Human Kinematics Measuring Using a High Speed Camera and Active Markers

IVO STANCIC, DANIELA BOROJEVIC, VLASTA ZANCHI
Laboratory for Biomechanics and Automatic Control
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture,
University of Split
Rudjera Boskovica b.b. 21000 Split
Croatia
istancic@fesb.hr, dborojev@fesb.hr, vzanchi@fesb.hr, http://labacs.fesb.hr/ivo

Abstract: - This paper presents simple, inexpensive, and fast procedure for motion kinematics analysis and measurement [1,2]. Measurement system developed in our laboratory was based on the industrial high speed camera, an active LED markers and a PC for handling the camera and data analysis. Active markers used in this work are assembled using small and lightweight white LEDs that allow large density of markers to be attached on a subject, thus tracking position and orientation of all segments relevant for motion kinematic analysis. Computer vision algorithm for marker detection and tracking was developed, followed by an algorithm for computing and analyzing kinematics data of human locomotion [3,4,5]. Procedures for camera calibration and sub pixel accuracy were also developed and integrated with the system. Accuracy and properties of our system was trialed, and results were compared with the existing referent systems used in the field. Proposed system has a few disadvantages; measurements and results that are representative in only one plane and use of battery powered active markers that could disturb subject during normal gait trial. As a greatest advantage, our system offers speed and accuracy that is comparable with the other commercially available systems at lower price [6,7,8]. Further development of our system will include additional cameras for 3D marker tracking and integration with an inertial sensor for full kinematics and kinetic measurement of a human movement.

Key-Words: - biomechanics, computer vision, active markers, human motion kinematics

1 Introduction

Kinematics quantities represent an exact geometrical description of spatial movements. The kinematic measurement of movement encompasses positions, velocities and angular acceleration between segments [8]. Methods of kinematic measurement that were developed and used in the field of biomechanics for last decades are exoskeletometry, accelerometry and stereometry. In work of T. Bajd [9] kinematic of normal gait was measured using an electrogoniometer. It was evident that electrogoniometer and similar exoskeletal devices were only capable of measuring angles in selected joints, and are not capable of supplying complete kinematic information of movements [8]. Second group of kinematic measurement encompasses inertial devices. These devices provide special acceleration of a rigid body, while full information of segment's kinematic is obtained using a triaxial accelerometer. Kinematic of stand up movements with acceptable accuracy was measured using inertial sensors in paper [10]. If initial conditions are known, velocities and displacements of monitored points can be calculated through numerical integration procedures. Number of applications that use integrated inertial sensors is rapidly growing, are threat to the popularity of the third, today most popular method of kinematic measurements. Stereometric methods use optoelectronic devices to track movements of a body; they offer comprehensive solution since they enable simple reconstruction in three spatial dimensions of a global coordinate system. The most common methods for the study of human movement use markers placed on the skin [7,11]. There are some evident drawbacks to marker based methods including the impediment to the motion by the presence of skin markers and relative movement between the skin, where the markers are placed, and the underlying bone. In paper [12] experiment was carried out to quantitatively evaluate the validity of using skin-mounted markers to measure the three-dimensional kinematics of the underlying bone. Kinematic data obtained from marker arrays mounted on skeletal pins that were screwed directly into the bone were compared with data from markers and markers arrays, mounted on the skin. Up to twenty millimeters displacements of the individual skin-mounted markers relative to the underlying bone were observed. Commercial optical systems such as Vicon (reflective passive markers) or Optotrak (active markers) are often considered as a "golden standard" in human motion analysis. Authors of the paper [6] determined the accuracy of motion between two rotation boards using an Optotrak optical motion capture system which uses active infrared LEDs. Tests of this commercial system showed great results; angular accuracy of 0.04° and linear accuracy of 0.03 mm. Markerless motion capture is a novel approach allowing the unencumbered capture of a human motion. Markless systems provide lower accuracy, but benefit in simplicity of measurement. Using a specific algorithms, 3D kinematic data is extracted from video recorded by multiple cameras. In paper [13] author developed method for markerless tracking of athletes interacting with sports equipment in real environments, paper [14] explains use of a markerless motion capture system to calculate COM (Center of Mass) and COP (Center of Pressure) from a visual hull with accuracy of 2mm.

