Development of Computer System for Digital Measurement of Human Body: Initial Findings

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Abstract: *Background:* Microsoft Kinect is used in the field of anthropometry (Sameijma et al., 2012; Xu et al., 2013; Clarkson et al., 2016; Zhang et al., 2015), gait analysis (Springer & Seligman, 2016; Pfister et al., 2014; Motiian et al., 2015; Prochazka et al., 2015; Cippitelli et al., 2015), motor performance (Lim et al., 2015; Sevick et al., 2016; Taha et. al., 2016), posture/balance evaluation (Dutta et al., 2014; Metiplay et al., 2013; Oh et al., 2014; Saenz-de-Urturi & Garcia-Zapirain Soto, 2016) and rehabilitation (Galna et al., 2014; Mobini et al., 2015; De Rosario et al., 2014; Shapi'i et al., 2015). Reliability of instruments in clinical and sport application differ, therefore the goal of this research was to initially determine the protocol of validation of a new measuring instrument for digital measurement of anthropometric dimensions of the body (structural and metric). Reliability of results in this paper was tested on three classically and digitally measured anthropometric variables, i.e. *height, left forearm length* and *left lower leg length*. *Methods:* Male and female employees of the Technology Park Zagreb (N=52) volunteered for this research. Subjects were wearing their everyday clothes. Among 471 assessed variables (3 + ((26 * 6)) * 3) three variables from a set of classically measured anthropometric dimensions were extracted - *height, length of left forearm* and *length of left lower leg*. Classical measurements were conducted through standard IBP protocols, a Standardized protocol for digital measurement (DM-I) was produced. Data were analyzed by Statistica 12 for Windows operating system. Mean, standard deviation, range, variability coefficient, skewness and kurtosis were used as descriptive parameters, as well as Pearson correlation coefficient, Spearman-Brown alpha, Cronbach`s alpha and Spearman-Brown (standardized) alpha. *Results:* Classically and digitally measured height in average results do not differ significantly, while for lengths of the left forearm and the left lower leg do indicate significant differences (lower values). The differences could be attributed to different reference points used in two measurement methods. Measures of internal consistency (reliability) for digitally measured variables: height of the body, length of left forearm and length of left lower leg demonstrate high reliability (Cronbach alpha, the standardized alpha 0.995 to 0.997) and the average inter-item correlation (0.973 to 0.985), indicates a high internal consistency between items related to digitally measured height. Reliability was slightly lower for digitally measured length of the left forearm and lower leg due to greater differentiation in average inter-item correlations coefficients. *Conclusions:* Digital measurements with Kinect are not appropriate for clinical trials demanding high precision. There is no statistical evidence that could differentiate distances of examinee from Kinect sensor in order to define optimal distance (as long as subject stands within Kinects range. Small errors occur due to clothing, possibly due to illumination, and sensor height and distance, which is in line with previous research.

1 INTRODUCTION

Anthropometry plays an important role in industrial design, clothing design, ergonomics and architecture. Morphological data is used to optimize products for particular populations and purposes. Lifestyle changes, changes in diet and ethnic profiles of given populations lead to morphological changes (e.g. obesity pandemy). Importance of possessing exact morphological data is crucial in order to react adequately to current problems. Therefore, it is important to regularly gather new morphological data.

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Various methods of human body assessment use various instruments. In the fashion industry, a common instrument is the measurement tape, while in biomedical sciences anthropometric instruments include: anthropometer, pelvimeter, caliper, centimeter tape, etc. Digital measurement methods for human body assessment use various electronic systems (e.g. Kinect, Structure Sensor). These methods range from laser scanners to mobile applications (e.g. Tailor Measure and Nettelo). Three-dimensional scanners enable innovative and quick digital anthropometric measurements based on gathered information from sensors, e.g. Kinect sensor.

