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DINAMIC AND STATIC CENTRE OF PRESSURE MEASUREMENT ON THE FORCEPLATE

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Abstract

We have extended in our previous paper described forceplate with direct kinematic parameter measurements to study the relation of the center of pressure (COP) and center of mass (COM) coordinates. Parallel with the direct optical determination of the kinetic parameter, we have also utilized the Kinect sensor for continuous automated measurements.

First a mathematical and a physical pendelum was studied. We have found that during dynamic motion, the COP coordinates vary in a larger scale, than the vertical projection of the COM coordinates, examined and tested the relation between these quantities.

As a biomechanical application, the pendelum type motion of the arm with a weight was also measured. When the body is constrained to a fixed position, the results are similar to the case of a physical pendelum. When the body is free to move, the large deviation of the COP coordinate are almost totally compensated by the motion of the torso. Compensation of dynamic loads can be applied as another approach to study the balancing skills of individual in addition to the quite standing.

I. Introduction

The human kinematics can be measured trough determination of mechanical quantities, like the spatial position of body parts and the determination of external forces and momentums. The forceplate provides an efficient way to follow the balancing motion of a standing trough the determination of the COP coordinates. Under nearly static conditions, the center of pressure COP is simply the vertical projection of the center of mass COM coordinates.

During dynamic motion, the vertical projection of the COM coordinates, which is called the “center of gravity line” (CGL) deviate from the COP coordinates. The relation of the two quantities was examined by Winter et al. both experimentally and theoretically for quite stance [1]. They have shown, that the CGL will fluctuate around the COM coordinates, and can be regarded as a low pass filtered version of the COP signal. The theoretical description was based on an inverted pendulum model. In order to compare the COM or CGL and the COP coordinates both parameters have to be measured or calculated.

The COP coordinates are easy to determine with the application of a forceplate. The COM coordinates cannot be directly measured, but have to be calculated from the combination of a mechanical model and kinematic measurements. Winter used LED light to measure the position of body segments, and calculated the corresponding COM coordinates form the estimated mass of the body segments [1]. Another approach is to use the measured COP coordinates and the inverted pendulum model to calculate the COP coordinates with a “zero-point to zero-point integration” [2]. For this calculation the horizontal forces acting on the force plate must be measured, and the zero value of this force corresponds to the coincidence of the COP and the CGL. This is the static equilibrium position, where no torque is acting on the system. The inverted pendulum model assumes that the body behaves as a rigid object above the ankle. This assumption was confirmed by Gage al. using a large number of IR LEDs and a camera system for 3D body segment motion estimation [3].

The above results show that it is important to make a difference between the COP and COM coordinates during dynamic loading. The distinction is even more important when one considers the balancing requirements during walking or running. A detailed analysis of walking has shown that the angular momentum compensation might play an important role in the preservation of dynamic stability [4].

We have used a suspended pendulum standing on a tripod on the force platform [5] as a simple dynamical load. The spatial coordinates of the moving mass was recorded using a nowadays developed measuring system, which utilizes a Kinect sensor. The measurements were extended to a physical pendelum, and finally, the effect of dynamic load on a standing human was studied.

II. Kinematic measurements with the Kinect sensor

The Kinect is a motion sensing input device, which was developed by Microsoft for the Xbox 360 console. The goal was to enable the user to communicate with the consol without touch or any hand held control device. The system become open for external developers in jun. 2011, when Microsoft released an SDK (Software Development Kit) for the Windows 7 operating system. Soon several physics based or related applications were developed.

One active research area is the motion capture for animation, where a human actors motion is captured with the Kinect sensor, and the geometric data is combined with physical simulation to generate a realistically moving animated character [6-8]. It was shown, that the precision of the motion capture can be improved with utilization of forceplate measurement data [9]. The main advantage of the Kinect sensor compared to other methods is that it can provide markerless position information for 3D motion analysis.

The Kinect sensor has two cameras and an infrared light source, which projects a textured light on the nearby objects. The RGB camera has 1280x1200 pixel resolution while the infrared camera, which provides the depth information has 640x480 resolution and 30frame/sec sampling rate.

