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Validation of an image-based body measurement system for sitting posture

Final report

Pierre Meunier

Robert Mertens

Defence R&D Canada – Toronto
Technical Report
DRDC Toronto TR 2005-264
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Abstract

In 1996, DCIEM initiated a preliminary study to explore the feasibility of using computer controlled digital cameras as a means of acquiring accurate anthropometric data on an automated basis. This system underwent several stages of development that culminated in a commercially available system known as the BoSS XXI (Body Scanning System). Validation studies of the BoSS XXI system's predecessor (the Intelligent Clothing and Equipment Sizing System (ICESS)) indicated that the accuracy and precision of the direct linear measurements were sufficiently high to extend the use of this technology to seated posture measurements.

The first development iteration demonstrated the feasibility of performing sitting posture measurements using the BoSS XXI technology, but the performance of some algorithms, namely those used for locating the eyes, was found to be less than satisfactory. The problems identified in that attempt were solved in a second iteration, as demonstrated by the results published in this report. The validation study involved 53 subjects: 28 males, 25 females. Manual and automated measurements of sitting height, eye height sitting, acromial height sitting, knee height sitting, and buttock-knee length were compared. The results showed that the correlation between expert manual measurement and the automated measurements was greater than 0.95 for all variables, and that the MAD[1] ranged from 4 to 8 mm, which was within the maximum allowable measurement error for all but one variable.

[1] Mean Absolute Difference

Résumé

En 1996, une étude préliminaire fut lancée pour explorer la faisabilité d'utiliser une caméra numérique anthropométriques précises sur une base automatisée. Ce système a passé par plusieurs étapes de développement qui ont abouti à un système commercial nommé DSCo XXI (Dispositif Scanneur Corporel). Les études de validation du prédécesseur du DSCo XXI, le Système Intelligent de Classement d'Habillement et d'Équipement, ont indiqué que l'exactitude et la précision des mesures linéaires directes étaient suffisamment élevées pour envisager d'autres applications comme celle de prendre des mensurations assises.

La première itération du développement a démontré la faisabilité d'effectuer des mensurations en position assise en utilisant la technologie du DSCo XXI, mais l'exécution de quelques algorithmes, à savoir ceux utilisées pour identifier les yeux, se sont avérées moins que satisfaisants. Les problèmes identifiés dans cette tentative ont été résolus dans une deuxième itération, comme le démontre cette étude. L'étude de validation a impliqué 53 sujets: 28 hommes, 25 femmes. Des mensurations manuelles et automatisées de la taille assis, hauteur yeux assis, hauteur acromion assis, hauteur genou assis, et de la portée arrière genou assis ont été comparées. Les résultats ont montré que la corrélation entre les mensurations manuelles expertes et les mensurations automatisées était de 0,95 et plus pour toutes les variables, et que la différence moyenne absolue de 4 à 8 millimètres se situait à l'intérieur des limites d'erreur permises pour toutes les variables sauf une.

Executive summary

In 1996, DRDC Toronto initiated a preliminary study to explore the feasibility of developing a low-cost, automated system for the measurement and sizing of individuals. The purpose of this system was to help make the management and distribution of clothing and equipment within the Canadian Forces more cost-effective by using high technology.

The concept was based on the use of computer-controlled digital cameras taking front and side pictures of individuals. The pictures were processed using advanced image processing techniques to extract the body contour and the necessary anatomical landmarks required to make accurate measurements. Those measurements were then used to select the appropriate size of clothing or equipment for the individual being measured.

An extension of this system was proposed as a means of measuring individuals in a seated posture. A preliminary development and validation effort was started in 2001 aimed at exploring the suitability of this approach. The results showed that while the levels of accuracy and precision were within acceptable limits, some of the landmarking algorithms needed further work. The algorithms responsible for poor measurement performance were reviewed as part of a second effort to improve the performance of the system

The results of this validation study show a close correspondence between the measurements taken by both measurers and those taken by the automated system; the correlations ranged from 0.95 to 0.99. Not surprisingly, the highest correlations were obtained in instances where the landmarks were easily translated to computer-based algorithms and where human measurements are highly reliable. The measurements included in that category were sitting height and buttock-knee length, and the correspending correlations were around 0.99. When the conditions are not as favourable on the human and machine side of the measurements, the correlations dropped somewhat but remained quite respectable, ranging from 0.95 to 0.98.