Microsoft Kinect is used in the field of anthropometrics (Sameijma et al., 2012; Xu et al., 2013; Clarkson et al., 2016; Zhang et al., 2015), gait analysis (Springer & Seligman, 2016; Pfister et al., 2014; Motiian et al., 2015; Prochazka et al., 2015; Cippitelli et al., 2015), motor performance (Lim et al., 2015; Sevick et al., 2016; Taha et. al., 2016), posture/balance training (Dutta et al., 2014; Mentiplay et al., 2013; Oh et al., 2014; Saenz-de-Urturi & Garcia-Zapirain Soto, 2016) and rehabilitation (Galna et al., 2014; Mobini et al., 2015; De Rosario et al., 2014; Shapi'i et al., 2015). Reliability of instruments in clinical and sport application differ, therefore the goal of this research was to initially determine:

a) The protocol of validation of a new measuring instrument for digital measurement of anthropometric dimensions of the body (structural and metric),
b) The Kinect anthropometric measurement error based on comparison with classical anthropometry,
c) The optimal distance between a subject and the Kinect sensor,
d) The optimal number of measurements for a given distance, etc.

The reliability of the Kinect sensor for three digitally measured anthropometric variables, i.e. height, left forearm length and left lower leg length will be calculated. Based on initial findings, later it will be possible to integrate future findings into sport applications and clinical applications related to other analyses conducted in a biomechanics laboratory (e.g. gait, pedobarography ect.)

2 METHODS

2.1 Subjects

Male and female employees of Technology Park Zagreb (N=52) volunteered for this research. Subjects were wearing their everyday clothes.

2.2 Variables

Among 471 assessed variables (3 + ((26 * 6)) * 3) three variables from a set of classically measured anthropometric dimensions were extracted - *height, length of left forearm* and *length of left lower leg*. Classical measurement procedures for assessing anthropometric dimensions were carried out according to the pre-defined and standardized IBP (International Biological Program) protocol (Mišigoj-Duraković, 2008).

Standardized measurement protocol for digital measurement of anthropometric dimensions, using a device, was defined via equipment, procedures and instructions, controlled during measurement of each entity for full control of factors that may affect the accuracy of measurements.

2.3 Classical Anthropometric and Kinect Measurement Protocols

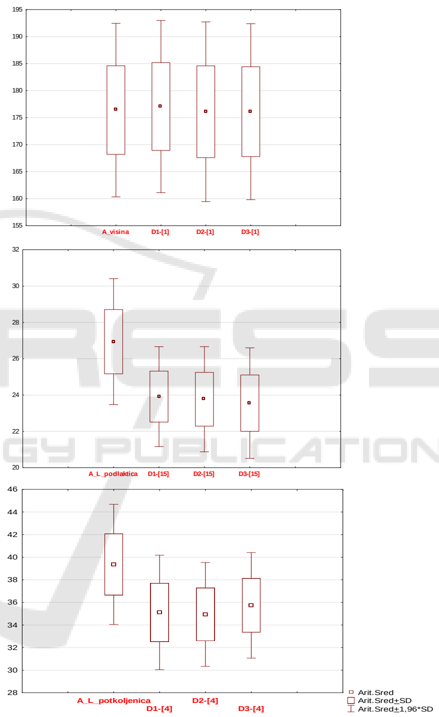
Standardized measurement protocol is predefined by IBP. Standardized protocol for digital measurement (DM-I) was: *Run time:* The total estimated duration of the test for one subject is 6-8 minutes. *Number of measurers:* 2. *Technical requirements:* A computer with configuration: 64-bit (x64) dual-core, 3.1 GHz or faster (Intel i3, i5 or i7), USB 3.0 controller dedicated for Kinect v2 sensor (Intel or Renasens chipset), 4 GB of RAM, the graphics card that supports DirectX 11, Windows 8, 8.1 or Windows 10, and Kinect version 2 for Windows. *Description:* The test was performed in a room with minimum dimensions 3 x 4 m. Kinect and computer device were on the table 75 cm high, with lines showing distance of 200 cm, 230 cm and 260 cm from the Kinect (a tape on the floor that followed an imaginary line perpendicular to Kinect). *The initial position of the examinees:* The subject stands upright in a straddle stand facing the measuring instrument, feet spread at hips-width and rotated outward (V-position). The hands are placed parallel to the trunk and away from it forming a 35-45 degree angle. Examinees' view was focused straight ahead in the direction of measuring device. The proper starting position and distance of subjects from instrument was checked by measurer before issuing instructions to start with protocol. *Measurement of performance:* After coming into the position to measure, participants were supposed to raise their left arm, which starts the process of positioning the object of measurement by the device. After dropping an arm and coming into the initial default position, measurer activates measurement procedure, and an examinee retains position until next instructions. The task was performed six times on each of three default distances. Between individual attempts, examinee has to leave the position and to come back. *Completion of performance measurement:* The task is completed when the subject performs six registered measurements on each of the three default distances. *Position of measurers:* The first measurer was in a position that allows him to control the position of the examinee in the measurement, visual inspection of the task and the registration results. Another measurer enters codes of each measurement in a prepared table. *Recording the results:* The device automatically registers the default digital (anthropometric) measures (3 x 6 measurements) in centimeters (with a precision of 1 decimal). After each measurement, measurer records identification number of a measurement in the prepared table. *Remark:* The examinee may begin the process of positioning at any time, raising his left hand after he was warned by the measurer that the instrument is ready. If the result wasn't registered for any reason, measurement procedure must be repeated. *Information to the examinee:* [task was demonstrated and described simultaneously] "This protocol measures the dimensions of your body. To start measuring, your task will be, after taking a starting position at a given distance, to raise and lower the left arm. Stand upright, facing the screen of the monitor, with eyes directed forward. The arms are slightly separated from the body, extended at the elbows, fingers outstretched and hands in continuation of the extended forearm." (Measurer demonstrates the position of the body and at the same time describes) "The task will be repeated six times, on each of the preset distances. On the measurer's sign, after each recorded measurement, you will leave your position and return back. Is your task clear? Take the starting position and prepare for measurements."