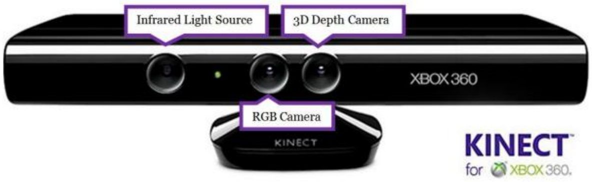

Figure 1: The Kinect sensor

The force measurements are performed by three calibrated load cells instrumented with strain gauge. The load cells were manufactured and individually calibrated by Kaliber Corporation from Hungary, Budapest. The nominal range of the force sensors are 0-100 kg. The side length of the triangle is 63cm. For the reduction of the electric noise, 200 samples were averaged to provide a single measurement data. This leads to a sampling rate of 2.5 kHz. For more details see our previous paper [5].

We wanted to combine the high resolution 2D image with the depth information coming from the measurement. The distance between the two sensor is 3 cm, which means, that the two image is originated from different perspective. We used a coordinate system fixed to the Kinect sensors image plane, where the x-axis is the horizontal, the y-axis is the vertical coordinate of the depth camera, while the z-axis denoted the depth information of a spatial point. The image plate of the RGB camera provided the x’ and y’ coordinates for the same point. The coordinates are related to each other through an affine transformation as a result of the image generating projection operation with unknown coefficients.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix} \tag{1}$$

The coefficients can be determined from the coordinates with the help of three identified points on both images, which provides six linear equations, rewritten in a matrix form as follows:

$$\begin{bmatrix} x_1' \\ x_2' \\ x_3' \end{bmatrix} = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ t_x \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} y_1' \\ y_2' \\ y_3' \end{bmatrix} = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{bmatrix} \begin{bmatrix} c \\ d \\ t_y \end{bmatrix} \tag{3}$$

The above equation can be inverted to get the coefficients from the known coordinates. The calibration was performed automatically using image processing to recognize three corners of the face of a box. On the RGB image the face was identified based on the contrast, and on the 3D image based on the position. Once the transformation matrix is determined, we could find the corresponding points on both images, and combine the depth and optical information.

III. Measurement of the simple pendelum

The experimental setup is shown on Fig. 2. A paper box was attached to the pendelum mass for the better detection of the spatial position. The mass of the supporting frame was included in the determination of the zero level of the force sensors. In this way, the change of the COP coordinate was affected only by the mass of the pendelum. The Kinetc sensor was placed at about two meters from the pendelum.

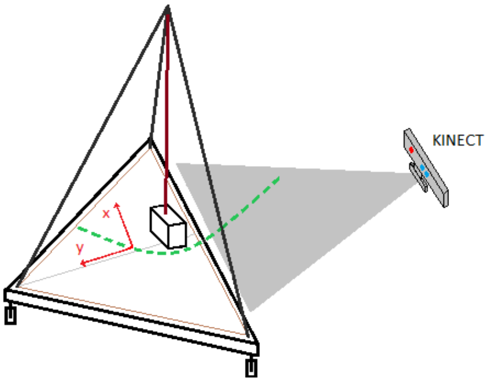

Figure 2: Composition of the Kinect sensor and forceplate

The data of the Kinetc sensor was processed with LabVIEW program utilizing the SDK. The image processing was performed with the IMAQ package. The region of interest can be selected on the image, where the motion is occurring. The program automatically identifies the box, and calculates its position based on the depth image. The actual orientation of the box could also be calculated from the image and 3D data. In this way, both spatial position and orientation of the moving object could be determined.

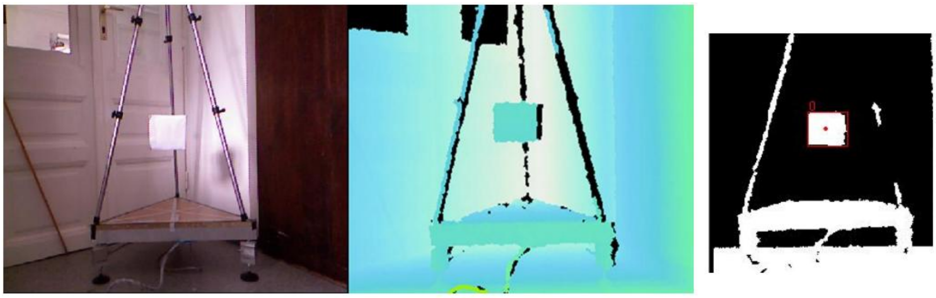

Figure 3: The pictures of the RGB camera, the depth sensor and the processed image for motion capture.

