Development and Testing of a Device for Human Kinematics Measurement

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Abstract: - This paper presents a simple, inexpensive, and fast procedure for motion kinematics measurement and analysis [1,2]. System developed in our laboratory is based on a high speed industrial camera, active LED markers and a PC for handling cameras video stream and data analysis. Active markers used in this work were assembled using small, lightweight and easily available white LEDs. Smaller LEDs allow larger density of markers to be placed on a subject in motion, tracking position and orientation of all segments relevant for motion kinematic analysis. Computer vision algorithm for marker detection and tracking was developed in-house, followed by an algorithm for computing and analyzing kinematics data of human locomotion [3-5]. Procedures for camera calibration and sub pixel accuracy were also developed and integrated with the system. The accuracy and properties of our system were tested, and results were compared with the existing referent systems presently used in the field. Results of testing marker – camera properties suggest that the system could support work in larger volumes (distances from camera) and almost perpendicular rotations of marker against camera. This property allows building of a 3D kinematics tracking system with two or more cameras placed at different angels against the subject in setup. 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. The major advantage of our system is that it offers acceptable accuracy, high speed (up to 320Hz) and easy upgradeability at much lower price when compared with the other commercially available systems [6-8]. 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 human movement.

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

1 Introduction

The science of human motion analysis becomes ever more interesting because of its highly interdisciplinary nature and wide range of applications. Motion analysis systems, their measurement precision, and amount of data captured have been developed to meet the requirements for their specific objective. Today, motion kinematic systems are mainly developed for the needs of biomechanical research and virtual reality. Kinematics quantities represent an exact geometrical description of spatial movements. Distance and displacement are quantities used to describe the extent of a body's motion. Distance is the length of the path a body follows and displacement is the length of a straight line joining the starting and finishing points, while speed and velocity describe the rate at which a body moves from one location to another. When a rotating body moves from one position to another, the angular distance through which it moves is equal to the length of the angular path. The angular displacement that a rotating body experiences is equal in magnitude to the angle between the initial and final position of the body. As described, kinematic measurement of human movement encompasses positions and its derivations (velocity and acceleration) of body and segments. Angular movements (angle, angular speed and acceleration) of body and segments in joints are also regularly analyzed [2,8,9]. Kinematic data sets are basic data set for all inverse dynamic calculations, and by knowing them, together with some basic anthropometry data, forces and moments that act in joints and segments are easily calculated.

2 Related work

Last decades of technological development have resulted in many systems for measuring body segment positions in coordinate system and angles between segments. They can be simply categorized (Fig. 1) in mechanical, optical, magnetic, acoustic and inertial trackers [10]. The simplest devices used were mechanical goniometers. In work of T. Bajd [11] kinematic of normal gait was measured using an electromechanical device called electrogoniometer. It was evident that electrogoniometer and similar exoskeletal devices were only capable of measuring angles in selected joints, and not in supplying complete kinematic information of motion [8]. Also, alignment of the goniometer with body joints is a difficult task, especially when measuring multiple degree of freedom (DOF) joints, like shoulder.