2.4 Statistical Analysis

Data were analyzed by Statistica 12 for Windows operating system. Mean, standard deviation, range, variability coefficient, skewness and kurtosis were used as descriptive parameters, supported by the Pearson correlation coefficient, Spearman-Brown alpha, Cronbach`s alpha and Spearman-Brown (standardized) alpha in validation analysis.

3 RESULTS

Comparing parameters of descriptive variables - *height* (classically and digitally measured), it is evident that the average results of digitally measured heights do not differ significantly from the classically measured heights, which were followed by the standard deviation values (Graph 1), the coefficient of variation and form of distribution parameters (Table 1 - in Addition 1).



Graph 1: Descriptive parameters for variables of height, left forearm length and left lower leg length.

The descriptive parameters of variables - *left forearm length* and *left lower leg length* (classically and digitally measured), indicate significant differences (lower values) between average results digitally measured in relation to results in the classically measured variables (Table 1). The value of parameters of standard deviation (Graph 1) and the total range of digitally measured results are lower than classically measured lengths of the left forearm. The difference is attributed to different reference points used in two measurement methods.

Table 1: Descriptive parameters for variables hight, left forearm and left lower legTable 1: Descriptive parameters for variables hight, left forearm and left lower leg.

	Mean.	Std.Dev.	Minimum	Maksimum	Range	Var Coef..	Skewness	Kurtosis
A_Height	176,41	8,19	159,00	192,30	33,30	4,64	-0,14	-0,30
D1-[1]	177,06	8,12	160,46	197,69	37,23	4,59	0,07	0,05
D2-[1]	176,10	8,48	159,50	197,89	38,39	4,82	0,11	0,05
D3-[1]	176,11	8,31	159,13	196,92	37,80	4,72	0,04	-0,06
A_L_forearm	26,94	1,77	23,10	30,70	7,60	6,57	0,07	-0,15
D1-[15]	23,92	1,40	21,35	26,47	5,12	5,87	0,01	-0,63
D2-[15]	23,77	1,48	21,00	26,38	5,38	6,21	0,02	-0,84
D3-[15]	23,56	1,55	20,33	28,42	8,08	6,59	0,45	0,98
A_L_lower leg	39,36	2,71	32,60	46,30	13,70	6,89	-0,08	0,07
D1-[4]	35,11	2,59	30,18	41,32	11,13	7,37	0,16	-0,03
D2-[4]	34,93	2,35	30,32	42,00	11,68	6,72	0,24	0,50
D3-[4]	35,74	2,38	30,40	41,30	10,90	6,67	-0,07	-0,15