Although the system could benefit from improvements to its eye location algorithm, it is concluded that the system produces measurement accuracies comparable to those of trained observers and could be used successfully as a tool in the pilot selection process.

Meunier, P., Mertens, R. 2005. Validation of an image-based body measurement system for sitting posture. Final Report. .DRDC Toronto TR 2005-264. Defence R&D Canada – Toronto.

Sommaire

En 1996, le RDDC Toronto a lancé une étude préliminaire pour explorer la faisabilité de développer un système automatisé peu coûteux pour la mesure et le classement par taille des individus. Le but de ce système était d'améliorer la gestion et la distribution de l'habillement et de l'équipement des Forces Canadiennes, pour les rendre plus rentables en employant une technologie de pointe.

Le concept est basé sur l'utilisation d'appareils photo numériques commandés par ordinateur prenant des photos du devant et de côté des individus. Les images sont traitées par ordinateur en utilisant des techniques avancées pour extraire la silhouette du corps et identifier les repères anatomiques nécessaires pour prendre des mensurations précises. Ces mesures sont alors employées pour choisir la taille appropriée de vête- ment ou l'équipement pour l'individu mesuré.

On a proposé une extension de ce système pour prendre des mesures assises. Un effort préliminaire de développement et de validation ont été entrepris en 2001 ayant pour but d'explorer la convenance de cette approche. Les résultats ont montré que bien que les niveaux d'exactitude et de précision étaient dans des limites acceptables, certains des algorithmes de positionnement de repères anatomiques nécessitaient un peu plus de travail. Les algorithmes responsables furent passés en revue et améliorés pour un deuxième effort de validation du système, ci rapporté.

Les résultats la présente étude de validation montrent une correspondance étroite entre les mesures prises par les deux observateurs et pelles prises par le système automatisé; les corrélations se sont de 0,95 à 0,99. Comme prévu, les corrélations les plus élevées ont été obtenues là où les repères anatomiques sont facilement identifiables par traitement d'image ainsi que par les méthodes de marquage conventionnelles. Les mesures incluses dans cette catégorie sont la taille assis et la longueur fessier genou, avec des corrélations de l'ordre de 0,99. Dans des conditions moins favorables, tant du côté humain comme du côté machine, les corrélations ont chuté légèrement mais sont demeurées tout à fait respectables, soit entre 0,95 et 0,98.

Bien que le système puisse bénéficier d'améliorations à son algorithme de localisation de d'oeil, il est conclut que le système performe de façon comparable à des observateurs qualifiés et pourrait être employé avec succès dans le processus de sélection de pilotes.

Meunier, P., Mertens, R. 2005. Validation of an image-based body measurement system for sitting posture. Final Report. .DRDC Toronto TR 2005-264. Defence R&D Canada – Toronto.

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Introduction

In 1996, DRDC Toronto initiated a preliminary study to explore the feasibility of developing a low-cost, automated system for the measurement and sizing of individuals (Meunier and Yin, 2001). The purpose of this system was to help make the management and distribution of clothing and equipment within the CF more cost-effective by using commercial-off-the-shelf (COTS) technology.

The concept was based on the use of computer-controlled digital cameras taking front and side pictures of individuals. The pictures were processed using advanced image processing techniques to extract the body contour and the necessary anatomical landmarks required make accurate measurements. Those measurements were then used to select the appropriate size of clothing or equipment for the individual being measured.