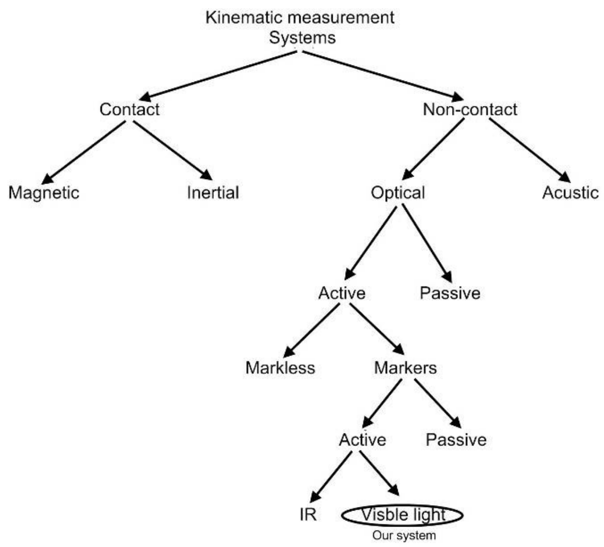


Fig. 1, Classification of kinematic measurement systems

Magnetic motion capture systems utilize sensors placed on the body to measure the low-frequency magnetic fields generated by a transmitter source. The 3D sensors measure the strength of those fields and calculate position and orientation of each sensor based on its nine measured field values. [10]. Acoustic tracking systems use ultrasonic pulses and can determine position through either time-of-flight of the pulses and triangulation or phase coherence. Another 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. Practical inertial tracking of a rigid body is made possible by advances in miniaturized and micro machined sensor technologies, particularly in silicon accelerometers and rate sensors. Sensors are placed on each body segments to be tracked. Kinematic of stand up movements with acceptable accuracy was measured using inertial sensors in paper [12]. If initial conditions are known, velocities and displacements of monitored points are calculated through numerical integration procedures. Noise and bias errors associated with small and inexpensive sensors make it almost impossible track kinematics of human movement for a long period of time, if no compensation or advanced algorithm is used. Numerous applications which use integrated inertial sensors have been rapidly increasing, and becoming a threat to the popularity of today mostly used, optical methods. Optical (stereometic) methods use optoelectronic devices to track movements of a body by tracking predetermined points (markers) on the subject's body segments, aligned with selected bony landmarks and placed on the skin [7,13]. Stereometric techniques correlate with common tracking points on the tracked objects (markers) in multiple images, and along with knowledge of camera setup, calculates position of a marker in fixed coordinate system. Optical systems offer comprehensive solution since they enable simple reconstruction in three spatial dimensions of a global coordinate system. There are some evident drawbacks of 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 [14] an 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. Tests of this commercial system showed stunning results; angular accuracy of 0.04° and linear accuracy of 0.03 mm. Another good example of using optoelectronical system pared with other optical and kinematic measurement systems is presented in work [15]. The method explained in paper allows simultaneous acquiring of kinetic and kinematic data with force plates, VICON system and a moving video-fluoroscopic system during normal level walking. This combination of the measuring techniques represents an improved analysis of load and movement of the human body. Properties of another optoelectronical system, ELITE-S2 are presented in paper [7], where they were used for the kinematic measurements of astronaut motion in the space station. This system was adequate for astronaut's kinematics measurement in space, since it is low-weight and designed to be used by only one person. Motion capture without markers is a novel approach allowing the unencumbered capture of a human motion. Systems without markers provide lower accuracy, but benefit in simplicity of measurement. Using specific algorithms, 3D kinematic data is extracted from video recorded by multiple cameras. One of the examples is presented in paper [16], where the author developed a method for tracking without markers refering to athletes interacting with sports equipment in real environments. Paper [17] explains the use of a motion capture system without markers for calculating COM (Center of Mass) and COP (Center of Pressure) from a visual hull with accuracy of 2mm. Another example of motion capture system with no markers is described in the paper [17], which demonstrates a visual motion estimation technique that is able to recover high degree-of-freedom articulated human body configurations in complex video sequences of people or animals. An ideal system for motion capture would be a system that could track motion of large support bones inside body segments and by not exposing subject with any dose of radiation. Unfortunately, for the time being, such a system does not exist. As mentioned in the introduction, by measuring underlying bones kinematics we are measuring exact body kinematics without impact of disturbance caused by skin and tissue movements.

3 Measurement and methods

A goal of this work is to develop and test a simple and cost effective human kinematic measurements system, which can be used as an alternative for commercially available motion capture systems. The implemented system is a derivation of an optoelectrical system with active markers. The software is capable of calculating kinematic data of all tracked segments using video feed from the camera. As an addition to the kinematic measurement capabilities, a component for kinematic data analysis and representation was also developed. A request was made to increase system resolution by implementing algorithm for sub pixel marker location accuracy. The idea is to create an open system, which could be upgraded with new algorithms or devices in the future, like emerging inertial sensor devices for full kinematic and kinetic measurement [18].

3.1 Measurement equipment

A room for measurement was prepared so the minimum distance of 8m was available for undisturbed walking, where only 4m were in cameras' sight. Measurements were preformed in medium lighted room with shattered windows, in order to minimize noise due to higher sun activity. In-doors lights showed not to be a problem, while small stripes of sunlight could be misinterpreted as a marker by camera. Another problem that occurred were reflections of a lower body placed markers (foot markers) from the sleek ground. This problem was successfully avoided by placing carpet on the floor. Camera used for this work was Basler 602fc fast industrial camera with Fujinon 12.5 mm HF12.5HA-1B lens. This camera was originally designed for control of a fast industrial process; it is capable of feeding computer with a raw video of 656x490 pixels resolution at speed of 100Hz using fast firewire interface. Higher speeds are also possible, but with considerable lowering of a frame size. Hamm Gama 74 tripod and custom made wall mounts were used for an optimal camera placement. Active markers used in the experiment were assembled using a small 3.0 mm white LEDs with maximum intensity of 5Cd. LED were inserted in specially prepared housing which allows easier attachment on the human body surface, as shown in Fig. 2. Markers with housings were then attached on skin or clothes by surgical tape.

