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Article · December 2010

DOI: 10.1109/ISPACS.2010.5704642

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LOW COST MOTION TRACKING SYSTEM BASED ON STRUCTURED LIGHT ILLUMINATION

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ABSTRACT

Advanced motion tracking systems have been generally applied to movie production and digital entertainment. Due to the successful of Nintendo's Wii game machines, low cost motion tracking solutions are of particularly great demand in the computer gaming industry. In this paper, a low cost optical based motion capture system is proposed. The proposed system makes use of 2 high frame rate DLP projectors which project specially designed IR light patterns to the target object with IR sensing device attached. The pattern of illumination as recorded by the IR sensing device is converted to digital data words and sent via a wireless channel back to the central computing unit for estimating the 3D coordinates of the target object. The system has the advantage of low cost with competitive performance in the update rate of the system.

1. INTRODUCTION

In the past decade, location-aware computing techniques have been generally applied to digital entertainment. They have been used in the so-called motion capture (MoCap) systems [1] which track the motion of human to assist in generating the animation of creatures and creating different visual effects for movie production and computer games.

The core of all MoCap systems is an accurate position sensing device that allows the physical positions and orientations (P&O) of the target objects to be precisely determined. Over the years, researchers in academia and industry have developed different P&O sensing technologies, which include the optical-based, acoustic-based, inertial-based, magnetic-based, electromagnetic-based, and the hybrid ones that combine any two or three of the above [2]. When assessing the merit of these technologies, the following criteria are often used: cost, accuracy, latency, form factor, update rate, capacity, and restriction on the working environment. None of the technologies however can excel in all criteria.

There is a constant interest in the acoustic-based system in particular using ultrasonic technology due to the low cost of its transducers. One example of ultrasonic ranging device is the Cricket developed at MIT [3]. Recently, there is an increased interest of using hybrid inertial-ultrasonic technology in object localization. Intersense, a company that is famous in its inertial-ultrasonic technology, has been shipping their IS-900 system [4] for some years. Thanks to the advance in MEMS technology, accelerometers and gyroscopes can be implemented by solid state material that greatly reduces their cost and form factor [2]. While the MEMS accelerometers and gyroscopes can provide high speed P&O information, the drifting in the readings can be a problem if they are not updated frequently [2]. The combination of the inertial and ultrasonic technologies is a good match that the former one provides the high speed readings, while the later one provides the constant updates economically. Nevertheless, the latest IS-900-VET Wireless system can cost around US$47,000. Besides, ultrasonic sensing devices (or the so-called markers) can be bulky and they also have the line-of-sight problem.

The magnetic-based systems detect object positions according to the strength of the magnetic field received from the target objects. The magnetic-based systems are at a similar cost as the ultrasonic-based systems. For instance, the latest Liberty Latus system from Polhemus [5] costs about US$45,000. As different from the ultrasonic-based systems, it does not have the line-of-sight problem. However, their accuracy is one of the major deficiencies. Our experiments show that the readings obtained from the magnetic-based systems can be severely affected by the environment, e.g., the ferromagnetic materials around the sensors and the markers.

Currently, most practically used MoCap systems are optical-based. In such systems, usually between 6 and 50 cameras are placed on the walls and ceilings of a recording studio. Infrared or visible light sources are mounted next to each camera. The projected light is reflected with maximum energy by the small "retro-reflective" markers back into the cameras, and therefore can be easily detected by further processing of the camera output [6]. The object positions can be evaluated using the triangulation method based on the analysis output obtained from different cameras. Advanced optical-based MoCap systems can allow 50 markers to be tracked at the same time. However, traditional optical-based technologies have the problem of extremely high cost. An eight camera passive marker system can cost over US$150,000.