An extension of this system was proposed as a means of measuring individuals in a seated posture. A preliminary development and validation effort was started in 2001 aimed at exploring the suitability of this approach. The results showed that while the levels of accuracy and precision were within acceptable limits, some of the landmarking algorithms needed work (Tai and Milgram, 2002). The algorithms responsible for poor measurement performance were reviewed as part of a second effort to improve the performance of the system. This report provides the results of the validation study conducted to assess the performance of the revised seated posture measurement system.

This work was approved by the DRDC Human Research Ethics Committee (HREC).

Method

Hardware

The seated posture measurement system is composed of two Olympus Camedia C-4000 cameras operated at a resolution of 1280 x 960 pixels, a blue backdrop with embedded calibration markers, and a computer (Figure 1). The system takes simultaneous front and side pictures of individuals sitting on a bench equipped with an adjustable footrest, as shown in Figure 2.

The digital cameras were set approximately 4m from the back panel of the sitting posture booth. The cameras were set approximately 1m from the floor. The BoSS-21 software default settings were used for the operation and calibration of the cameras. The cameras were calibrated each day prior to testing and following two to three hours of inactivity.

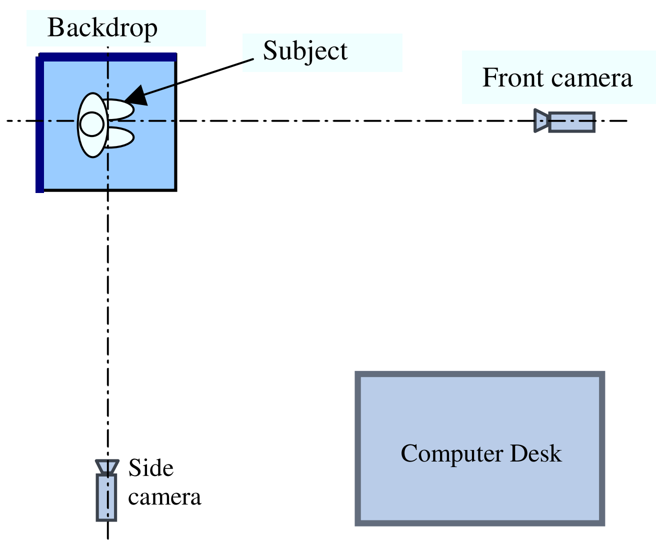

Figure 1 Plan view of automated measurement set-up.

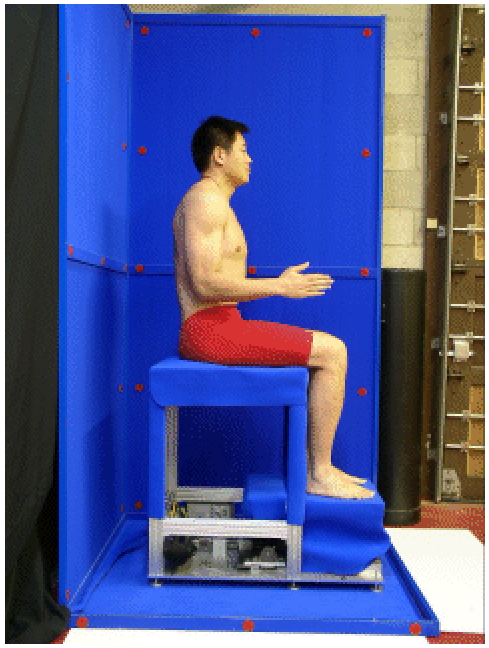

Figure 2 Side view.

Observer training

Two observers, one male and one female, were trained to take the measurements using traditional anthropometric instruments. The measurements were taken in accordance with the definitions described in the 1997 survey of the land forces (Chamberland et al., 1998). Males were landmarked and measured by the male observer, and the females by the female observer.

Both measurers assessed the same individual weekly, same day of the week and time, to demonstrate (1) acceptable intra- and inter-observer variability and (2) to demonstrate the absence of technique drift over time. Ten measurements of each variable were made by each measurer by alternating measurements to prevent slight postural changes over time from skewing the results. Table 1 summarizes the performance of the observers during the training phase (weeks 1 through 4) and during the trial period (weeks 5 through 7). During the trial weeks, the observers were well within the allowable measurement error for all but one variable, where they were off by only 0.1 cm.