Fig. 2, Subject with attached active markers (left), fast industrial camera Basler 602fc (top) and enlarged active marker (bottom)

Two sets with five markers were created, and connected in parallel using small and flexible cable with the marker central unit. Central unit holds the batteries pack (4xAA) and electronics for markers operation. For the task of image processing and data analysis a PC was used, with the following configuration; Core 2 duo processor @ 2.66Ghz, 4GB RAM and fast FireWire support. System was running on Microsoft Windows XP SP3 operating system, while program for motion capture and data analysis was developed using MathWorks Matlab 2006 software package. We tried to achieve real-time operating capability, but that was impossible with current configuration and software support developed in Matlab. As we had to choose between real time capability and possibility to improve and debug code without constant compiling, we have chosen the second option.

3.2 Camera calibration

In order to obtain accurate results, some of the camera and setup properties have to be considered. Achieving precisely positioning of the camera in a setup, so its image plane is parallel with the measurement plane is a difficult task. Also, slight misalignment of a camera with a horizontal plane is possible. To avoid the mentioned problems, camera has to be calibrated using one of the camera calibration techniques [20]. For the process of calibration we used a simple calibration board with the known size of 100 cm width and 80 cm height. A board was placed in the vertical position, parallel to the line marked on the ground defining walking track, as shown in Fig. 3. With camera set up and fixed in desired position, in which it will remain till the end of the measurement process, one image of background with calibration board was taken. The calibration process had a goal to eliminate geometric distortion caused by the imperfect camera setup and to transform any location from image into the location defined in referent coordinate system. Calibration process was done using a technique based on Projective transformation [4]

$$\begin{pmatrix} x'_1 \\ x'_2 \\ x'_3 \end{pmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} \qquad (1)$$

Or in short (2) :

$$x' = Hx \qquad (2)$$

Projective transformation is a linear transformation on homogenous 3-vectors represented by a non-singular matrix (1). Position of minimum four selected points on image is required to be compared with their real positions in local coordinate system, four points are edges of our calibration board [21,22].

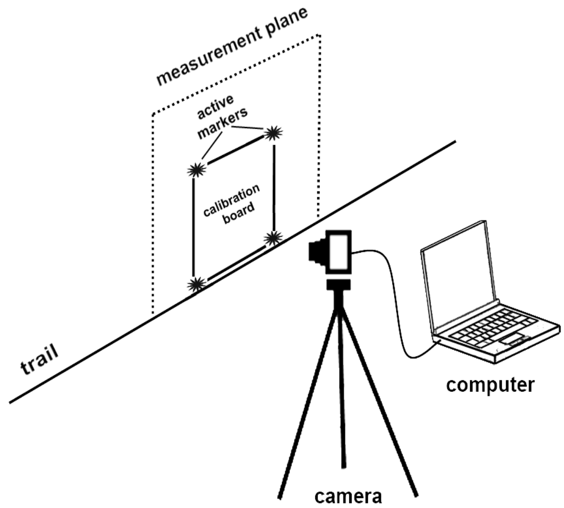


Fig. 3, Camera calibration setup

Algorithm is capable of calculating transformation matrix, which transforms marker center location detected on image plane and located in pixel, to location in measurement plane where markers estimated location is located in mm. Calculated calibration matrix is valid for all images that were taken with the same camera setup, and if camera or measurement plane moves, calibration becomes invalid.

