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# Markerless Camera System vs. Marker Based System: Which is the most repeatable?

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## SUMMARY
Low-cost markerless camera system is available on the market. Originally developed for games these devices could be used in clinics (rehabilitation, motion analysis…). This study evaluated the repeatability of such device compared to state-of the art stereophotogrammetric device.

## INTRODUCTION
Repeatability is the degree of agreement between measurements conducted by the same observer. Repeatability is one of the major issues when developing new devices especially in clinical settings where patient follow-up request robust measurement methodologies. The recent availability of low-cost single Markerless camera Systems (MLS) for 3D vision provides opportunities for low-cost applications in biomechanics and revalidation sciences. The currently available Kinect software, provides a crude skeleton (i.e., a stick figure model composed of 20 points), with sufficient accuracy for tracking movements in games. Although some works have studied the precision of the Kinect [1-2] no information can be found about repeatability of measurements. Marker Based System (MBS) are commonly used in clinics [3]. Precision and reproducibility of MBS are highly sensitive to markers' placement [4]: discrepancies will appear if markers are not placed exactly on the same anatomical locations of the subject undergoing the analysis. The aim of this work was to evaluate the repeatability of a low cost MLS (based on a fully automated method for marker position estimation) in comparison with gold standard MBS (requiring manual palpation to set markers on the subject prior to motion analysis) for assessing segment lengths.

## METHODS
Forty healthy adults (25 ± 7 years old, 174 ± 8 cm height, 70 ± 11 kg weight, 23 ± 3 of BMI, 16 women) were recruited to participate in this study. This study was approved by the Ethics Committee of Erasme Hospital (CCB: B406201111989) and written informed consent was obtained from all subjects prior to participation in the study.
The MLS used was the Kinect camera (PrimeSense's 3D sensor). The skeleton model (stick figure) - used to estimate segments' length - was obtained using the Microsoft Kinect SDK software (Beta 1). The camera was placed on a tripod at 1.5 meter from the ground.
In order to compare repeatability a stereophotogrammetric system (Vicon, 8 MXT40s cameras, Vicon Nexus software) was used (MBS). Subjects were equipped with 31 markers set in order to reconstruct a skeleton as similar as possible to the one obtained from MLS.
Subjects were placed at a distance of 2 meters from the camera, theses distances are recommended for a good utilization of the device [5]. Subjects were asked to remain motionless in front of the camera. Data were recorded simultaneously with MLS and MBS.
To assess Intra-Session repeatability five trials were recorded during one session. The same protocol was repeated one week after to assess inter-session repeatability. The same operator performed all measurements.
Segments' lengths were computed: arm, forearm, hand, thigh, shank, foot and total height.
Intra-Class Correlations (ICC) were computed to assess Intra and Inter repeatability for both devices. Coefficient of Variation (as CV=(Standard-deviation/Mean)*100) was also computed.

## RESULTS AND DISCUSSION
ICC results for Inter-Session are presented in Table1, ICC for Intra-Session in Table 2 and CV in table 3.
For both devices, all ICC values for inter-session repeatability are higher than 0.8 (mean ICC=0.88 and 0.87 for MLS and MBS respectively) indicating a satisfactory agreement between measurements performed during session 1 and 2.

**Table 1: ICC results for MLS and MBS Inter-Session repeatability**

| Inter-Session | MLS | MBS |
|---|---|---|
| Arm | 0.85 [0.72 0.92] | 0.91 [0.83 0.95] |
| Forearm | 0.91 [0.82 0.95] | 0.92 [0.85 0.96] |
| Hand | 0.82 [0.66 0.91] | 0.85 [0.72 0.92] |
| Thigh | 0.97 [0.94 0.98] | 0.78 [0.58 0.88] |
| Shank | 0.81 [0.64 0.90] | 0.95 [0.91 0.98] |
| Foot | 0.86 [0.80 0.91] | 0.89 [0.82 0.94] |
| Height | 0.97 [0.94 0.99] | 0.82 [0.62 0.89] |

For trial to trial repeatability (5 trials), all ICC were higher than 0.89 (mean ICC for Session 1 and 2=0.94) for MLS and higher than 0.95 (mean ICC for Session 1 and 2=0.98) for MBS

Concerning CV, mean CV were 8.9 and 9.5% for MLS during Session 1 and 2 respectively. For MBS mean CV were 7 and 7.4% during Session 1 and 2 respectively.

Due to high accuracy with respect to the position of the markers in 3D space [6], intra-session repeatability is almost perfect for MBS (mean ICC=0.98). However MLS shows also very high value (mean ICC=0.94)
Since MBS are highly sensitive to markers placement [4] inter-session repeatability was the most interesting point to compare repeatability of both devices. ICC values were the same (0.88 for MLS and 0.87 for MBS) for both devices.

CV are higher for MLS, these difference are due to relatively poor results obtained for hand and thigh.

## CONCLUSIONS

Both devices show excellent repeatability. Results of this study suggested that a cost-effective, relatively easy to use and portable single markerless camera offers the same repeatability of expensive, time-consuming and non-transportable marker-based device. Precision of this device has been evaluated and precision is good [7]. This should open up new perspectives in motion assessments. A running study is assessing the MLS reproducibility, i.e., degree of agreement between measurements conducted by different observers.


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**Table 2: ICC results for MLS and MBS Intra-Session repeatability during session 1 and 2**

| Intra-Session | MLS | | MBS | |
|---|---|---|---|---|
| | Session 1 | Session 2 | Session 1 | Session 2 |
| Arm | 0.92 [0.87 0.95] | 0.89 [0.82 0.94] | 0.99 [0.99 0.99] | 0.99 [0.99 0.99] |
| Forearm | 0.91 [0.85 0.95] | 0.91 [0.85 0.95] | 0.99 [0.99 0.99] | 0.98 [0.98 0.99] |
| Hand | 0.89 [0.79 0.94] | 0.92 [0.96 0.95] | 0.99 [0.99 0.99] | 0.99 [0.99 0.99] |
| Thigh | 0.99 [0.98 0.99] | 0.99 [0.98 0.99] | 0.97 [0.96 0.99] | 0.99 [0.99 0.99] |
| Shank | 0.96 [0.93 0.97] | 0.93 [0.88 0.96] | 0.99 [0.99 0.99] | 0.95 [0.92 0.97]] |
| Foot | 0.93 [0.91 0.95] | 0.92 [0.90 0.95] | 0.97 [0.96 0.99 | 0.98 [0.97 0.99] |
| Height | 0.99 [0.98 0.99] | 0.99 [0.98 0.99] | 0.99 [0.99 0.99] | 0.97 [0.95 0.98] |

**Table 3: Coefficient of Variation (expressed in percentage) for MLS and MBS during Session 1 and 2**

| CV | MLS | | MBS | |
|---|---|---|---|---|
| | Session 1 | Session 2 | Session 1 | Session 2 |
| Arm | 5.3 | 7.5 | 6.1 | 5.4 |
| Forearm | 7.2 | 7.9 | 6.6 | 6.5 |
| Hand | 14.9 | 16.1 | 10.1 | 11.3 |
| Thigh | 11.5 | 10.8 | 5.7 | 6.5 |
| Shank | 7.8 | 7.6 | 6.4 | 7.4 |
| Foot | 10.3 | 10.2 | 8.9 | 9.9 |
| Height | 5.9 | 6.1 | 5.5 | 5.2 |