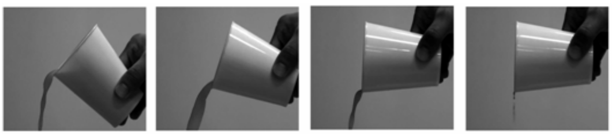
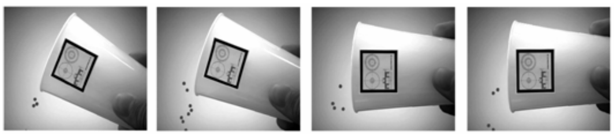


Fig. 10. Our interactive interface.



(a) Results of pouring in real world



(b) Results of our system

Fig. 11. The results of the experiment.

We examine the flow as controlled with this interface. The results are shown in Fig. 11. We define the number of particles in our simulation as 1000 for a 270 ml cup that is full of water. In the experiment, we fill the cup with 180 ml of water and set the number of particles as 666, which corresponds to two-thirds of the cup being filled with water. As a result, the proposed simulation results differ from the real world results by 2 s. The flow of particles decreases with the remaining number of particles, as observed in the real world. Users are thus able to interactively control the flow by using the proposed interface instead of a keyboard.

4. Conclusions

In this paper, we presented an AR-based training system. As is important for the training system work in real-time, we treated the particles as rigid bodies in the calculations to simulate the flow into the mold in real-time. We also constructed an interactive interface that controlled flow through the motion of a tipped marking cup. The flow into the mold could be visualized for training, and the flow could be controlled interactively by using the AR-based training system. With this system, users can train without the limitations of time and cost, and achieve better understanding of the metal casting process.

References

[1] The Ministry of Health of Japan, *Analysis of Labor Economy*, (2005) 30.

[2] Japan Cast Iron Foundry Association, *Casting Design of Cast Iron*, Japan Cast Iron Foundry Association, (1998).

[3] H. Kato, ARToolKit: Library for Vision-based Augmented Reality, *Technical report of IEICE PRMU*, 101(652) (2002) 79-86.

Keiichi Watanuki received his Ph.D. degree from Tokyo Institute of Technology, Japan, in 1991. He is currently a Professor in the Graduate School of Science and Engineering, Saitama University, and Saitama University Brain Science Institute. His research interests include human interface, brain-machine interface, robotics, knowledge management, virtual reality, and human-centered design.

Lei Hou received his B.S. degree in Mechanical Engineering from Saitama University, Japan in 2007. He then received his M.S. degrees from Saitama University, Japan in 2009. Hou is currently a Student at the Graduate School of Science and Engineering, Saitama University, Japan. Hou's research interests include virtual reality, augmented reality, and skill transfer.