A_height *Standard measured height,* ***D1-[1]*** *Digitally measured height at distance of 200 cm,* ***D2-[1]*** *Digitally measured height at distance of 230 cm,* ***D3-[1]*** *Digitally measured height at distance of 260 cm.;* ***A_L_forearm*** *Standard measured length of left forearm,* ***D1-[15]*** *Digitally measured length of left forearm at distance of 200 cm,* ***D2-[15]*** *Digitally measured length of left forearm at distance of 230 cm,* ***D3-[15]*** *Digitally measured length of left forearm at distance of 260 cm.;* ***A_L_lower leg*** *Standard measured length of left lower leg,* ***D1-[4]*** *Digitally measured length of left lower leg at distance of 200 cm,* ***D2-[4]*** *Digitally measured length of left lower leg at distance of 230 cm,* ***D3-[4]*** *Digitally measured length of left lower leg at distance of 260 cm.*

Reliability of a relatively new digital measuring instrument was determined by the method of internal consistency (appropriate for this type of composite measuring instrument). Measures of internal consistency for digitally measured variables: *body height*, *left forearm length* and *left lower leg length* (measured six times at each of three distances - Table 2) demonstrate high reliability. (Cronbach alpha, the standardized alpha 0.995 to 0.997) and the average inter-item correlation (0.973 to 0.985), indicate a high internal consistency between items related to digitally measured heights. Reliability coefficients for digitally measured left forearm and lower leg lengths was slightly lower (greater differentiation in average inter-item correlations).

Simulation of the possible impact of reduced number of items indicated a decline of reliability (e.g. in digitally measured height at a distance of 200 cm, and after removing the last 3 items, Cronbach alpha reduced its value to 0.987). Same simulation for digitally measured left forearm length revealed a value reduction of Cronbach alpha from 0.9777 to 0.952, which could consequently result in an increase of the standard error of measurement.

Analysis of differences between the descriptive parameters (Table 3 – in addition 1, with the accompanying graph 2) of classically and digitally measured variables (body height, left forearm length and left lower leg length), reveal the size of systematic and non-systematic errors and its effect on measurement results. Increased variability (standard deviation, total range, coefficient of variation) indicate a presence of large quantities of non-systematic errors probably caused by technical /environmental factors. Differences in heights and left forearm lengths increase by distance, while differences in lower leg lengths relatively decrease in variability by an increase in distance.

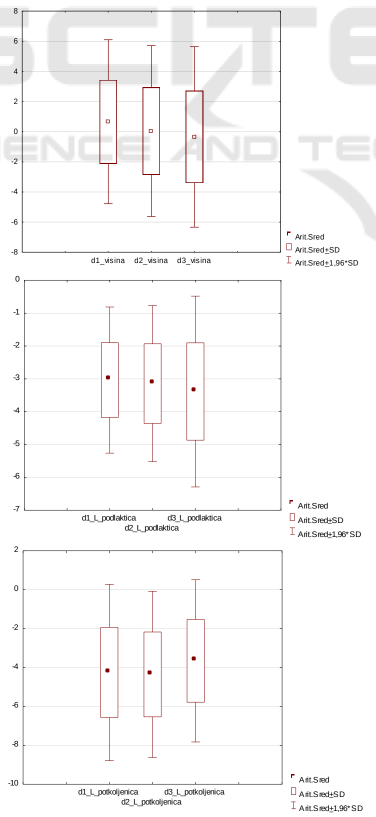
Table 2: Coefficients of reliability for variables hight, left forearm and left lower leg.

	Cronbach alpha	Standardiz. Alpha	Average inter-item correlation
D-1[1]	0,995	0,995	0,973
D-2[1]	0,997	0,997	0,985
D-3[1]	0,997	0,997	0,985
D-1[15]	0,983	0,983	0,914
D-2[15]	0,990	0,991	0,952
D-2[15]	0,990	0,990	0,949
D-1[4]	0,978	0,979	0,887
D-2[4]	0,987	0,988	0,932
D-3[4]	0,97	0,97	0,886

Table 3: Differences in descriptive parameters for variables hight, left forearm and left lower leg.