In this paper, a low cost optical based 3-D object motion tracking systems is proposed. The system makes use of the digital light projection (DLP) technology [7] for generating infrared light patterns at a rate of over 8000 frames / second. To receive the infrared light pattern, an infrared receiving unit was developed and attached to the object to be detected. The pattern of illumination across time was recorded and sent thru a wireless channel back to the central computing unit, where the 3-D position of the object was computed using the triangulation method.

2. THE PROPOSED SYSTEM

The proposed system consists of two DLP projectors with infrared (IR) light sources, wireless IR sensing modules, and the central computing unit. Fig.1 shows the proposed system architecture:

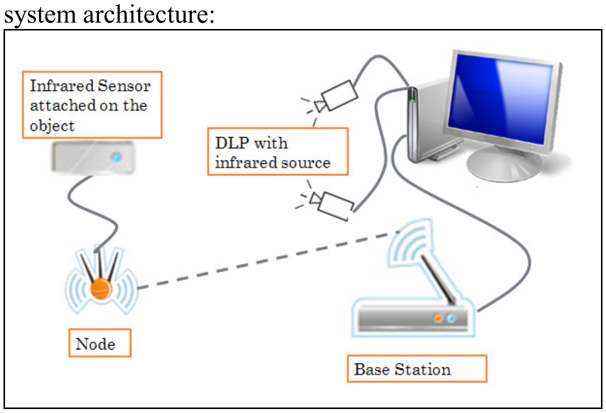

Fig.1 – The proposed system architecture

The Digital Light Processing (DLP) technology was originally developed by Texas Instruments [7]. When constructing the prototype of the proposed system, two ViALUX ALP-1 DLP development kits [8] are used. Each kit supports the projection of 1024x768 images at a rate up to 8000 frames per second for 1 bit representation. Let us use an example to illustrate how the 3D coordinates of a sensor node can be determined by using these light patterns. Assume the light patterns as shown in Fig.2 are projected by a DLP projector to the sensor node sequentially. These light patterns are simply black and white fringes of different scales.

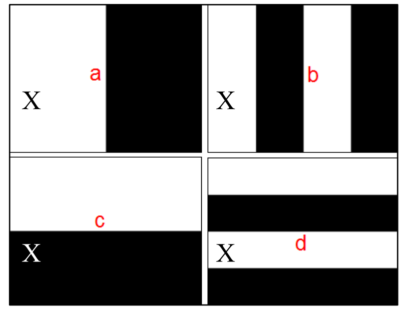

Fig.2 – An example of light patterns to be projected

Since each light pattern has both light and dark regions, a sensor node may or may not sense the light for each light pattern projected onto it. The sensor node is designed such that if it senses the light, a digital bit '1' will be saved into the memory; and a '0' will be saved instead if no light is received. The aggregation of these bits encodes the 2D position of the sensor node with respect to the light patterns projected on it. As to the example in Fig.2, let us assume a sensor node is located at point x. After patterns a and b are projected, a digital word "11" will be saved in the memory. And after patterns c and d are projected, another digital word "01" will be saved in the memory. These two digital words give the information about the x and y coordinates of the sensor node. By using more light patterns with further refined black and white fringes, we can increase the resolution of the system in determining the x and y coordinates. In practice, 5 light patterns are used for determining the y coordinate and 10 light patterns are used for determining the x coordinate. It is because the 3D space that we are interested has a larger width than height. Hence two data words, one of 5 bits and one of 10 bits, will be saved in the memory of the sensor node after all light patterns have been projected. They will then be sent back to the central computing unit via the radio channel for estimating the 3D coordinate of the sensor node using the triangulation method. Note that to make sure the sensor node knows a light pattern has been projected (since the sensor node may not sense the light), a radio signal will be sent out by the projector each time a light pattern is to be projected. It serves as a means to synchronize between the projectors and the sensors.