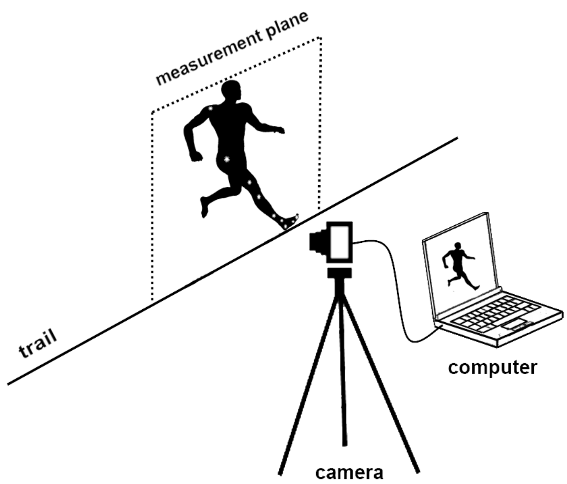


Fig. 4, Measurement setup

3.3 Measurement setup and process

Active body markers were placed on strategic points on a body surface; at least two markers per segment near joint in order to minimize the error due to skin movement. We used ten markers placed as shown in Fig. 1, attached to the body using a surgical tape. Marker central unit was kept attached to the subject's back, while connecting cables were additionally fastened to the body by flexible bands, thus preventing covering the marker with cables. Markers and cables were placed so that the minimum impact to the free gait was achieved. Seven volunteers participated in our research, four females and three males, aged 22-25, Caucasian student population. A subject with markers attached was instructed to walk following the line marked on the floor with his right foot, Fig. 4 and 5.

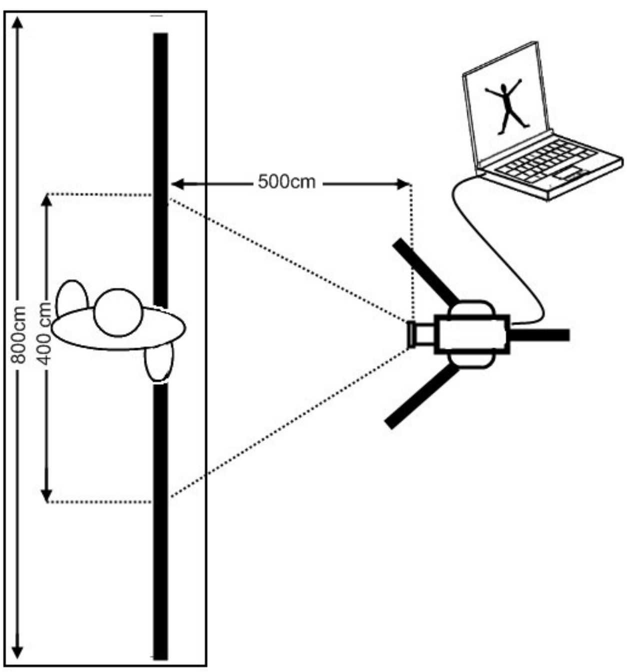


Fig. 5, Setup top-view, subject is walking following the line defining measurement plane

Few attempts of walking along the line were allowed before measurement, in order for a subject to train his gait so that two complete gait cycles could be captured on camera. We measured kinematics of a slow and fast walk and sit-to-stand motion. All measurements were repeated for minimum of five times in order to eliminate invalid measurement and create norms.

4 Analysis of a captured data

In this section, process of calculating kinematic data from camera images is described in detail. As mentioned in previous section, ten measurements were executed on each subject. Each measurement was arranged and saved as an individual video file. Each video file was then analyzed by video editing tool (VirtualDub) [23], so the only one full gait cycle was extracted from the original video (from heal-strike to heal strike). Key gait phases were detected by analyzing location of a heel marker in Y-axis (vertical). Two large bottoms in time – Y-axis plot represent heal strike moments/frames. After removing all but one full gait cycle, videos were finally prepared for marker recognition and tracking part.

4.1 Marker recognition and tracking software

In this section the image processing and analysis are described. Videos were processed by in-house developed software. Described software was made using Mathworks Matlab 2006 GUI [24], that allows creation of simple and user friendly graphical interface with powerful, easy accessible developing support, Fig. 6. Matlab was a good choice because it allows us to use simple commands for complicated image processing tasks. Software that we have developed was capable of recognizing and tracking up to 20 markers in video sequence. Estimated marker location in measurement plane is described in metric units, and was calculated by known location of marker in cameras image plane with support of subpixel accuracy algorithm, described in next section. Basic kinematic marker data (locations or displacement of markers) were then filtered using predefined 10 Hz or 5Hz 4^{th} order Butterworth filter, fast movements were filtered with 10Hz filter while slower movements were filtered by 5Hz filter. The processed data was then saved in Matlab data file (mat), and as such prepared to be used by other software components. Movements of each segment were then reconstructed by tracking pairs of markers which define segments endings, by knowledge of basic anthropometric data (anthropometric tables) [25-27], segments center of mass kinematic were calculated. Angles in joints were calculated from relative orientations of two neighboring segments, definitions of joint angles and segment orientations we used are described by Winter in [1]. Basic kinematic data sets (positions and angles) were further processed with 1^{st} and 2^{nd} derivation with time in order to calculate markers/segments speeds, accelerations and angular speeds and accelerations in joints. Higher order derivations were also possible, but considered insufficiently accurate with the current recording speed for more detail analysis. A component for reconstruction of gait was also created; it is a simple program that connects neighboring markers into the "walking skeleton". This component was used to visually inspect quality of measured data and remove unusual or invalid measurement.