Table 1 Observer error estimates

Anthropometric Variable	*Allowable error (cm)*	*Mean Absolute Difference between the two measurers (cm)* Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Knee height sitting	**0.2**	0.1	0.2	0.1	0.3*	0.1	0.3*	0.2
Acromial height sitting	**0.9**	0.3	0.4	0.3	0.4	0.4	0.2	0.3
Eye height sitting	**0.8**	1.6*	0.7	1.2*	0.6	0.3	0.5	0.3
Sitting height	**0.6**	0.3	0.3	0.3	0.2	0.3	0.3	0.4
Buttock-Knee length	**0.6**	0.2	0.2	0.4	0.3	0.5	0.4	0.4

* greater than allowable error

Test protocol

The test protocol included the following steps:

(1) Completion of consent and pay forms
(2) Subjects were asked if they had any questions prior to commencement of testing
(3) Subjects changed into the green combat briefs and red swim caps provided as well as the red sports bras (female subjects)
(4) Three landmarks were placed on the subject with a pen, (1) top of patella with quadricep muscles relaxed, (2) side of face in line with the corner of the eye, and (3) the top of the acromion process
(5) Traditional measurements were made of the following variables in the following order: stature, kneeling height, functional leg length, knee height sitting, acromial height sitting, eye height sitting, sitting height, and buttock-knee length. Subjects were instructed to sit tall and look straight ahead with their arms set at 90 degrees. A picture of the correct posture was placed above the front camera for subjects to use as a guide and as a target for looking straight ahead. Subjects were allowed to relax their posture between each measurement.
(6) Pictures were taken with the subjects in the correct posture
(7) Alcohol swabs and a mirror were provided so that the subjects could remove the pen landmarks
(8) Subjects changed into their street clothes/uniforms and a copy of their results were provided to them

Results

Comparisons of manual measurements, taken by the two observers, and those of the image-based system are shown in Figures 3 to 7. The corresponding correlations are listed in Table 2.

