

AI-Driven Virtual Simulation for Packaging Customization

Lei He, Hefei Normal University, China*

ABSTRACT

Recently, virtual reality technology has been paid attention to by the researchers from various fields. With the help of virtual reality technology, packaging customization environment can be simulated more intuitively. Thus, the workers can understand the structural layout in the packaging process, be familiar with the packaging workflow, and know how to deal with emergencies. These will effectively solve the impact of workers' misoperation on packaging quality and waste, and also avoid a series of issues caused by careless operations. This paper adopts artificial intelligence (AI) technology to simulate the packaging customization environment. Experiments show that the packaging customization environment can be simulated by AI technology effectively.

KEYWORDS

AI Technology, Packaging Customization, Virtual Reality, Virtual Simulation

1. INTRODUCTION

Virtual reality (VR) technology was first proposed by Jaron Lanier in the early 1990s (Firth 2013). Since then, VR technology has been valued by various industries and gradually developed into a complete discipline. Virtual reality technology utilizes computer graphics (Aristidou 2018, Jarabo 2017), artificial intelligence (L'opez 2020, Miller 2019) to reproduce the real world, and simulates human interaction experience in the virtual environment through language, gestures, senses etc. with the help of various sensors to make human have the sense of immersive.

The VR technology has three characteristics: immersion, interaction and imagination. It can be divided into distributed virtual reality system, desktop virtual reality system, augmented reality system and immersive virtual reality system. Virtual reality technology has made great progress in various fields since its establishment. It has been applied in many fields, such as aerospace (Tadeja 2020, Shi 2020), communication (Stadler 2019, Warburton 2019), transportation (Zhu 2020, Kreimeier 2020), military (Ahir 2019, Gače 2019), industry (Roldán 2019, Salah 2019), medical treatment (Ren 2021), education (Dean 2020, Yamakawa 2020), and entertainment (Olanda 2006, Kodama 2017). The virtual reality has attracted wide attention all over the world and plays a significant role in promoting related fields.

In the packaging customization environment (Knoll 2019), the equipment has complicated procedure and is heavy workload. The error operation will affect the printing quality and cause waste.

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*Corresponding Author

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The careless operation may easily cause danger and induce heavy losses. In order to solve this issue, a clear management and training system has been created for packaging customization. However, at the beginning of the formulation of the system, managers may lack an intuitive understanding of the specific packaging customization environment, such as the activities of personnel in the printing workshop, the interaction between personnel and machinery or equipment, and the cooperation between personnel and personnel. This will cause loopholes and unreasonable points in the system. At the same time, the system for packaging customization is often written in works and lacks intuition and operability. Thus, it is not conducive for managers to find and solve bottlenecks in management and training, and even more unfavorable for executors to accurately implement the system.

If a method can be used to simulate the packaging customization more intuitively, managers and workers will better understand the structure and layout of the packaging customization environment, be familiar with the task flow of the packaging customization, and understand how to escape in distress, etc. Therefore, the previous issues can be alleviated. This paper adopts the social force model (SFM) (Huang 2018, Kanamori 2018) to simulate the packaging customization environment, which can be used in future simulation by using 3D virtual reality for packaging customization.

The rest of this paper is organized as follows: in section 2, a virtual simulation for packaging customization is proposed by utilizing social force model; in section 3, the simulated results are provided for packaging customization; in section 4, the conclusion and discussion is provided.

2. VIRTUAL SIMULATION FOR PACKAGING CUSTOMIZATION

For virtual simulation of packaging customization, the motivation is to specify the paths and tasks of the virtual person during packaging customization according to the packaging process to restore the real packaging customization scene. When specifying a path, the virtual persons will move back and forth between the starting point and ending point. The virtual persons will start from the starting point and arrive at the ending point along the shortest path. During the moving process, they must avoid obstacles and the collisions with other persons or things. Before packaging customization, the human needs to walk along the task path between the digital proofing machine. During the process of packaging customization, the human needs to walk along the task path between the digital printing press, offset printing press, paper stack and console to complete the packaging customization work. In the post stage of packaging customization, the human needs to walk along the task path between the binding machine and the finished product to complete the packaging customization. In the management part, the human needs to walk between the desks according to the task path to complete the corresponding work.

Based on the social force model of Newtonian mechanics (Varieschi 2018), the different motives and influences of persons are embodied by the expression of each force. Since the factors that affect individuals are comprehensively considered and the modeling process of individual behaviors is more reasonable, the social force model can realistically simulate the movement of virtual humans in the virtual environment and the evacuation process of crowds.

