The Application of the Depth Camera in the Social Manufacturing: A review

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***Abstract*—In recent years, the Information Technology develops rapidly. With the development of the Information Technology, the social manufacturing, a new mode of manufacturing, has been proposed. The social manufacturing combines the Internet technology, the three-dimensional scanning technology and the virtual reality technology, and is used in the apparel industry and other fashion industries for the mass customization. The three-dimensional scanning technology and the virtual fitting mirror technology are inseparable from the depth camera. Depth cameras play an important role in the social manufacturing. Manufacturers use depth cameras to obtain three-dimensional models of the body of customers to design suitable clothes. Customers can visually see the effect of clothes by using a virtual fitting mirror which is based on the depth camera. The social manufacturing makes mass customization possible, and the depth camera help develop the social manufacturing. This paper introduces the principles of depth cameras, and the application of depth cameras in the social manufacturing.**

Keywords—social manufacturing; depth camera; PMD; Kinect; time of flight; structured light

I. INTRODUCTION

In recent years, the Internet Technology develops rapidly, and has brought a lot of convenience to our lives. On the Internet, people can make friends, look for jobs, and go shopping, etc. People can find what they want without leaving home. The development of smart phones and computer technology make people rely on the Internet.

With this trend, the social manufacturing, a new mode of manufacturing, has been proposed and developed. The social manufacturing is a new mode of production, which is introduced in the apparel industry and other fashion industries for the mass customization [1]. The social manufacturing is based on the Internet, the three-dimensional scanning technology, and the virtual fitting mirror technology. A costume designer uses three-dimensional scanning technology to obtain three-dimensional model of the body of a customer to design suitable clothes. Customers can visually see the effect of clothes by using a virtual fitting mirror. Designers can send pictures which show the effects of clothes to the user's mobile phone via the Internet, and customer can make their own assessment. This mode of production will not only improve labor efficiency, cost savings, but also simplifies the customization steps and saves time.

The three-dimensional scanning technology and the virtual fitting mirror technology are two key technologies of the social manufacturing. These technologies are inseparable from the depth camera. The depth camera for civil applications began to emerge around 2000's, as the semiconductor processors became fast enough for such devices. Depth cameras not only can offer rich sensory information of a large part of the scene, but also can acquire the depth information. People use the depth camera to get three-dimensional model [2-3]. M Böhme, et al. use a time-of-flight camera to detect the face [4]. Compared with traditional scanning methods, the advantages of the depth camera is that it has a small size, fast scanning speed and high precision.

This paper introduces the principle and applications of depth cameras in the social manufacturing. The remaining parts of this paper are organized as follows: two types of depth cameras are introduced in Section 2. Two representative depth cameras are described in Section 3. Some typical applications of depth cameras in the social manufacturing are presented in Section 4. In Section 5 we conclude the paper.

II. MECHNISM OF DEPTH CAMERAS

According to different mechanism of measurement, depth cameras can be divided into two categories, time of flight and structured light.

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A. Time of Flight

The time of flight depth cameras can be divided into two categories, direct measurement method and indirect measurement method. The first is that people directly measure the time of flight to calculate the distance. Due to the high speed of light, it is difficult to measure the precise time difference, and the error of time of flight will result in a low measurement accuracy. Therefore, a new measurement method is presented, which can get precise time of flight. People measure the phase change of the modulated light to calculate time of flight, which is also called indirect measurement.

For the direct measurement, a laser transmitter sends light pulses to the object . The object reflects the light pulse, and the sensor accepts the light signal. According to the time of flight of light, we can calculate the distance of the object [5].

We show the basic equation of time of flight method as follows,

$$d = \frac{1}{2} c\Delta t,$$

where c is the light velocity (c=3×10^8m/s). The method is suitable for ranges starting from some centimeters to several hundreds of meters with a relative accuracy of 0.1% [6-8].