	Mean.	Std.Dev.	Minimum	Maksimum	Range	Var Coef..	Skewness	Kurtosis
d1_height	0,660000	2,775005	-5,39333	6,603333	11,99667	420,455	0,056505	-0,341834
d2_height	0,044864	2,892967	-7,37500	5,585000	12,96000	6448,312	-0,107315	-0,006973
d3_height	-0,345400	3,054981	-6,52833	5,328333	11,85667	-884,476	0,016068	-0,688745
d1_L_forearm	-3,03700	1,134939	-5,56667	-0,866667	4,700000	-37,3704	-0,400635	-0,146473
d2_L_forearm	-3,14354	1,211910	-7,11667	-0,916667	6,200000	-38,5524	-0,886378	1,451982
d3_L_forearm	-3,38433	1,481333	-7,21667	-0,483333	6,733333	-43,7703	-0,697201	0,538982
d1_L_lower leg	-4,25300	2,312616	-9,9333	2,716667	12,65000	-54,3761	-0,160595	1,364843
d2_L_lower leg	-4,35306	2,180120	-10,2167	3,400000	13,61667	-50,0825	0,183605	3,541605
d3_L_lower leg	-3,65567	2,126289	-9,2000	2,916667	12,11667	-58,1642	0,060458	1,395540

d1_height *– variable of difference between digitally and standard height measure at distance of 200cm,* ***d2_height*** *– variable of difference between digitally and standard height measure at distance of 230cm,* ***d3_height*** *– variable of difference between digitally and standard height measure at distance of 260cm.;* ***d1_L_forearm*** *– variable of difference between digitally and standard left forearm measure at distance of 200cm,* ***d2_L_forearm*** *– variable of difference between digitally and standard left forearm measure at distance of 230cm,* ***d3_L_forearm*** *– variable of difference between digitally and standard left forearm measure at distance of 260cm;* ***d1_L_forearm*** *– variable of difference between digitally and standard left lower leg measure at distance of 200cm,* ***d2_L_forearm*** *– variable of difference between digitally and standard left lower leg measure at distance of 230cm,* ***d3_L_forearm*** *– variable of difference between digitally and standard left lower leg measure at distance of 260cm.*



Graph 2: Differences in descriptive parameters for variables height, left forearm length and left lower leg length.

The correlation matrix between classically and digitally measured variables (Table 4) reveals statistically significant correlation coefficients. It is noticeable that the correlations in variables of *height* and of *left forearm length* decrease proportionally with distance, while in the variable *left lower leg length* increase proportionally with higher distances. Although relatively high, coefficient values of correlations between classically and digitally measured variables are not sufficient for this type of measuring instrument.

Table 4: Correlations between classically and digitally measured *body height*, *left forearm length* and *left lower leg length.*

	D1	D2	D3
A Height	0,944	0,940	0,935
A_L_ *forearm*	0,776	0,745	0,614
A_L_ *lower leg*	0,616	0,646	0,664

(A_height, A_L_ *forearm* & A_L_ *lower leg* - clasically measured *body height*, *left forearm length* and *left lower leg length*, D1 - digitally measured at 200 cm distance, D2 - digitally measured at 230 cm distance, D3 - digitally measured height at 260 cm distance.)

4 CONCLUSIONS

With regard to study aims, in these initial findings we conclude:

a) Digital measurements with Kinect are not appropriate for clinical trials demanding high precision. There is no statistical evidence that could differentiate distances of examinee from Kinect sensor in order to define optimal distance (as long as subject stands within Kinect's range)
b) Recommended number of measurements with Kinect is 6,
c) Reliability of Kinect is excellent for height and acceptable for left forearm length and left lower leg length, and
d) Small errors occur due to clothing, possibly due to illumination, and sensor height and distance, which is in line with previous research (e.g. Espitia et al., 2015)

For improving digital measurement of human body it is advisable to:

1. Determine correction factors for further reduction of measurement error,
2. Determine metric characteristics for Kinect using other anthropometric measurements,
3. Standardize protocols for Kinect measurements with regard to specific environment conditions (e.g. indoor vs outdoor), and
4. Include gender differentiators within a larger sample in order to generalize phenomena with better accuracy.

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