In social force model, the persons are abstracted as self-driven masses. The social forces in group are used to model the physical, social, and psychological effects. The actual behavior of person i is affected by subjective consciousness, other persons and obstacles, which is equivalent to the effect of force on person i . The expression of social force model is represented as follows:

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{i,j} + \sum_w f_{i,w} \quad (1)$$

In equation (1), $m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i}$ represents self-driving force of $f_i^0(t)$, $\sum_{j \neq i} f_{i,j}$ represents the force generated by person j on person i , $\sum_w f_{i,w}$ represents the environmental force, $v_i(t)$ represents the actual speed of person i , and m_i represents the quality of person i . In the following part, we will explain the self-driving force, the force between persons, the force between person and obstacle, and associated parameters in the social force model.

The self-driving force of person i is defined as the influence of subjective consciousness on person i . It reflects the motivation of person i moving to the destination at the expected velocity. The expression of self-driving force is written as following equation:

$$f_i^0(t) = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} \quad (2)$$

In the equation (2), m_i represents the quality of person i , $v_i^0(t)$ represents the expected speed of person i , and τ_i represents characteristic time. Here, the expected direction of movement can be calculated by current position r_i and target position p of person i , which is represented as following equation:

$$e_i^0(t) = \frac{p - r_i}{p - r_i} \quad (3)$$

The force generated by person i on person j is defined the direction of movement of person j , which is affected by person i , during his or her movement. Person will keep a certain distance between each other, which is mainly determined by the density of persons and the expected velocity $v_i^0(t)$. Here, the personal space is called the “territorial effect”, which plays a key role in virtual reality simulation. When a person j gets closer to a strange person i , person i will feel uncomfortable. At this time, person i has a repulsive effect on person j . This effect can be expressed by the following equation:

$$f_{ij} = \left(A_i e^{\frac{r_{ij} - d_{ij}}{B_i}} + Kg(r_{ij} - d_{ij}) \right) n_{ij} + kg(r_{ij} - d_{ij}) \Delta v_{ij}^t t_{ji} \quad (4)$$

The equation (4) consists of three terms. This first term $A_i e^{\frac{r_{ij} - d_{ij}}{B_i}} n_{ij}$ represents the psychological force, the second term $Kg(r_{ij} - d_{ij}) n_{ij}$ represents the physical force, and the third term $kg(r_{ij} - d_{ij}) \Delta v_{ij}^t t_{ji}$ represents the sliding friction to prevent person falling. The psychological force is represented as following equation:

$$f_{psy} = A_i e^{\frac{r_{ij} - d_{ij}}{B_i}} n_{ij} \quad (5)$$

In the equation (5), r_{ij} represents the sum of the radii of person i and person j , d_{ij} represents the distance between person i and person j , both A_i and B_i are constants,. The A_i is the interaction between two persons. The n_{ij} is the unit vector from person i to person j , which is represented as following equation:

$$n_{ij} = (n_{ij}^1, n_{ij}^2) = \frac{r_j - r_i}{d_{ij}} \quad (6)$$

The distance between person i and person j is illustrated in figure 1.

The physical force is represented as following equation:

$$f_{ph} = Kg(r_{ij} - d_{ij})n_{ij} \quad (7)$$

Equation (7) represents the physical force generated by person j on person i to avoid physical touching. The function $g(x)$ in equation (7) is a step function, which is represented as follows:

$$g(x) = \begin{cases} x, & x > 0 \\ 0, & x \leq 0 \end{cases} \quad (8)$$

In the equation (8), when $x > 0$, it means the sum of radii of two persons is larger than the distance between these two persons and they can contact with each other; when $x \leq 0$, it means these two persons have no contact and the physical force between them is 0.

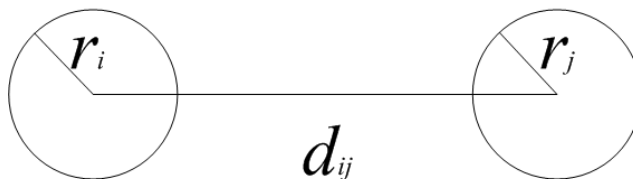
The sliding friction force is represented as following equation:

$$f_{fri} = kg(r_{ij} - d_{ij})\Delta v_{ij}^t t_{ji} \quad (9)$$

The aim of adding sliding friction force to person in the virtual reality model is to prevent sudden falling when he or she walk on slipping floor. In the equation (9), $t_{ji} = (-n_{ji}^2, n_{ji}^1)$ is the tangential direction, $\Delta v_{ij}^t = (v_i - v_j)t_{ij}$ is the speed difference along the tangential direction, and k is a large constant.