Fig.3 gives an illustration of how the 3D coordinates are determined. The figure in fact shows the top view of the proposed system. Let us assume l and d are the distance between two projectors and the distance of the sensor node from line l. Our objective is to determine d based on the light patterns projected onto the sensor node. The operation of the system starts with the projection of light patterns from one of the 2 projectors. Two data words are then received from the sensor node. They allow the determination of the x and y coordinates of the sensor node on the virtual plane of the first projector. The operations are then repeated using the second projector hence the x and y coordinates of the sensor node on the virtual plane of the second projector are obtained. Then we can estimate the distance *d*. From the coordinates of the sensor node on the virtual planes, α and β can be found. Let $l = l_1 + l_2$, then

$$d = l_1 \tan\alpha = l_2 \tan\beta \tag{1}$$

$$l_1 = d / \tan\alpha \quad \text{and} \quad l_2 = d / \tan\beta \tag{2}$$

Substitute l_1 and l_2 into l, we have

$$l = d / \tan\alpha + d / \tan\beta \tag{3}$$

Therefore

$$d = l / (1 / \tan\alpha + 1 / \tan\beta) \tag{4}$$

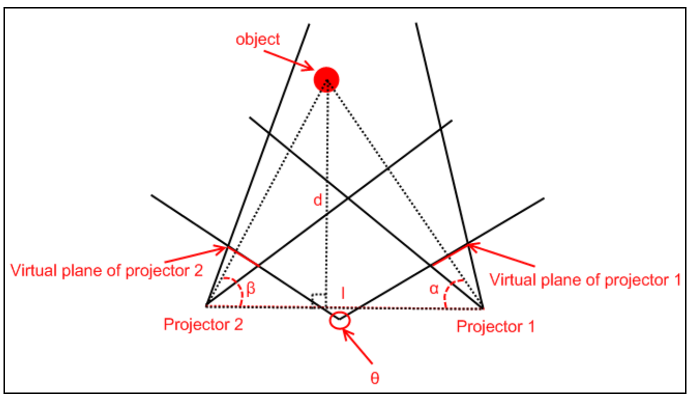

Fig.3 – Determining the 3D coordinates of a sensor node

It should be noted that the abovementioned structured light illumination method does not have the restriction on the number of light sensors to be used. The capacity of the system is only restricted by the capacity of the radio communication system when transferring the data words of different sensor nodes to the central computing unit. In general, frequency division multiplexing techniques are more favorable than time division multiplexing in this application. It is because the time division multiplexing technique can greatly affect the update rate of the system if there are many sensor nodes.

3. SYSTEM PROTOTYPE AND EVALUATION

At the moment, we have completed the implementation of the system prototype as shown in the picture below:

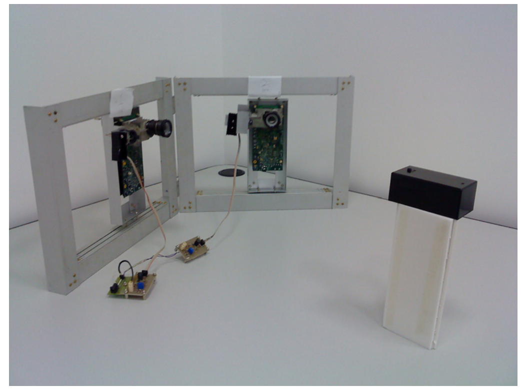

Fig.4 – The system prototype which contains two DLP projectors and a wireless infrared sensing unit

As mentioned above, we adopted two ViALUX ALP-1 DLP development kits to construct the DLP projection units. The IR light sources and related driving circuits are tailor-made for the system. The black box in the figure is the sensor node, which contains an IR sensor and circuit, a RCM3100 MCU board with eb506 Bluetooth module [9]. The Bluetooth module provides the wireless communication channel between the central computing unit and the sensor node. The functional area of the system was measured as shown in the figure below:

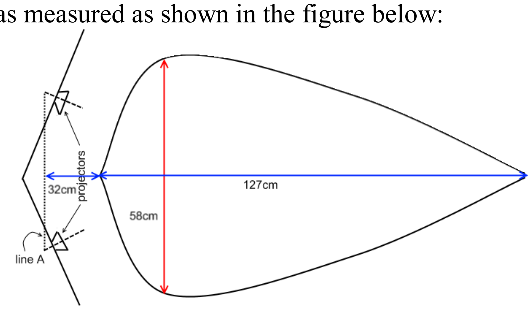

Fig.5 – The estimated functional area of the system

The functional area can be further divided into 5 regions and the performance of each region is different.