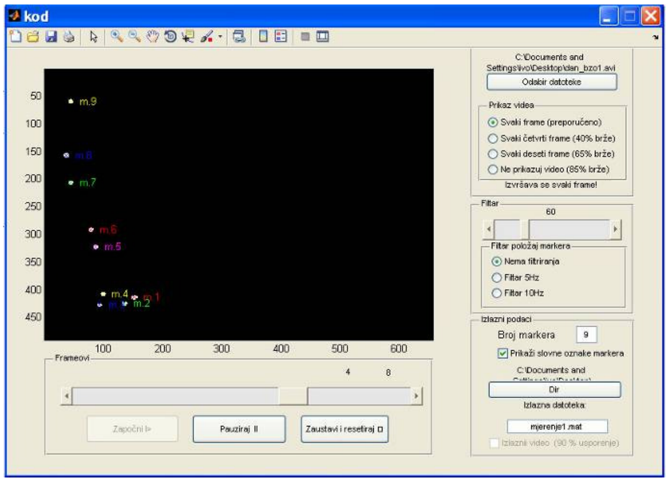


Fig. 6, Software for marker detection and tracking

4.2. Subpixel Accuracy

Full resolution of camera's image is 659 x 490 pixels. As camera was placed 5m from the measurement plane, only 4m of measurement plane are in cameras sight, and basic resolution (pixel size) of system in this setup is ~ 0.6 cm. We search for a method that will improve this resolution without obtaining new higher resolution camera. As shown in Fig. 7, marker pixels don't have the same intensity; center is recognized with higher intensity pixels with intensity uniformly dropping when reaching marker edges. It is noticeable that exact location of the marker center is hidden "inside" one of pixels. Different approaches exist for subpixel marker center estimation, and most of them are based on statistical distribution of marker pixel intensities, where center of marker is calculated by matching model with its real image. Example of the one of today most used algorithms is described in paper [28], which is dedicated to IR markers captured with high-quality IR camera. In our case, we have to use a different approach due to unusual distribution of pixels around marker center. Firstly, we have estimated approximate marker center location by calculating its binary image centroid. For the sake of faster algorithm execution, only small area around estimated marker center was further analyzed in search for sub-pixel precise localization of a marker. If higher resolution marker image is rendered, based on mathematical marker model, it looks similar as a marker captured during measurement, but with higher resolution. Algorithm for searching a marker center is based on 2D convolution of a marker rendered model and reseampled captured image. Subpixel where maximum convolution or best matching is achieved is estimated center of a marker.

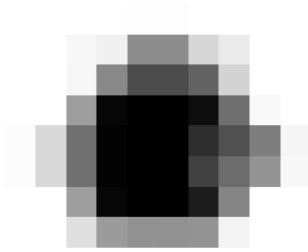


Fig. 7, Enlarged marker image

Procedure is described as follows: Each pixel was divided to 10 horizontal and 10 vertical divisions into the total 100 subpixels. Experience showed that with current setup and equipment no more than 10 x 10 divisions were required. Estimated marker center with subpixel accuracy was found as minimum of (3), which calculates effective center of gray-scale body with non-normal distribution of pixels intensities. Equation is written as:

$$\min\left(\sum_{x,y} I_{m,n,} r_{x,y}(m,n)\right) \qquad (3)$$

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).

5 Results and discussion

As in this paper a completely new, non-commercial and untested system was used, testing of its accuracy and other useful properties was a mandatory task. Testing of a system is divided into three sections, the first explains static accuracy of a system (Section 5.1), the next section deals with the optical system properties and usability (Section 5.2), while the last section (Section 5.3) compares results of few non-simultaneous measurements done with our system and referent literature.