This method has been developed for a long time. Now the representative products are DepthSense and ZCam. The advantage of this method is that it owns a high frame rate. The disadvantage is that the product can be easily influenced by ambient light [9].

For the indirect measurement, a modulated light source is used. And the modulated light is continuous, which is different from direct measurement. The distance is achieved by measuring the phase of the light. We introduce the mechanism as follows [5].

Assume: R is the amplitude of the reflected light, d is the distance between the sensor and the target, and c is the speed of light, λ_m is the wavelength. Let $s(t) = \sin(2\pi f_m t)$ be the transmitted light where f_m is the modulation frequency. The light reflected from the target falls on the sensor pixel with a phase shift $\Delta\phi$,

$$r(t) = R\sin(2\pi f_m t - \Delta\phi).$$

r(t) is the waveform of modulated light which is reflected. $\Delta\phi$ can be calculated from *s(t)* and *r(t)* [10]. The distance d can be calculated from the phase shift as follows,

$$d = \frac{c}{4\pi f_m}\Delta\phi = \frac{\lambda_m}{4\pi}\Delta\phi.$$

Due to the phase of cyclical changes, the formula of measuring range is,

$$D = \frac{\lambda_m}{2} = \frac{c}{2f_m}.$$

When measuring the distance is greater than D,

$$d = \frac{c}{4\pi f_m}\Delta\phi + k\frac{c}{2f_m},$$

where k is a constant, representing the number of cycles of the modulated light. With the change of k, d is different. This shows that the measured results are uncertain, so we should use other methods to determine the constant k. Readers can refer to papers like [7] for the specific methods.

The modulated light makes the sensor ignore light from sources other than the laser, so the anti-interference ability of this method is strong. What is more, this method has a high precision. But its measuring range is limited. Typical products are the Photonic Mixer Device (PMD) by PMDTec and the Swiss Ranger 4000 by MESA.

B. Structured Light

This method is based on the coded modulated light source. When light is irradiated on objects at different distances, different light spots will be formed. According to these light spots, we can encode the light. Light sources emit light signals, and a sensor can capture the light spot on the object. So we can get the distance information by the light coding information [5].

The structured light source has various forms. We can use the point light source, line source, three lines source, circular light source and so on [11]. There are many other kinds of light source. According to the requirements of different measurements, we can choose an appropriate light source .

Instead of measuring one point at a time, the structured-light depth camera scan multiple points or the entire field of view at once. Therefore, this kind of depth cameras has advantages of high accuracy and high speed. The Kinect is based on the structured light method. It is often used in the virtual fitting mirror technology.

III. Introduction to Two Depeth Cameras

We introduced two types of depth cameras in section II. In order to make readers have a better understanding of how the two methods are applied, we introduce two representative products, the Photonic Mixer Device (PMD) and the Kinect. The PMD is a typical depth camera which is based on time of flight method. It can be used to obtain 3D models in the social manufacturing. The Kinect is based on the structured light method.

A. PMD Camcube 3.0

The Photonic Mixer Device (PMD) is a kind of time of flight camera, which can measure the phase delay to calculate the distance.

PMD Camcube 3.0, shown in Figure 1, is one of depth cameras which can be used in outdoor environment. It is widely used in scientific research, industrial application, mobile robot, auxiliary driving, etc. A PMD camera consists of a chip and its peripheral electronics, a modulated light source, the receiver optics, a system for controlling the camera including digital interfaces and a software package [3].