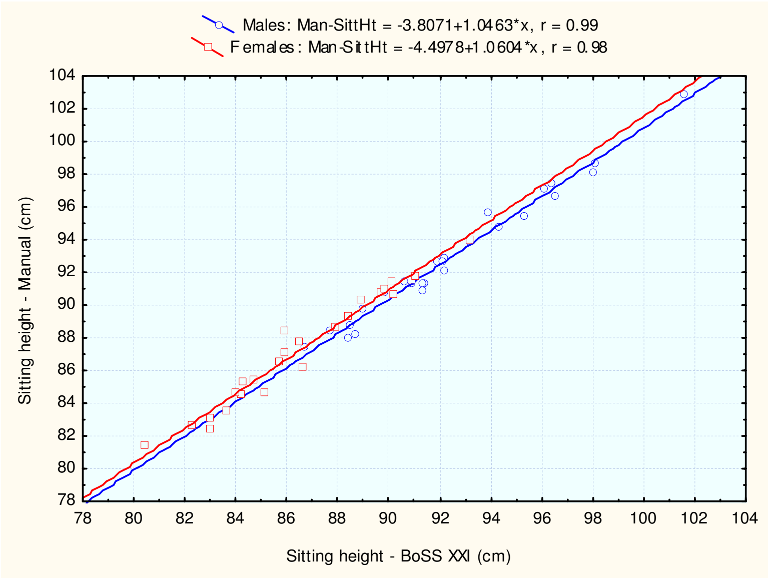

Figure 3 Manual vs BoSS XXI measurements for Sitting Height

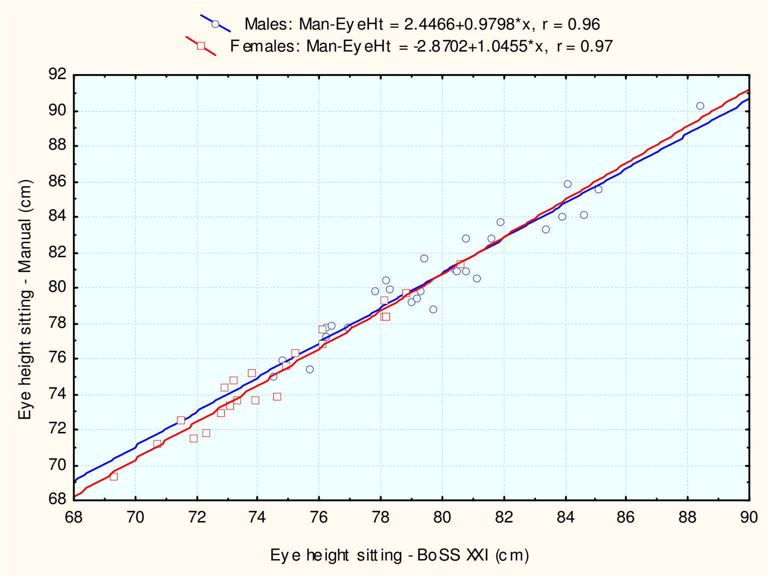

Figure 4 Manual vs BoSS XXI measurements for Eye Height Sitting

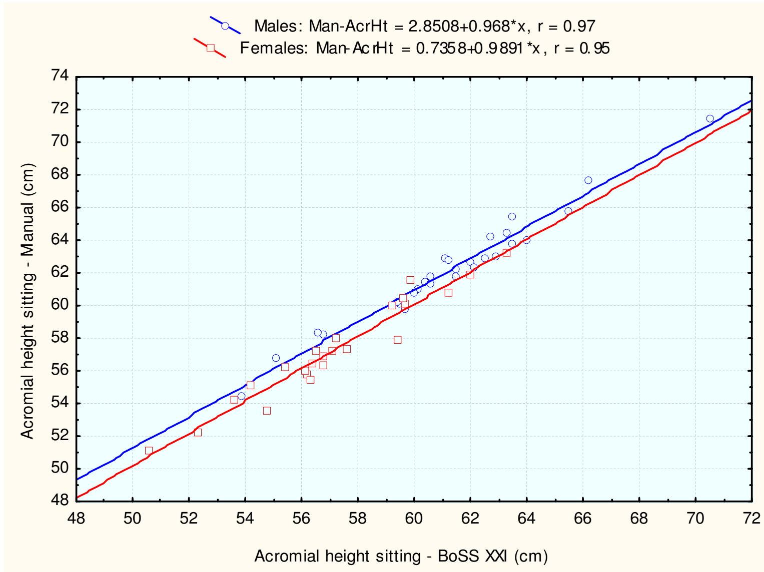

Figure 5 Manual vs BoSS XXI measurements for Acromial Height Sitting

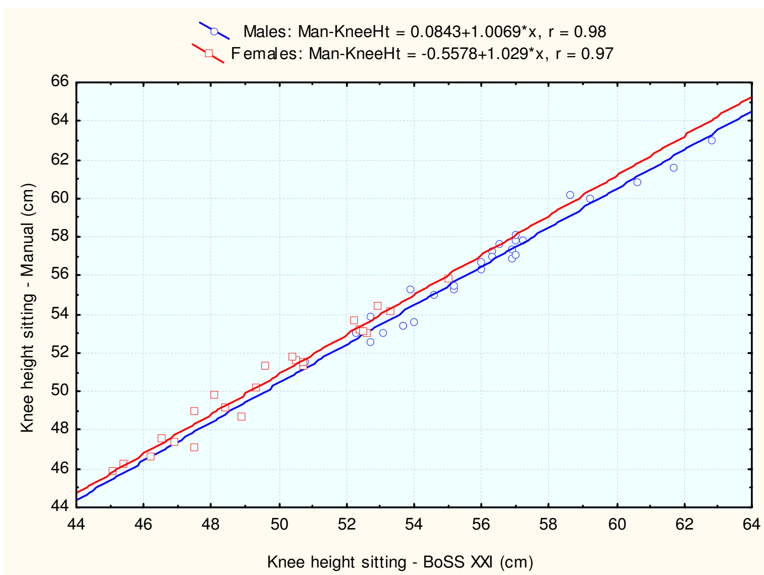

Figure 6 Manual vs BoSS XXI measurements for Knee Height Sitting

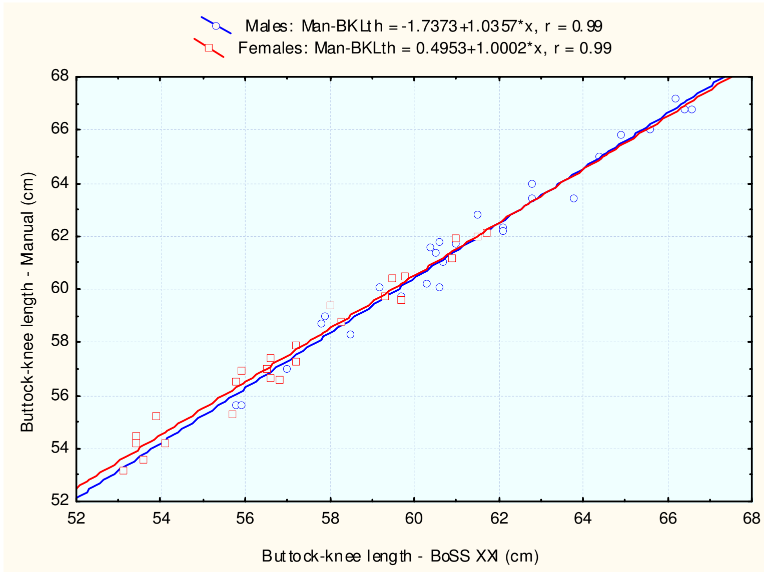

Figure 7 Manual vs BoSS XXI measurements for Buttock-Knee Length

Table 2 Correlation between manual and BoSS XXI measurements.

Variable	***Pearson correlation***	
	Male	***Female***
Knee Height	0.98	0.97
Acromial Height Sitting	0.97	0.95
Eye Height sitting	0.96	0.97
Sitting Height	0.99	0.98
Buttock-knee Length	0.99	0.99

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Discussion

The results of this validation study show a close correspondence between the measurements taken by both measurers and those taken by the automated system, with correlations ranging from 0.95 to 0.99. Not surprisingly, the highest correlations were obtained in instances where the landmarks were easily translated to computer-based algorithms; measurements such as sitting height and buttock-knee length fall in this category, and had correlations around 0.99. Bony landmarks, on the other hand, are more difficult and sometimes impossible to locate through image processing techniques, and are therefore subject to greater discrepancy when compared with manual measurements. This is probably one of the main reasons for the slightly lower correlations (Pearson r of 0.95 to 0.98) observed for acromial height and knee height sitting.