The pendelum was suspended from a tripod, which was standing on the force platform. The 3D image data acquisition was performed by a separate computer, and the measured coordinates were sent as UDP data packaged to the computer performing the COP measurement with the forceplate.

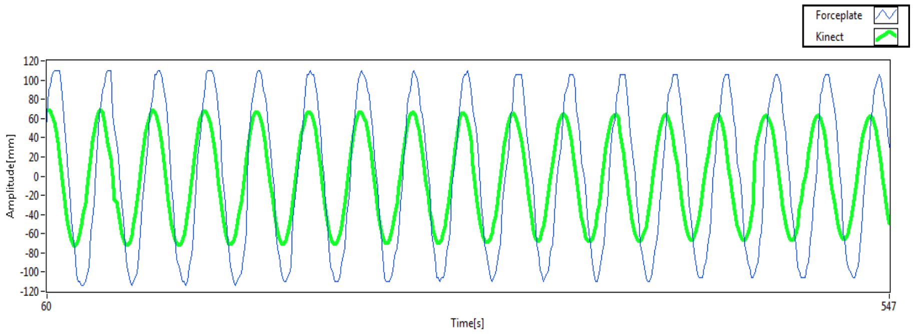

Figure 4: Comparison of measured depth and COP coordinates before the time lag correction.

Time “lag” with variable length appeared, caused by the speed of the network communication between the two systems. In order to provide a common time base, a time stamp of the measurement was added to the data package. With this method, the proper synchronization of the two measuring system was achieved.

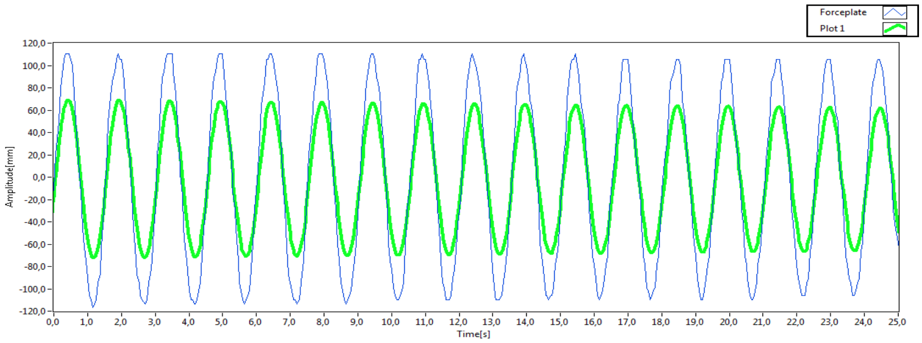

Figure 5: Deviation along the line of vibration of the COM coordinate and the COP coordinate.

One can observe, that the measured amplitudes are still different. This difference is a real effect, because the COP deviates from the CGL coordinate. The deviation is related to the external momentum, which is needed to restore the pendulum to the equilibrium position. The COP is the point of application of the external force, which is situated at the projection of the COM coordinate along the direction of the supporting wire to the base plate.

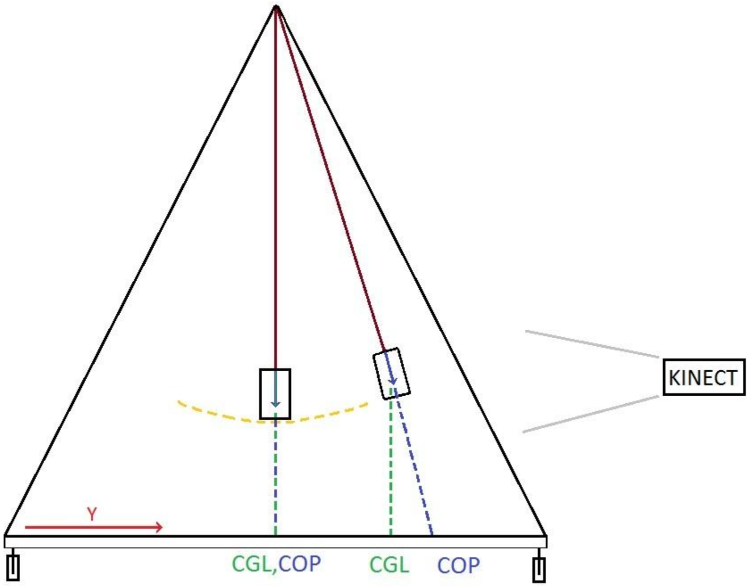

Figure 6: Difference of the COP and CGL coordinates for a mathematical pendulum.