2 Measurement and methods

Goal of this work was to develop and test simple and cost effective human kinematic measurements system, which can be used as an alternative for commercially available motion capture systems. Implemented system is capable of calculating kinematic data of active markers attached to the body using camera and PC. As an addition to the kinematic measurement capabilities, component for kinematic data analysis and representation was also developed.

2.1 Measurement equipment

Room for measurement was prepared so the minimum distance of 8m was cleared for undisturbed walking, where only 4m was in cameras sight. Measurements were preformed in medium lighted room with shattered windows, in order to minimize noise due to higher sun activity. Camera used for this work was Basler 602fc fast industrial camera with Fujinon 12.5 mm HF12.5HA-1B lens. Camera is capable of feeding computer with a video of 656 x490 pixels resolution at speed of 100Hz via firewire interface. Hamm Gama 74 tripod was used for an optimal camera placement in the setup. Active markers used in the experiment were assembled using a small 3.0 mm white LEDs with maximum intensity of 5Cd. LED were placed in specially prepared housing which allows easier attachment on the human body surface, as shown on Fig 1. Two sets with five markers were connected using small and flexible cable with the marker central unit, which holds the batteries and electronics for markers operation. For image processing and data analysis, personal computer with the following configuration was used: Core 2 duo processor @ 2.66Ghz, 4GB RAM, Microsoft Windows XP SP3 operating system, FireWire 800 interface. Program for motion capture and data analysis was developed using MathWorks Matlab 2006 sofware package.


[redacted]

Fig.1, Subject with attached active markers (left), fast industrial camera Basler 602fc (top) and magnified active marker (bottom)

2.2 Camera calibration

In order to obtain accurate results, some of the camera and setup properties have to be considered. Achieving the precisely positioning of the camera in setup, so its image plane is parallel to the measurement plane is a difficult task. Also, slight misalignment of a camera with horizontal plane has to be considered. To deal with the mentioned problems, camera has to be calibrated using one of the camera calibration techniques [15]. For process of calibration we used simple calibration board with the known size of 100 cm width and 80 cm height. Board was placed in the vertical position, parallel to the line marked on the ground defining walking track. Calibration process was done using technique based on Projective transformation, where position of minimum four selected points is required to be compared with their real positions in local coordinate system. That four points were active markers placed on the edges of our calibration board [3,5]. Algorithm calculates transformation matrix, which transforms any pixel location in the image to position in a global coordinate system defined in the calibration process. Calculated calibration matrix is valid for all measurements with the same camera setup, but if camera or measurement plane moves calibration is invalid

2.3 Measurement setup and process

Active body markers were placed on strategic points on a body surface; at least two markers were placed per segment near joint, in order to minimize the error due to skin movement. A problem caused by skin movement under underlying bone is explained in paper [12]. We used nine markers placed as shown on Fig.1, fasted to the body using a surgical tape. Marker central unit is kept attached to the subject's back, while connecting cables were additionally fastened to the body by flexible bands, thus preventing covering a marker with cables. Kinematics of fast and slow human walk was recorded and analyzed for seven subjects, aged 22-25 (four females and three males Caucasian, student population). Subject with attached and powered markers was instructed to walk following the line marked on the floor, while video of that movement was recorded, as shown in Fig.2. All measurements were repeated for five times in order to easily eliminate possible invalid measurements. Few attempts were allowed before measurement in order for a subject to train his gait so that one full gait cycle could be captured on camera.