The Eye Height Sitting algorithm performed reasonably well achieving Pearson correlations of 0.96 and 0.97 for male and female data respectively. However, there is room for improvement, as it identified the eye correctly only about 75% of the time. Improvements to the eye location algorithm are possible and should be implemented as soon as possible in order to reach the accuracy the system is capable of. It is important to note that the system operator can interactively move any misplaced landmark with a click of the mouse after the image is processed. Although this route is always open, in the long run, it is preferable to improve the algorithm than to rely on operator involvement.

As a means of characterizing the overall performance of the system, the mean absolute difference (MAD) between manual and automated measurements was calculated for each anthropometric variable and compared to the maximum allowable error (MAE) for each dimension. The concept of maximum allowable error is related to the fact that inter- and intra-observer errors are burdensome conditions in anthropometry, which cannot be eliminated. However, with good experience and practice it is possible to minimize the magnitude of the error. Each dimension has its own challenges in terms of accuracy and precision, be they due to landmarking soft tissue deformation, breathing posture, etc. Hence, each one needs to be assessed individually. Gordon et al., 1989) published a set of such limits for the variables measured in the US Army survey as a means of controlling the quality of the data collected. The MAEs listed in that report, and used in the foregoing discussion, reflect what well-trained observers are able to achieve - as well as the level of error one needs to accept in the data.