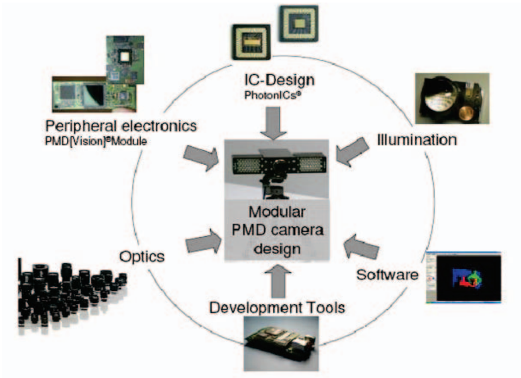

Figure 1. *PMD Camcube3.0* [3](Courtesy of IT Ringbeck)

Figure 2 shows the basic structure of a PMD camera. As the picture shows, on both sides of PMD Camcube 3.0 there are pixel arrays which can emit modulated light. The entire scene can be illuminated by modulated light, and the depth camera can individually measure the turnaround time of the modulated light which is projected by each pixel. The PMD camera measures the phase delay to calculate the distance. The PMD camera can measure distance of many points at the same time, so the PMD camera can obtain the 3D model without scanning [3].

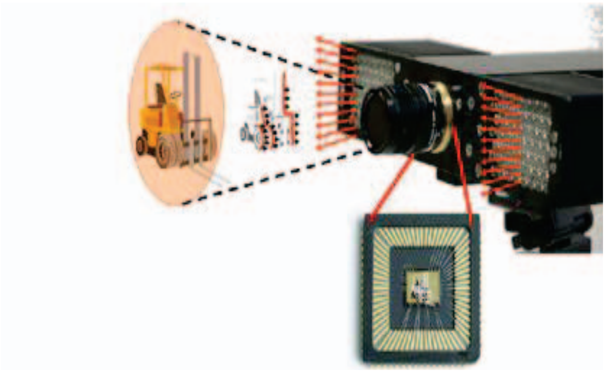

Figure 2. *The mechanism of PMD Camcube3.0* [3](Courtesy of IT Ringbeck)

To reduce the influence of obstacles, a PMD own two symmetrical pixel arrays. Two pixel arrays working at the same time can improve the reflectivity of modulated light, which can improve the accuracy of the depth measurement [12]. In conclusion, the anti-interference ability of PMD is strong, and the PMD can adapt to different environments. The PMD is expensive. Generally speaking, it is suitable for enterprises or research institutions to use.

B. Kinect

As shown in Figure 3, the Kinect contains three cameras. From left to right in sequence are an infrared (IR) emitter, a RGB camera and an infrared camera. In addition, the Kinect has a motor and a multi-array microphone. The processing core is a PrimeSense chip [13].

The Kinect has a depth sensing system which is used to obtain the depth information. The depth sensing system consists of the IR laser emitter and the IR camera, and it is based on the structured light method. The IR laser emitter projects a known pattern of dots. These dots are captured by the IR camera and then compared to the known pattern to acquire the depth information. The RGB camera can capture colored images. The resolution of the RGB camera is 640×480 pixels, which is higher than the resolution of the infrared camera. The Kinect also owns four microphones, which are used for speech recognition. The motor is used to drive the head up and down [5][13-15].

The Kinect can realize motion capture, voice recognition and other functions. People often use it in the virtual fitting mirror technology to get 3D models. These technologies play an important role in the social manufacturing. In addition, the Kinect is much cheaper than other types of depth cameras.

Figure 3. Kinect

IV. APPLICATION OF DEPTH CAMERAS

The apparel industry is an important part of manufacturing. Traditional manufacturers often produce massive products to reduce costs, which cannot meet different requirements of customers. The cost of customization is usually high, and the process of customization is complicated. The development of the depth camera is closely related to the 3D modeling technology and the virtual reality technology. People can use a depth camera to obtain the three dimensional model of the human body and determine the size of the garment. When the design of the costume is completed, the customer can make use of the virtual reality technology to check the effect of the fitting, which makes the process simplified. What is more, depth cameras are often used in the robot navigation. Robots can perform various tasks in the social manufacturing, such as transportation, packaging, stacking. The application of these techniques has made it possible to realize the mass customization in the apparel industry.

