MEASUREMENT AND ANALYSIS OF GAIT BY USING A TIME-OF-FLIGHT CAMERA

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Commission III, WG III/3

KEY WORDS: Human Motion, Measurement, Time-of-Flight Camera, Mobile Measurement, Three-Dimensional, Range Imaging Camera

ABSTRACT:

Biomedical applications generally needs measurement the human body parts in motion. On the other hand, the analysis of the human motion includes mobile measurements. The mobile measurement is complicated task because it needs two or more sensor combination, specific measurement techniques and huge computation. Thus, it is actual research topic in photogrammetry and computer sciences community. Time-of-flight (ToF) camera can make measurement the moving object. It can be used for robotic and simultaneous localization and mapping applications. Human motion capture is recent application area for ToF camera. In this study analysis of the body motion were made with time-of-flight camera. We made measurement to runner on treadmill. The motion was analysed with computing the angle between body parts.

1. INTRODUCTION

Time-of-flight (ToF) camera has active optical measurement system. It is emerging technology for three-dimensional (3-D) measurement, motion detection, mobile measurement and robotic applications. New application areas and data processing techniques have been introduced by using ToF cameras in photogrammetry and engineering measurements. Oggier et al. (2005) investigated the measurement principle of ToF cameras. They showed that the ToF camera can be used in many measurement tasks instead of photogrammetry and laser scanning. Jamtsho (2010) used ToF camera for measurement of structural deformation. Piatti (2010) tested PMD CamCube3 and SR4000 cameras and 3D modelling task was performed by the cameras. Additionaly, Altuntas and Yildiz (2013), Jamtsho (2010), Boehm and Pattinson (2010) and Cui et al. (2010) used the cameras for 3-D modelling.

There are many study related to use of ToF camera in mobile and robotic applications. Clemente et al. (2007) made measurement while the camera is being moved by hand. The consecutive frames were registered into the reference system using detected features from the images. A similar study was also performed by Pirker et al. (2010). The robotic applications were carried out in the study of Cazorla et al. (2010) and Frank et al. (2010). On their study the object on field of view of the mobile robot was detected by the camera. Unexpected motion of the workers on construction site was also detected with continuously imaged the field of view by ToF camera (Teizer, 2008). Lichti et al. (2012) made structural deformation measurements under different loading environments. On the further study, real time hand motion tracking and the American sign language alphabet recognition was given at Lahamy and Lichti (2011) and Lahamy and Lichti (2012) respectively. Wide variety of applications which has been performed by the camera can be found on literature (Breuer et al., 2007; Hussmann et al. 2008).

Detection of human motion is active research area in computer vision. A number of significant research are identified together with novel methodologies for automatic initialization, tracking, pose estimation, movement recognition and etc. (Moeslund et al., 2006). On the other hand, in medical applications, specialists generally need definition positions of the body parts during the movement for designing the medical apparatus for disabled persons. Palagemann et al. (2010) and Ganapathi et al. (2010) identified the body parts in depth images at video frame rates. The orientation of body parts were estimated from 3D orientation vector for a given interest point. In this study, the motion of runner on treadmill was recorded by SR4000 ToF camera. The angles between the body parts were estimated and changing between them during the movement was analyzed.

2. TIME-OF-FLIGHT CAMERA

ToF camera measures distances between pixels and their corresponding object points. The measurement data are range from pixel to object point. The 3-D coordinates are computed from them according to local camera coordinate frame, which has X,Y axis joined to front plane while the origin is on the optical axis (Figure 1). SR4000 camera has 144x176 pixel array and the object points correspond to the pixels are measured instantly. Moreover this measurement can be repeated 50 times for per second. Thanks to the measurement technique and light weight, it can be used for mobile measurement in case of motion the camera or object. In addition, ToF camera records intensity of laser beam reflected from the object surfaces for every pixel. Its measurement range is reach to 5m.

The measurement accuracy of ToF camera depends many effects such as illumination, surface reflectivity, range, temperature and integration time (Altuntas, 2014; Beringe, 2012). Kahlman et al. (2006) investigated the accuracy depended on temperature arising from environmental and interior of the instrument. In addition, the same study carried out a few millimetre differences between the distances measured by total station and the camera. The warm-up time of the camera was investigated on Piatti and Rinaudo (2012). Jamtsho (2010) was investigated accuracy of the ToF camera, and measured the structural deformation with 0.3mm accuracy.