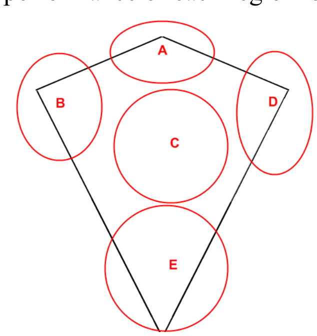

Fig.6 – The 5 regions which have different resolutions

While region C is the most linear region (with a size of about 30x50cm), region B and D are also acceptable.

The detection of object in region A and E can be unstable. The functional area can be expanded by using a higher power infrared light source for the DLP system. The following table shows the resolution of the tracking system in x, y and z directions:

Region	X direction	Y direction	Z direction
A	0.47mm	0.47mm	0.49mm
B	0.50mm	0.50mm	0.57mm
C	0.50mm	0.55mm	0.55mm
D	0.50mm	0.50mm	0.60mm
E	0.60mm	0.71mm	0.65mm

Table 1 The resolution of the proposed system

At the moment, we have only completed the prototype implementation of the proposed system. Certainly, the performance of the system cannot compete with practical systems in the market. However, there are a few interesting figures that can show the potential of the proposed system. The update rate is an important parameter that describes how close the system follows the motion of the target object. For instance, the magnetic based system Liberty Latus has an update rate of 188Hz when using 1 to 8 markers but will drop to 94Hz when using 8 to 12 markers. As mentioned above, the system costs about US$45,000. The proposed system uses 2 high frame rate (about 8000 fps) but relatively low cost DLP projectors (less than USD1,000) to determine the 3D coordinates of moving objects. Since each measurement requires 15 frames of light patterns from each projector, the update rate can be calculated as $8000/(2*(5+10)) = 267$Hz, which is comparable, if not better, than the much more expensive magnetic based system. When comparing with other optical based systems, the proposed system is also a much more economic solution since a traditional optical system working at a high update rate (e.g. 267Hz) would require multiple high frame rate (e.g. 267 fps) high resolution cameras. Each of them can cost tens of thousands USD.

Nevertheless, the current system prototype still has room for further improvement. First, as shown in Fig.6, the region where stable readings can be obtained is not very large. It is mainly due to the brightness of the IR light source. A much larger working region will result when more powerful IR light sources are used for the DLP projectors. Second, it is noticed that error measurements may be resulted if the sensor node is rapidly moving. A possible reason for such errors is the narrow viewing angle of the IR sensor. If the IR sensor does not face to the projector, it may not be able to sense the IR light projected onto it. Nevertheless, if the viewing angle of the IR sensor is too wide, it may pick up light which is originally projected to other regions. To solve the problem, an appropriate optical lens system should be used to transfer the light to the IR sensor. Finally, the proposed system suffers from the line-of-sight problem and does not have the information about the orientation of the sensor node. These problems however are in common to all optical MoCap systems.

4. CONCLUSION

In this paper, the architecture of a low-cost optical based 3D object tracking system is proposed. The system makes use of the structured light illumination technique for determining the 3D coordinates of moving objects. The proposed system has the advantage of low cost while providing a competitive performance in the update rate of the system. Although the current system prototype still has room for improvement, we believe further development in this direction will be fruitful and will result in a practical solution for the realization of low cost high performance MoCap systems.

5. ACKNOWLEDGEMENT

This work is supported by the Hong Kong Polytechnic University under research grant no.G-YG05.

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