When walking, a person should keep a certain distance from the boundaries of walls, obstacles, streets, buildings, etc. When a person gets closer and closer to the boundary, he or she will feel

Figure 1. The illustration of the distance between person i and person j



uncomfortable. Thus, the person tries to avoid the boundary of the obstacle when he or she walks. The environmental power is the effect of boundary of obstacle on the person. The role of environmental power is the same as that of the force between persons. The environmental power of boundary or obstacle w on the person i is defined as following equation:

$$f_{iw} = \left(A_i e^{\frac{r_i - d_{iw}}{B_i}} + Kg(r_i - d_{iw}) \right) n_{iw} + kg(r_i - d_{iw}) v_i t_{iw} \quad (10)$$

In the equation (10), r_i represents the radius of person i , d_{iw} represents the distance from the boundary w to the person i , both A_i and B_i are constant, k and K are coefficients of pressure and sliding friction force, and n_{iw} represents the vertical direction from the person i to the boundary w .

Based on the social force model, the workers in virtual packaging customization is simulated. The associated flowchart is illustrated in Figure 2.

In the step 1, the simulation initializes virtual personal parameters including the radius of virtual person, constants A_i and B_i , and coefficients K and k .

In the step 2, the simulation computes the acceleration a_i when the social forces are applied to the virtual person. The applied social forces include self-driving force, the force generated by other person on him or her, and the force generated by an obstacle on the virtual person.

In the step 3, through calculation, the simulation makes the virtual person move towards the target direction according to the task path at the current acceleration a_i .

In the step 4, the simulation needs to recalculate the acceleration generated by the social force on virtual person when the virtual person changes his or her position.

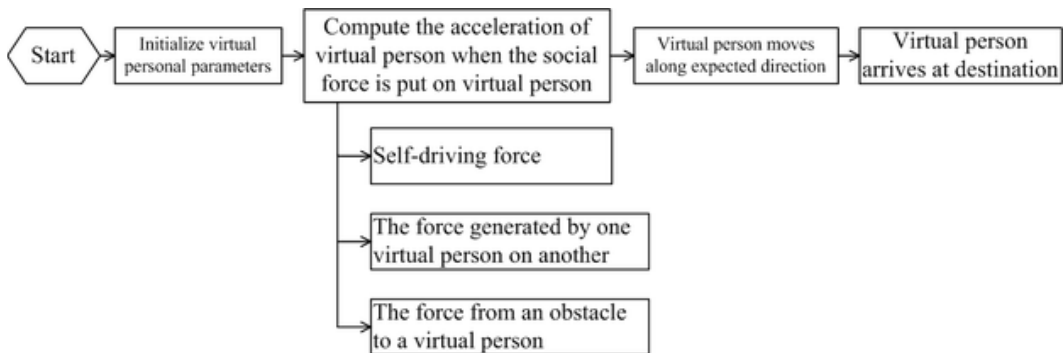
In the step 5, the virtual person reaches the destination and the simulation terminates.

Inherent synergy and repulsion between individuals increase the overall complexity of person movement simulation. On the basis of the social force model, the interaction between persons is embodied and modeled to describe the dynamic process of human's movement. Thus, the simulation of person movement can be more realistic.

3. VIRTUAL SIMULATION VALIDATION FOR PACKAGING CUSTOMIZATION

In this section, the established virtual customization environment is divided into four parts: pre-processing, processing, after processing, and management. The virtual person does corresponding

Figure 2. The illustration of the flowchart to simulate virtual customization by using social force model



tasks for customization in these four parts according to the task path. The virtual person starts from the beginning point according to the pre-designated task path to avoid obstacles, collisions with other persons or obstacles and finally arrives at the destination along the shortest and optimal path. The social force model is adopted to realize this process.

The parameters in simulation are adjusted by repeated several trials. Some parameters are set as follows. The quality of virtual person is set as $m = 80kg$, constants are set as $A_i = 2 \times 10^3 N$ and $B_i = 0.08m$, the characteristic time is set as $\tau_i = 0.5s$, $K = 2.5 \times 10^5 kgs^{-2}$, $k = 3 \times 10^5 kgm^{-1}s^{-1}$, the diameter of virtual person is set as $0.45m \leq d_i \leq 0.65m$.

Based on the social force model, the persons in the virtual packaging customization are simulated. The details are described in the following part.

In the processing of packaging customization, the persons need to walk along the task path between the digital proofing machine, plate making machine, and console to complete the corresponding tasks. An illustration is shown in Figure 3.