5.1 Static measurement accuracy

There are many suggestions for testing accuracy of kinematic measurement systems, with markers or without them. The best possible solution is to track exact and predetermined motion of a robot manipulator, as it was done in the paper [6] for Optotrak system. In this way both static and dynamic accuracy were tested. Simple test of static accuracy of an optical three-dimensional motion analysis system was suggested by Lujlan in the paper [29]. Authors 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. After calibration procedure successfully preformed, 50 markers were placed one by one at the randomly selected points on the measurement plane. Their locations were estimated by the algorithm explained in section 4.2, and compared with original locations. Results show average error of 2.509 mm with STD +/- 1.34mm, which is size of 1/3 of a pixel or slightly smaller than markers' physical dimension. As all markers were placed manually on board by the examiner, we presume that better results could be achieved if human impact was avoided by precise mechanical manipulator or robot. Our future task is to test our system side-by-side with proven systems like Optotrak or Vicon.

5.2 Optical system properties

In this section camera-marker system was tested for its optical properties, maximum rotation angle and camera-marker range are important information if we want to use different setup or upgrade our system with more cameras or markers. Active marker light distribution is not homogenous in all directions because of its half-sphere shaped tip. Maximum light intensity is expected at 0 degree rotation against camera, while no or minimum intensity was expected at 90 degree rotations. Goal of this measurement was to test maximum rotation angle of marker against camera, where at working distance (5m) marker is still clearly visible and its center could be estimated with sub-pixel accuracy. As shown in Fig. 8, curve of an intensity drop from 0 to 40 degrees follows regular shape, while after 40 degrees rotation, when "base part" of marker becomes larger light source; intensity is almost constant with small degradation. At 90 degree rotation, intensity drop is significant, and not measured, because source of light is a reflection from different parts of a marker. Measured intensity drop was 50% of its maximum intensity after 35° rotation and at 10% at 80° angle. These results suggest that marker could be used in virtually all rotations [+/- 90°] with marker still visible with sufficient number of pixels. Another conclusion is that markers could be used in multi-camera system where normal orientations of ~45° against camera are normally expected.

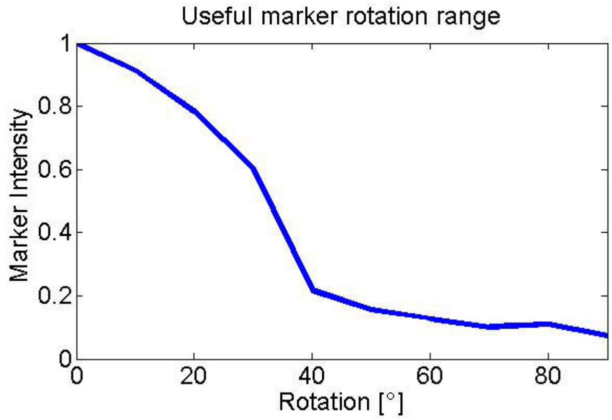


Fig. 8, Marker intensity with rotation

In the second part of a measurement, marker light intensity drop with range was tested and analyzed. These results should be considered with some reserve, as markers and camera are both optoelectronic devices, and ability of detecting a marker against background is under strong impact of noise and laboratory conditions. Outdoors, during high sun intensity, visible range of a marker is small, and could be measured in just few centimeters, while in total dark conditions (i.e. tunnel) visible range could be up to few hundred meters. Our task was to determinate maximum and working range for normal indoor conditions. As normal laboratory conditions we consider a situation when all indoor lights are turned on (fluorescent lamps) and windows shuttered.