It is important to remember also that the MAE values may or may not be of practical significance, depending on the dimension's variability in a given population or the application's tolerance for error. The ability to measure stature within one millimetre is of little significance when diurnal variation can be of the order of 2 to 3 cm (NASA, 1978).

The results, displayed in Figure 8, show that all measurements fell within what is considered to be the MAE, with the exception of knee height sitting. The reason for the discrepancy in this variable is twofold. Firstly, the MAE listed for knee height sitting does not include landmarking error - this is also the case for the other MAEs listed. Therefore, the low MAE value of 0.2 cm is more a reflection of the ease of measurement of this variable once a landmark is present, since it is relatively free of the common sources of errors such as tissue compression, posture, etc. Secondly, it is very difficult for the automated system to achieve a comparable way of landmarking the knee. For instance, the manual measurement relies on the location and marking of the suprapatella landmark while the subject is standing. As the subject sits, the landmark appears to move relative to the femur and tibia as the skin stretches at the knee. The amplitude of this action varies from person to person, which means that the position of the landmark, and by extension the measurement itself, vary depending on the underlying shape of the thigh. But since the landmark itself is crisp and visible, observers can make the measurement very accurately.

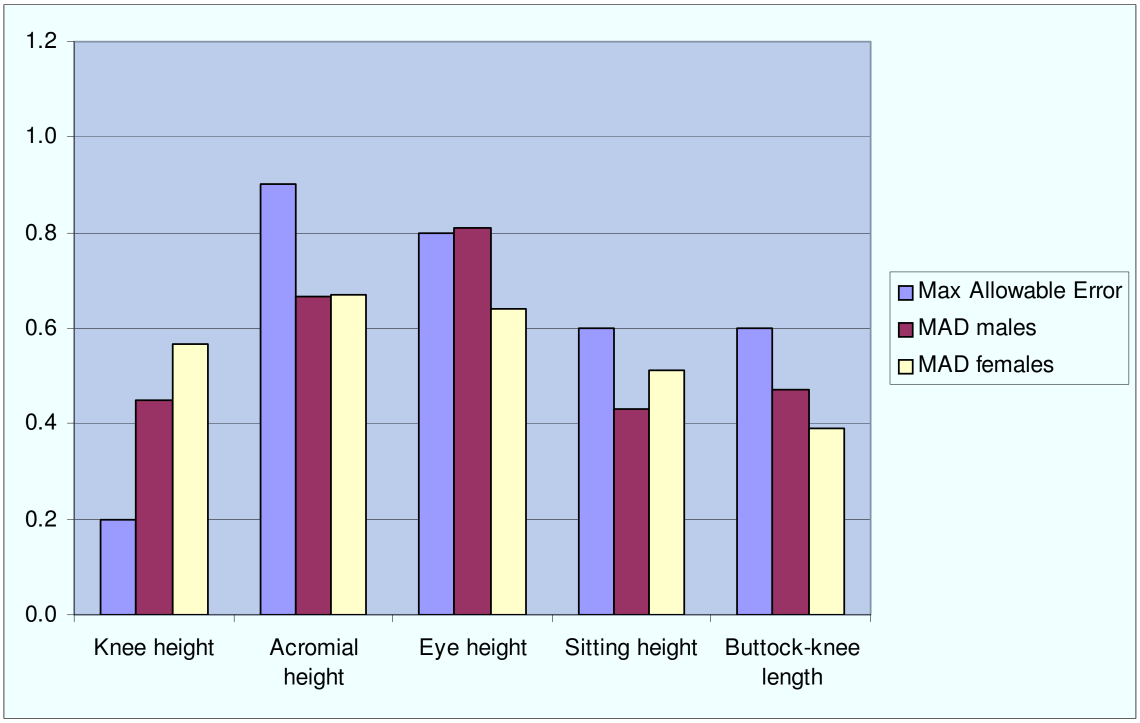

Figure 8 Mean absolute difference (MAD) between manual and computer-based measurements vs Maximum Allowable Error