A. The usage of a depth camera to obtain the 3D model

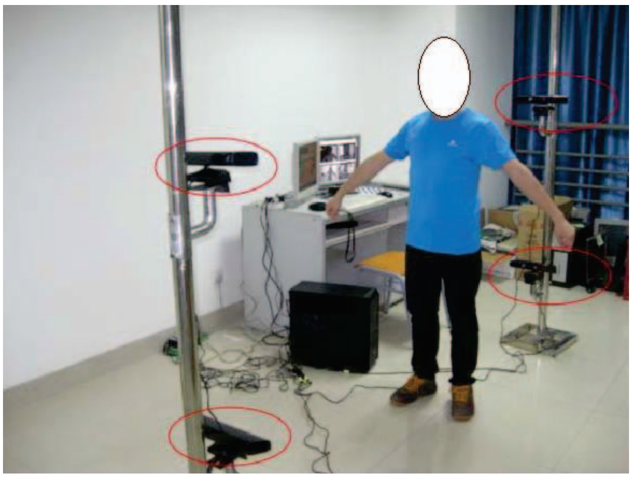

Figure 4.*Three-dimensional modeling system* [16] (Courtesy of Jin Zhou)

In 2013, Jin Zhou describes a system which uses depth cameras to obtain three-dimensional model of the human body in his paper [16]. As shown in Figure 4, the system consists of four Kinects. When only using one Kinect to obtain information of the body, the data has a great error. Therefore, they try to model the upper and lower parts of the human body separately, and the human body is measured by using four Kinects. Two cameras measure the front of the body, and the other two cameras measure the back of the body. In this way they not only can improve the measurement accuracy, but also can improve the measurement speed. The system only requires 1 s to obtain the depth information of human body. This is an advantage as it is difficult for a person to maintain one position for a long time, and the movement of body will result in an error of the model [16].

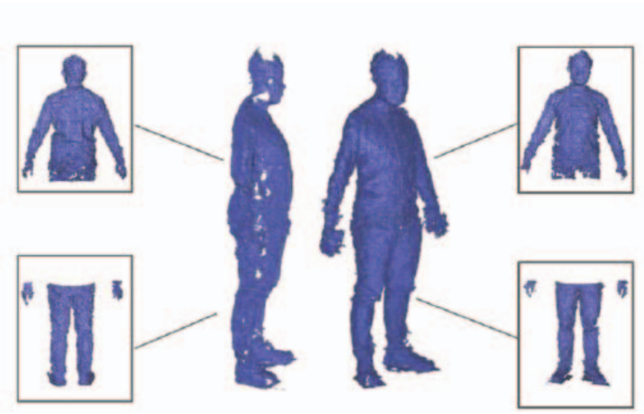

Figure 5.*Piont Cloud Data* [16](Courtesy of Jin Zhou)

People use depth cameras to obtain the point cloud data, which is the first step to obtain a three-dimensional model. An example of the point cloud data is shown in Figure 5.The point cloud data is the basis for modeling. The point cloud need the de-noise and stitching steps to build a model. In this paper we will not introduce the details.

In the apparel industry, a three-dimensional model can be used to obtain the parameters for the production of clothes. In addition, the model of clothes can be combined with the model of the body to generate two-dimensional renderings. According to these pictures, customers can see the effect of the clothes. The time for customization is reduced a lot.

B. The Virtual Fitting Mirror Technology

As shown in Figure 6, the virtual fitting mirror technology is a key technology of the social manufacturing, which is used to try on clothes without changing real clothes in shops. A virtual fitting mirror makes the process of shopping more convenient.

The Kinect plays an important role in the virtual fitting mirror. According to the depth information, the Kinect can build a 3D model quickly. Furthermore, the Kinect can capture customer's motion, and it can update the model in real time. This technology is called the motion sensing. By using the motion sensing technology, people can try on virtual clothes based on the model of body, and merchants can get essential parameters from the 3D model. The tailor needs not to measure the physical parameters of a human body, which can save times and reduce the costs [1].

Figure 6. Virtual fitting mirror [17] (Courtesy of XXX)

The Kinect has good performances in the motion sensing. Besides, it is much cheaper than other types of depth cameras, and people can afford it.