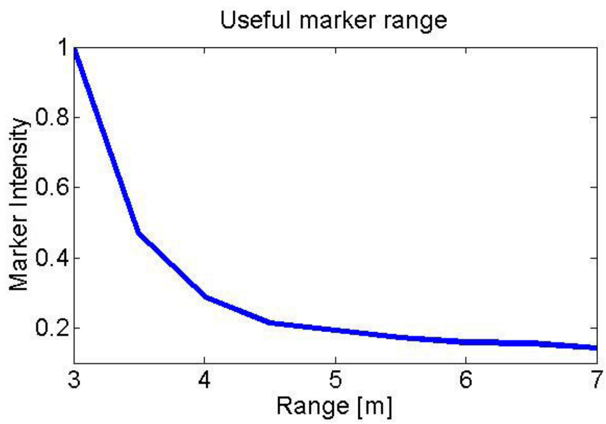


Fig. 9, Marker intensity with distance from camera

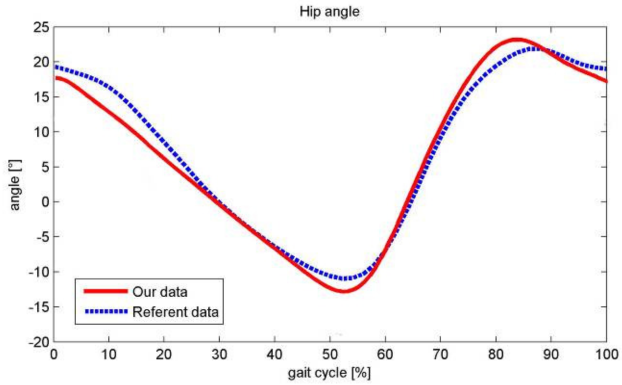
Fig. 9. presents marker intensity drop with distance; it is clearly visible and expected that curve follows the equation (2).

$$I_d = I_0 \frac{1}{d^2} \quad (2)$$

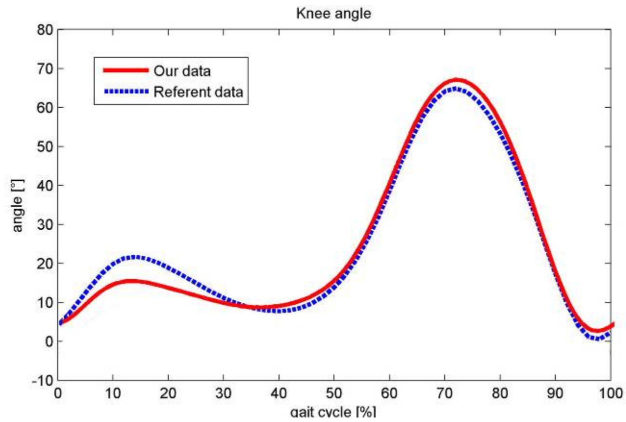
With intensity measured only in few points, maximum and working range is easy to calculate. In normal light conditions, working range with marker visible at all angles and with minimum of 16 marker pixels, was around 5m. Maximum range, with at least 4 markers visible at all rotations showed to be more than 7m. Number of 4 pixels is chosen as minimum of pixels for subpixel algorithm to work, while 16 pixels are number of pixels where significant degradation of marker detection could be ignored. Results suggest that one or more cameras could efficiently cover measurement volume, occupied by single subject performing any kind of everyday motion. Further development of our system, with results obtained by this measurement, proposes use of a secondary camera, which will expand measurement plane of 4 x 2 m to the measurement volume of 4 x 2 x 2 m.

5.3 Comparison of a measured data

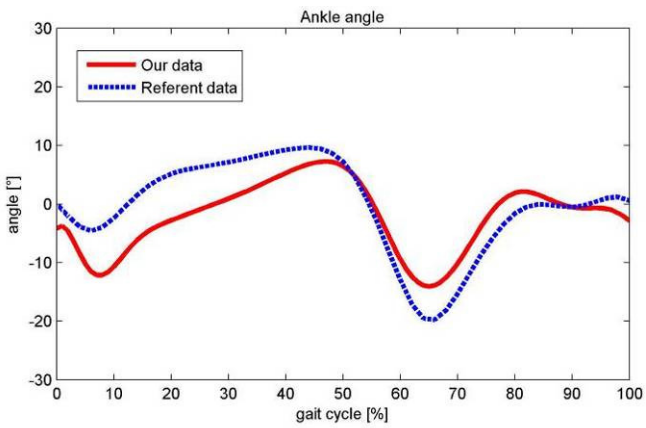
Section 5.1 covers the static system accuracy, in ideal conditions. In order to test our system in every-day dynamic working conditions, we had to measure kinematics of a motion and compare results obtained with data found in today referent literature. The easiest way to compare data is to measure kinematic of one well known and described movement like normal gait. In literature [1,9] segment displacements, speeds, accelerations of segments and joints angular data are well described in details with its numerical data for comparison. We must note that results of these two non-simultaneous measurements are not expected to be the same, but shapes have to match. With placement of marker on a body we tried to follow descriptions given in the [1]. In Fig. 10, we compared hip, knee and ankle angle for one full gait cycle (red full line) with referent norms (blue dotted). Differences for hip and knee angels are minimal, and could be explained due to different gait style, speed, different acquisition rates of just differences between individuals. Relative differences between ankle angels are slightly larger than for hip and knee example. This could be explained with increased sensitiveness of an algorithm when markers are placed extremely close (few cm) from each other. Differences between absolute values are clearly visible and existing while curve shapes are almost matching in all three shown examples.