In Figure 3, the person i moves between the console and plate-making machine according to the specified path under the action of his or her self-driving force, while person j moves between plate-making machine and console according to the specified path under the action of his or her self-driving force. They may meet each other on the way. Under the influence of the social force model, the person i and the person j can avoid collision and avoid to encounter each other. The avoiding process is illustrated in Figure 4.

In the management part of virtual packaging customization, the person i moves between two desks along the specified path under the action of his or her self-driving force to execute the formulation of packaging customization tasks. During the moving process, the person i will hit the desk if he or she walks in a straight path. Under the effect of the social force model, the person i can avoid the work desk and reach the destination smoothly. Figure 5 is the illustration to prevent collision between virtual person and obstacles in virtual packaging customization environment.

4. CONCLUSION

In this paper, the virtual reality technology is introduced to simulate the environment for packaging customization. The virtual simulation environment can help workers to understand and be familiar with the workflow of packaging customization. The social force model is adopted to simulate the interaction between persons and the interaction between person and obstacle. Compared with other models, the social force model has the following features. The persons in the social force model can contact each other when the crowd is dense and they can escape from disasters and panics. Thus, the social force model can simulate the self-organizing behavior of persons, such as the automatic

Figure 3. The illustration of the virtual packaging customization environment by using social force model

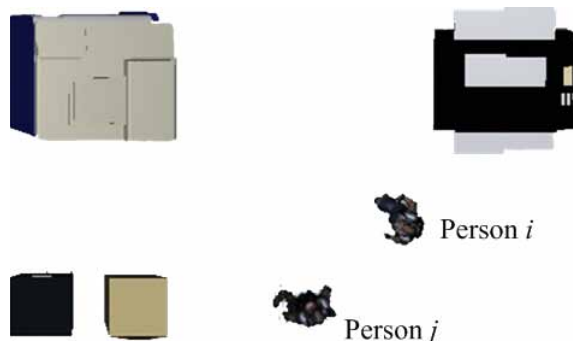


Figure 4. The illustration of the process of avoiding collision in virtual packaging customization simulation by using social force model

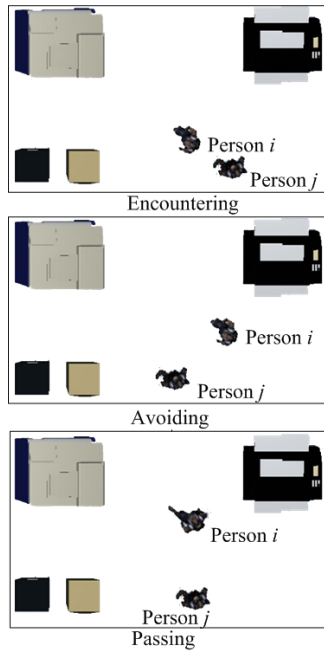
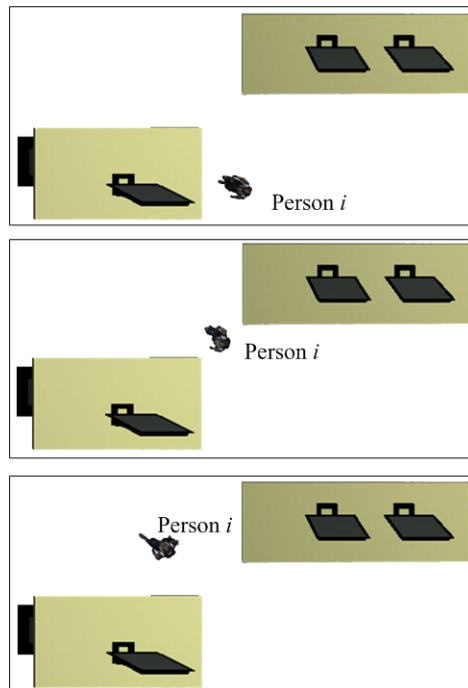


Figure 5. The illustration of the collision avoidance in virtual packaging customization simulation by using social force model



channelization of persons, the oscillation phenomenon when two-way flows pass through a narrow passage, the flow streak phenomenon herd behavior, fast or slow self-organization phenomena when persons in different directions meet. The social force model can realistically simulate the movement of persons and provide the support for the development of the packaging customization environment simulation. The virtual packaging customization environment by using social force model can also help person to avoid randomly emergencies during operation, some of which has been evaluated by the simulations. In the future work, more emergencies require to be introduced in the virtual packing customization environment.

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