C. Using PMD-Camera for the Robot Navigation

The social manufacturing makes mass customization possible, which requires high efficiency of transport and packaging. The robot not only can complete these tasks efficiently, but also can save labor costs. Therefore, robots are widely applied in the social manufacturing. The robot navigation is an important technology, which is inseparable from the depth camera. Below we introduce how a PMD camera is use in the robot navigation.

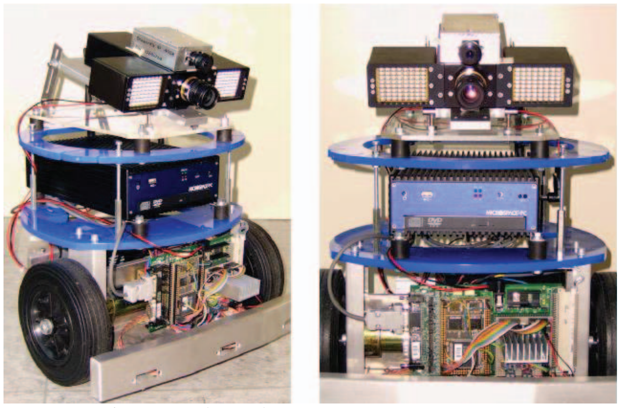

Figure 7. *Robot with PMD Camera* [18] (Courtesy of A. Prusak)

At the University of Siegen the so-called mobile robot Tom3D (Tele Operated Machine with 3D PMD-Camera) is developed (Figure 7). They use the PMD camera to identify obstacles. The detection range of the PMD camera is 7.5 m. In order not to exceed the range, the PMD camera must be fixed with a suitable inclination angle on the mobile vehicle. The inclination angle of the PMD camera is very important, as different inclination angles can lead to different detection results of the obstacles. This inclination is measured by the inclination sensor. The controller uses the measurement to adjust the camera angle [18].

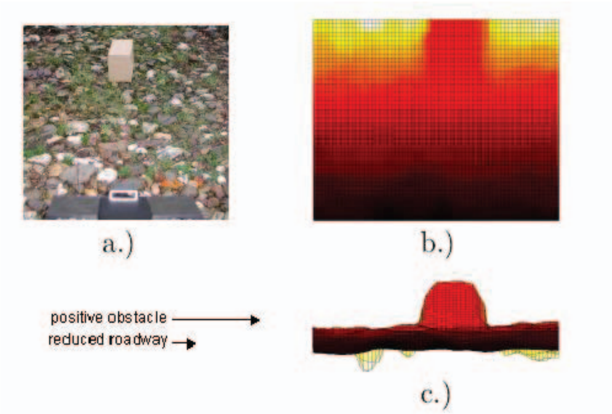

Figure 8. *Pictures of the PMD camera* [18] (Courtesy of A. Prusak)

In Figure 8, a) shows the robot view of the outdoor driveway with an obstacle. b) shows the PMD video image before correction, and c) shows the PMD video image after correction [18]. As these figures show, after correcting, the position of the obstacles is more clear. The robot can avoid obstacles more easily.

V. CONCLUSIONS

Nowadays, the demand for personalized products becomes stronger and stronger. In order to meet the needs of mass customization, the social manufacturing becomes popular. The social manufacturing combines the Internet technology, three-dimensional scanning technology and the virtual reality technology. It is used in the apparel industry and other fashion industries for the mass customization. The three-dimensional scanning technology and the virtual fitting mirror technology depends heavily on the depth camera. In this review, we introduced two types of depth cameras. One is the time of flight method and the other is the structure light method. The PMD camera is based on time of flight method and has the advantages of high accuracy and high speed, but it is expensive. The PMD is often used to obtain a three-dimensional model in the robot navigation. The Kinect camera is based on a structured light method. We see a promising future of the social manufacturing and the usage of the depth cameras can be more and more popular.

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