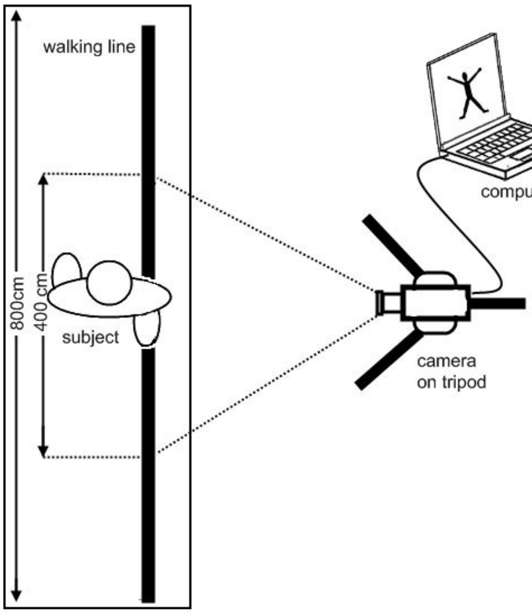

Fig.2, Measurement setup

3 Analysis of a captured data

For each measurement, single video file was created by camera software. Using video editing tools, videos were edited so only one full gait cycle was left from the original video file. Videos were then processed by in-house developed image processing software for marker recognition and tracking. Marker center was first estimated by calculating its centroid location. Small area around estimated center was further analyzed in search for sub-pixel precise estimation of a marker center. Each pixel was divided to 10 horizontal and 10 vertical divisions in to the 100 subpixels. Estimated marker center in subpixel accuracy was found as minimum of (1), which calculates effective center of gray-scale body with non-gaussian distribution of pixels intensities. Equation is written as:

$$\min\left(\sum_{x,y} I_{m,n,}r_{x,y}(m,n)\right) \tag{1}$$

where x,y are subpixel locations, $I_{m,n}$ is an intensity of a pixel at image location at coordinate (m,n), $r_{x,y}$ is distance between current pixel at (m,n) and subpixel at (x,y).

4 Results and discussion

Test of accuracy of an optical three-dimensional motion analysis system was suggested by Lujlan in paper [16]. Author tested system for the measurement of soft tissue strains and joint kinematics by examining the variation of the 3D positions of stationary markers over time. We used similar procedure for testing an accuracy of our system, calculated marker center locations were compared with their known positions for 50 markers. Results show average error of 2.509mm with std +/- 1.34mm. Active markers were further tested for angle visibility; intensity drop was 50% of maximum intensity after rotating marker 35° against camera, and at 10% at 80° angle.

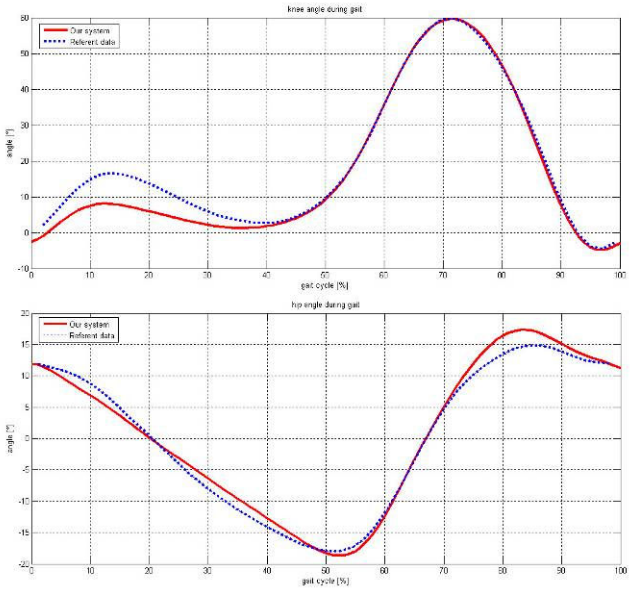

Fig.3, Compared knee and hip angle of our system (full line), and referent data (dotted line)

Results suggest that currently active markers could be used in multi-camera system where cameras are oriented ~45° against marker. Next trial was testing the marker maximum range; markers could be positioned up to 7m from camera with full range marker visibility (0°-90°). Second phase of our testing was to compare average of ankle, knee and hip angle, angular velocities and acceleration with data available from today available referent literature [16]. Fig.2. shows graphs comparing referent literature data and our norms obtained on seven subjects for knee and hip angle, differences between these non-simultaneously acquired results are small but existing.