IV. Biomechanical applications

The arms swing can be treated as a physical pendulum. We have planned a pilot study of the effect of free arm swing on the standing balance. During the swinging the COP position is shifted, and also the total force is changing. We have a maxima at the vertical position of the hand, and a minima at the extremal positions, thus the frequency of the total for is twice of the frequency of the swinging arm.

The swinging was treated as a physical pendelum for which the maximal angle α of deflection was also determined. After some elementary calculations, the following formula was derived

$$mg = \frac{F_{max} - F_{min}}{2(1-cos\alpha) + sin^2\alpha} * \frac{L}{L_0}, \qquad (4)$$

where m is the mass of the physical pendelum, L is the distance of the COM from the rotation axis, L0 is the length of a mathematical pendelum with the same period.

The above formula was checked with the measurements of a physical pendulum, where all parameters could be individually determined. The period was 1.986 s, corresponding to a mathematical pendulum with length 97.85 cm, while L=76 cm was measured with balancing method. For an angle of deflection of α 12.15° the amplitude of COP measured on the force plate was 29.4 cm, which is smaller than the projected amplitude of a the corresponding mathematical pendelum (31.81 cm) but larger than the amplitude of the CGL line (15.8 cm). From the Fmax – Fmin = 5.8 N values measured by the pendelum was estimated from (4) to be 6.8kg, which was actually 6.77 kg.

Three volunteers were asked to stand on the balance, and swing both of their arms in sync in at a natural relaxed way. As a further variation two equal weight of about 1kg mass were held in the hands while swinging the arms. In one experiment, the trunk was fixed to a column supported by the force plate. In this way the effect of the swinging are on the COP could not be compensated.

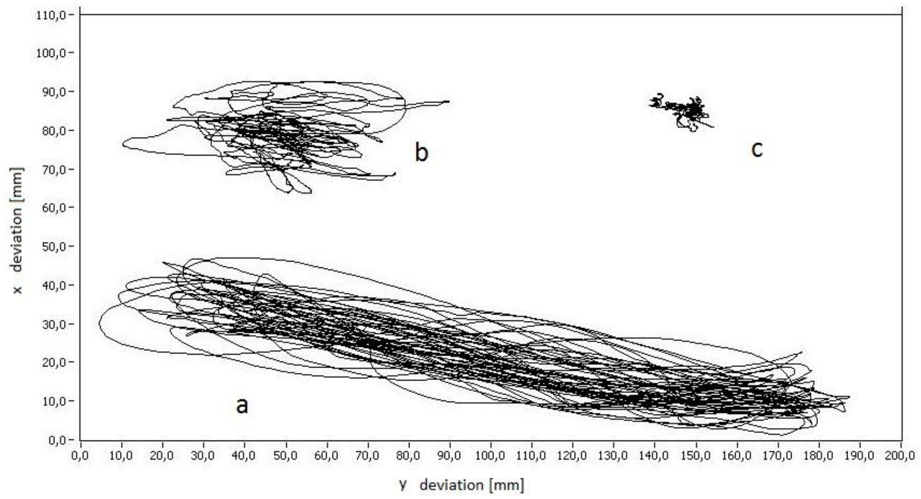

Figure 7: Stabilogram for the three different cases. (a) Fixed trunk with swinging arms. (b) Free standing with swinging arms. (c) Quite standing.

The numerical data shows, that the effect of hand swinging is largely compensated by the synergetic motion of the body in free standing conditions.

	free arm			arm + 2.2kg		
arm swing, fixed trunk [mm]	182	128.7	133.5	182.9	158.3	126.69
free standing with swinging arms [mm]	31.2	40.3	35.9	49.7	35.1	45.5
quite standing [mm]	15.6	21	13.7	15.6	21	13.7

Table1: Deviation of the three different cases

Acknowledgements

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