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The measurement accuracy of SR4000 is about 2cm at maximum distance. On the other hand, multipath reflections on a concave scene cause error on the distances (Mesa Imaging, 2012).

The calibration of the camera is performed by special measurement configuration on test field (Lichti and Qi, 2012; Shahbazi et al., 2011). The distortion effect is eliminated from the measurement by the factory settings on SR4000 camera. Some technical specifications of SR4000 camera are given on Table 1.

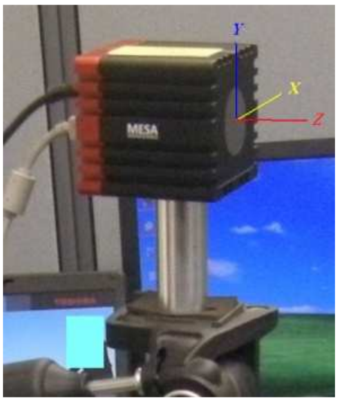

Figure 1. SR4000 camera (Altuntas, 2014)

Company	Mesa Imaging
Model	SR4000
Field of view	43° (H)x34° (V)
Pixel array size	176 (H) x 144 (V)
Detection range	0.1 m-5 m
Focal length	10.0mm
Absolute accuracy	+/- 10mm or +/- 1%
Pixel pitch	40 µm
Angular resolution	0.24° standard field of view cameras
Illumination wavelength	850 nm
Modulation frequency selection	29/30/31MHz
Integration time	0.3 to 25.8 ms, steps of 0.1 ms
Operating temperature	+10 °C to +50 °C
Maximum frame rate	50 fps
Weight	470gr for USB cameras
Dimensions	65x65x68 mm
Connection	USB

Table 1. Some specifications of used SR4000 camera (url-1)

3. METHODS

3.1 Motion Measurement

Range data sequences acquired by a 3-D camera suffer from a substantial amount of noise. This noise can be reduced by employing temporal filtering of a large number of frames (Matzka et al., 2007). But we did not use filter in this study. Because characterised points of the body parts is enough to computing angles between them. Nevertheless points were signalized on characteristic place of the body (Figure 2). The angles on intersection of the body parts can be computed from 3-D coordinates that has been extracted from the successive images of ToF camera. Thus, successive frames must be recorded by the camera during the motion periods. In this study motion of runner on treadmill was measured and analysed. The camera was set one meter away from side of the treadmill for recording the motion (Figure 3). On the other hand, this task can be performed for runner on the way by measuring the images in mobile position of the camera.

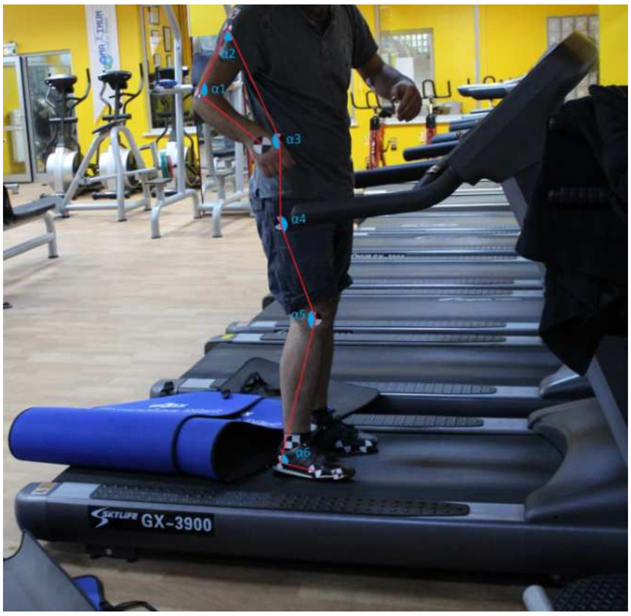

Figure 2. The measurement side

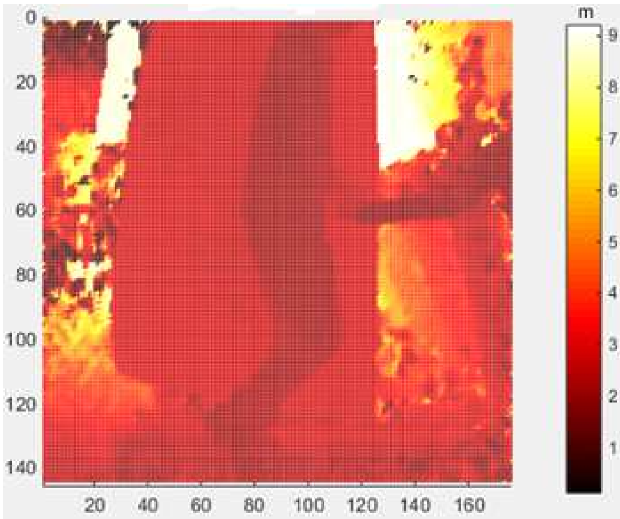

Figure 3. Depth image [legend unit is meter]