5 Conclusion

Proposed method for human motion kinematics recording and analysis turned out to be promising. Price of realized system is lower than for any other present commercially available motion capturing system with the similar properties. Calculated error of 2.5 mm in plane and recording rate of 100Hz is acceptable for most of the today's biomechanical applications. Subpixel marker location precision allows us to locate marker in ¼ of image resolution. Visible drawback of our system, besides requirement of relatively complicated marker placement is mandatory of off-line data processing, and measurement in one plane only, but development of equally simple multi-camera 3D kinematic measurement system is on the way. Active marker benchmarking suggests that visible angle is adequate to be used in simple 3D system, while reduction of active marker light intensity by distance allows us to place markers up to 7m without major degradation of marker quality. Results of normal gait obtained and analyzed on seven subjects by our system were comparable with the results available from today referent literature [1,16].

References:

[1] David A. Winter, *Biomechanics and Motor Control of Human Movement*, Wiley; 3 edition, 2004.

[2] Duane Knudson, *Fundamentals of Biomechanics*, Springer, 2007.

[3] G. Shapiro, George C. Stockman, *Computer vision*. Prentice-Hall, USA, 2001.

[4] Emanuele Trucco, Alessandro Verri, *Introductory Techniques for 3-D Computer Vision*, Prentice Hall, 1998.

[5] Richard Hartley, *Multiple View Geometry in Computer Vision – second edition*, Cambridge University Press 2003.

[6] Lorin P. Maletsky, Junyi Sun, Nicholas A. Morton, *Accuracy Of An Optical Active-Marker System To Track The Relative Motion Of Rigid Bodies*, Journal of Biomechanics, Vol. 40, 2007. pp 682–685.

[7] Amir Baroni, G. Pedrocchi, A. Newman, D. Ferrigno, G. Pedotti, *Measuring astronaut performance on the ISS: advanced kinematic and kinetic instrumentation,* Instrumentation and Measurement Technology, 1999. IMTC/99. Proceedings of the 16th IEEE Volume 1, 1999, pp 397 – 402.

[8] Vladimir Medved, *Measurement of Human Locomotion*, CRC Press, 2001.

[9] T. Bajd, M. Klaijić, A. Trnkozcy, U. Stanić, *Electrogoniometric measurement of step length*, Scand. Journal of Rehabilitation, Vol 6, pp 78-80, 1974.

[10] J. Musić, R. Kamnik, M. Munih, *Model Based Inertial Sensing of Human Body Motion Kinematics in Sit-to-Stand Movement*, Simulation Modeling Practice and Theory, Vol. 16, No. 8, pp. 933-944, 2008.

[11] M. Cecić, S. Cecić, T. Šupuk, *Free and Treadmill Walking in a View of Kinemtaic Data*, Proceedings of 2nd European Medical & Biological Engineering Conference EMBEC'02. 2002, pp 828-829.

[12] Fuller J. Liu L. J. Murphy. M. C. Mann R. W, *A comparison of lower-extremity skeletal kinematics measured using skin- and pin-mounted markers*, Human Movement Science 16 , 1997, pp 219-242.

[13] B. Rosenhahn, C. Schmaltz, T. Brox, J. Weickert, D. Cremers, *Seidel Markerless Motion Capture of Man-Machine Interaction*, IEEE Conference on Computer Vision and Pattern Recognition, Anchorage, Alaska, 2008, pp 1-8.

[14] Stefano Corazzaa, Thomas P. Andriacchi, *Posturographic analysis through markerless motion capture without ground reaction forces measurement*, Journal of biomechanics, Volume 42, Issue 3, 2009, pp 370-374.

[15] A. Saaidi, A. Halli, H. Tairi, K. Satori, Self-Calibration using a Particular Motion of Camera, *WSEAS Transaction on Computer Research*, Issue 1, Volume 3, 2008. pp. 295-299.

[16] Lujan TJ, Lake SP, Plaizier TA, Ellis BJ, Weiss JA, *Simultaneous measurement of three-dimensional joint kinematics and tissue strains with optical methods*, Journal of Biomechanical Engineering, 127: pp 193-197, 2005.

[16] David a. Vinter, *The Biomechanics and Motor control of Human Gait: Normal, Elderly and Pathological – second edition,* University of Waterloo Press, Canada 1991.

ACKNOWLEDGMENT: This work is supported by Croatian Ministry of Science under the Project 023-0232006-1655 'Biomechanics of Human Motion, Control and Rehabilitation'