a) hip angle



b) knee angle



c) ankle angle

Fig. 10, Compared knee and hip angle of our system (full line), and referent data (dotted line)

In the paper [30] another interesting way of visualizing kinematic data is presented, instead of time axis, graph uses two values axis (i.e. knee and hip angle) where correlations between joint angles could be better understood and analyzed without their time dependencies. As this graph is normally more sensitive than time-domain graphs, result in Fig. 11, shows acceptable curve shape matching. After upgrading our system with more cameras and creation of full 3D measurement system, our plan is to perform full static and dynamic trials with "golden standard" devices like Optotrak or Vicon for precise manipulator motion and/or for real-life measurements (i.e. normal gait, jumping, sit to stand motion). Upgrading with simulation and modeling component or integrating with existing 3rd party software is also an option [31].

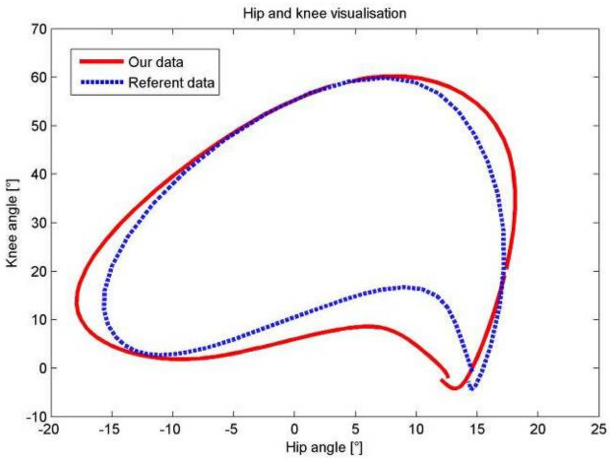


Fig. 11, Visualization of correlation between hip and knee data

6 Conclusion

Method for human kinematic measurement proposed in this paper showed to be promising. Realized system is capable of measuring segments and joints kinematic data (linear and angular displacements, speeds and accelerations), analyzing and representing data in different domain graphs. Described system was tested for its static accuracy in one plane, where it showed acceptable results comparable with today commercially available systems. Measured error of detecting marker location was ~2.5mm with STD of 1.3mm, which is acceptable for a research in biomechanics. Measurement speed of 100Hz gives analyzing component of our system enough data for quality analyzing of a higher derivations of displacement (up to 2nd derivation), while larger speeds are possible with considerably reduced area of measurement. Subpixel marker locating precision implemented in recognition and tracking software allows us to locate marker in 1/3 of pixel actual size, there is still place for improvement of final systems resolution with improved algorithm. Our system comes with a few disadvantages, relatively and sometimes complicated marker placement and wiring takes our valuable measurement time. Another large drawback in measurement in only one plane (measurement plane), but stereo-vision improvement is planned and will considerably increase measurement volume and quality of measurement. System properties described in section 5.2 suggest that existing system could be easily upgraded with one or more cameras, where rotation angles of marker allow us to detect marker in virtually all orientations against camera, where partial rewriting of software and extending the calibration procedure is mandatory. As this paper was a proposal for a simple kinematic measurement system, we also considered possible improvement of a system which will allow mentioned 3D measurement capability or higher resolutions. As our own software was developed, system is easily upgradable with the new code or methods, and could use large number of included Matlab libraries. This allows us to use our system in parallel with other devices, or to ad-hoc test new algorithms. Off-line data processing is for now not considered as a drawback, all calculations, filtering, and reconstruction of a motion take only few minutes. Real time operating capability is possible with better configuration and code optimization, but we have chosen slower off-line option that offers us more precise results and more options for results representation. System was tested in laboratory conditions, measuring kinematic data of normal gait for seven subjects, and compared with referent kinematic data in the field. Comparison of these non-simultaneous measurements shows acceptable matching of curves shape, but with small differences in absolute values, which could be explained as individual differences of gait style of our subjects and subjects involved in referent norms measurement.

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