3.2 Computation of the Angles

The proper one has to be selected from consecutive frames to compute the angles at each position. After successive images, which have cover one period of the motion, were selected, intensity images were created for each one. Targets were selected from the intensity images and then we got their 3-D coordinates from the measurement data of the frames. The angle at intersection of body parts were computed in 3-D space (Figure 4).

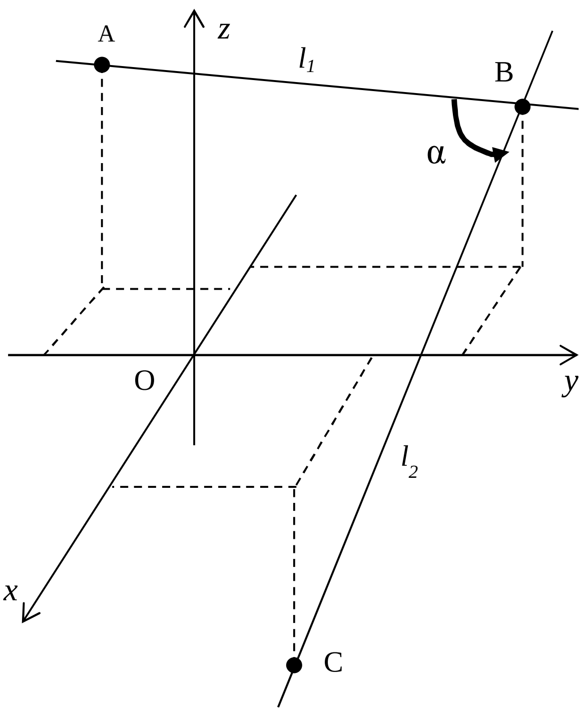

Figure 4. Angle (α) between lines l_1 and l_2 in 3-D space

The equation of a line (l_1) passing through the point A(x_1,y_1,z_1) and B(x_2,y_2,z_2) is given by Equations (1) and (2) (Figure 4)

$$\frac{x-x_1}{x_2-x_1}=\frac{y-y_1}{y_2-y_1}=\frac{z-z_1}{z_2-z_1} \quad (1)$$

$$\frac{x-x_1}{a_1}=\frac{y-y_1}{b_1}=\frac{z-z_1}{c_1} \quad (2)$$

Similarly, equation of a line (l_2) passing through B(x_2,y_2,z_2) and C(x_3,y_3,z_3) is given (3)

$$\frac{x-x_2}{a_2}=\frac{y-y_2}{b_2}=\frac{z-z_2}{c_2} \quad (3)$$

Thus, the angle (α) between lines l_1 and l_2 are computed by Equation 4

$$\cos\alpha=\frac{a_1.a_2+b_1.b_2+c_1.c_2}{\sqrt{a_1^2+b_1^2+c_1^2}.\sqrt{a_2^2+b_2^2+c_2^2}} \quad (4)$$

4. RESULTS

The camera was fixed on a station 2.5 meters away from treadmill for measuring the runner motion. Integration time was set to 30 (3.3ms). The motion period is less than 2 seconds while the man was running on treadmill. The 280 frames (about 5 seconds) were recorded during the movements. Target shapes were located on the model before the measurement. The locations of the target on the body were decided according to angle that will be measured.

The intensity images were created for the frames. Then successive 10 frames that have covered the motion period were selected from the intensity images (Figure 5, Figure 6, Figure 7).

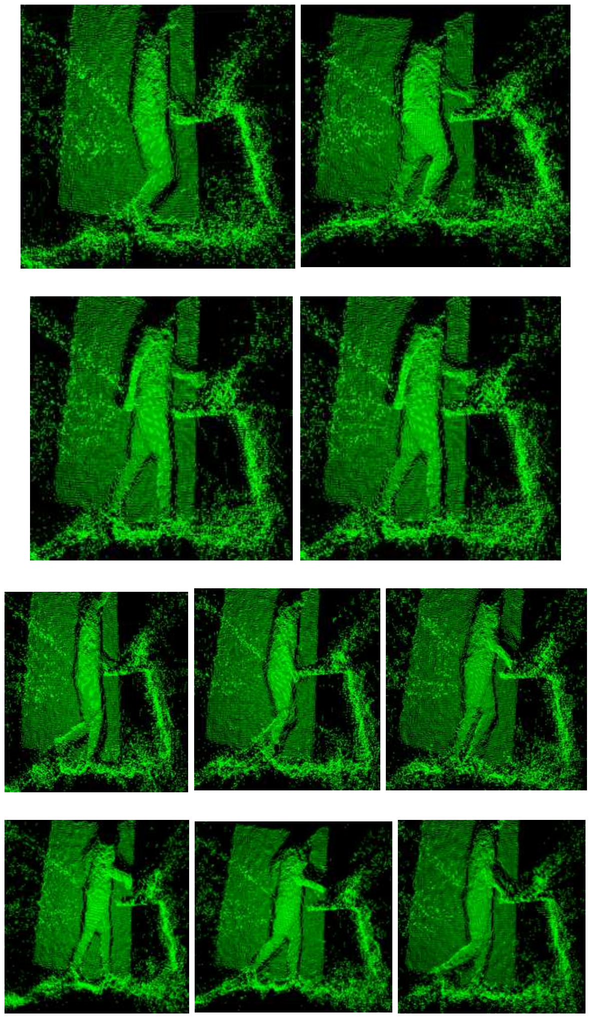

Figure 5. Point cloud data of selected frames

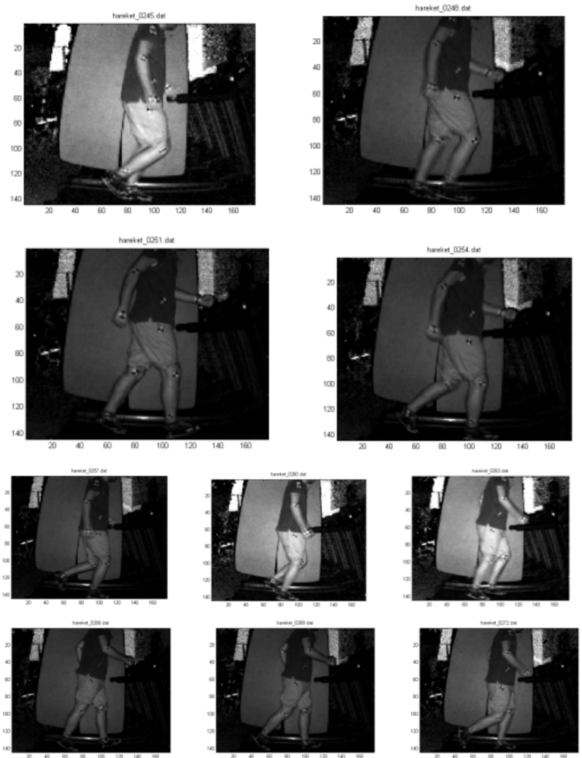

Figure 6. Intensity images of selected frames

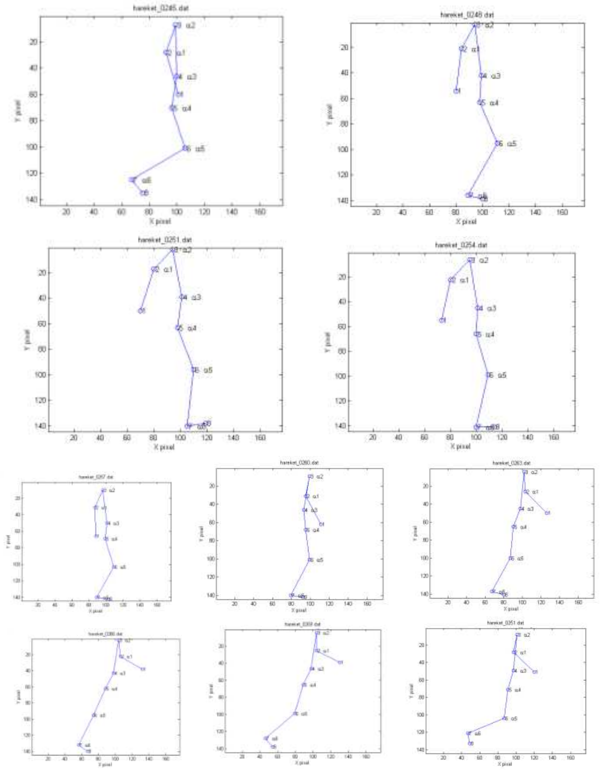

Figure 7. Angle positions on the selected successive frames

After the pixel coordinates of the targets were determined from the intensity images, their 3-D coordinates were extracted from the image files (Table 2). The 6 angles between the 7 lines were computed from selected frames by Eq.4 in 3-D space (Figure 7, Figure 8). The variations on the angles during the motion are shown on Figure 9.

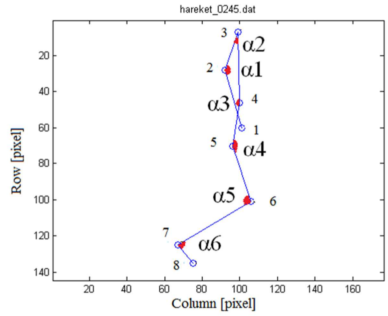

Figure 8. Target points and the angles on the first of consecutive frames

Point No	Image coordinates		3-D coordinates		
	Col	Row	X(m)	Y(m)	Z(m)
1	101	60	-0.08	0.10	2.17
2	92	28	0.00	0.37	2.07
3	99	7	-0.06	0.57	2.07
4	100	46	-0.07	0.23	2.26
5	96	70	-0.03	0.01	2.15
6	106	101	-0.13	-0.28	2.28
7	67	125	0.23	-0.49	2.16
8	75	135	0.17	-0.62	2.29

Table 2. Image and 3-D coordinates of the targets in the first image of the sequence

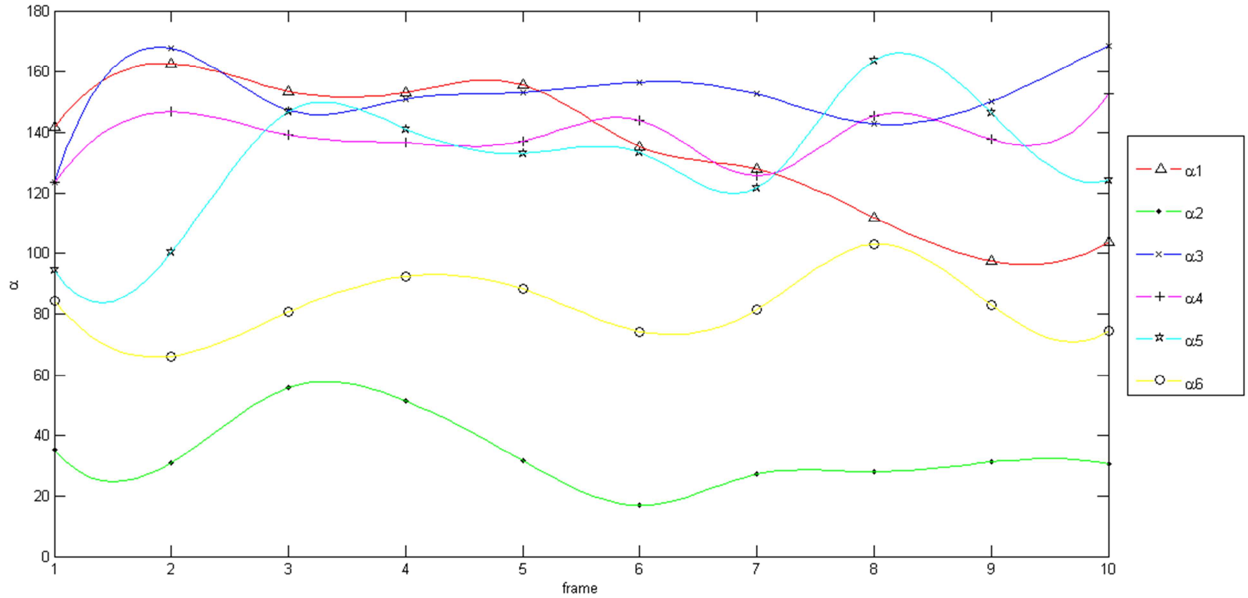

Figure 9. The angles between the body parts during the motion

5. CONCLUSIONS

ToF camera is new technology in 3-D measurement. Its application areas have been ascended day by day thanks to its low cost and ability to repetitive and mobile measurement. Nevertheless, it has weak property like short measurement range and accuracies depended surface reflectivity. Even then, it is proper instrument for modelling, robotics and motion detection at indoor environment. In this study it has been used for measurement of body motion on treadmill. The angles during the movement were computed from the consecutive frames. The result show the human motion can be analysed from ToF camera images.

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