Image-based systems rely on shape and/or colour to identify the landmarks. In the case of the knee, neither shape nor colour is a reliable means of identifying this landmark due to the lack of features in this area, unless a colour dot can is affixed to locate it. Figure 9 illustrates the nature of the problem with two different knee shapes. It can be seen that for the subject on the left, a slight horizontal misplacement of the top of the knee landmark causes little or no effect on the knee height measurement. For the subject on the right, this same misplacement will have a significant effect on knee height. It is argued that if landmarking error were to be added to the manual measurements, the MADs would be comparable. All things considered, the mean differences between manual and automated measurements (of 4-5 millimeters) are deemed quite acceptable from a practical standpoint.

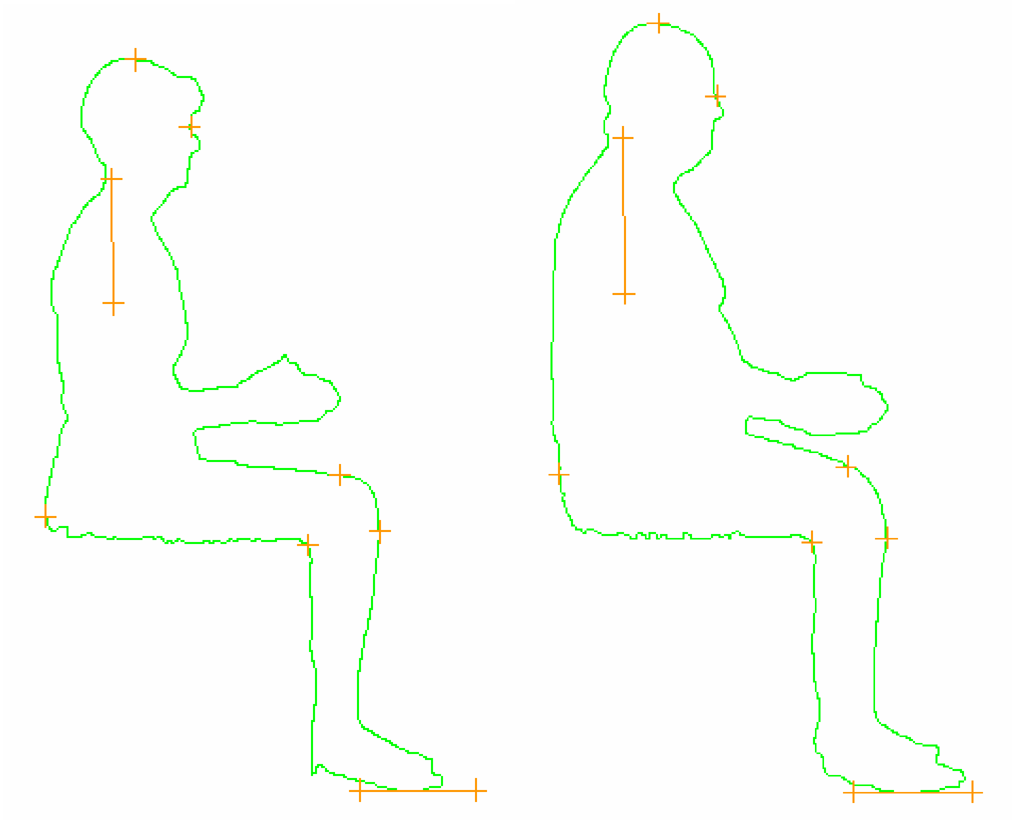

Figure 9 Different cases in automated knee landmarking.

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Conclusions and recommendations

The results of this validation study show that the image-based anthropometric measurement system developed to measure seated postures produces measurement accuracies comparable to those of trained observers, opening the door to applications such as pilot selection.

Although the system operator can correct landmarking errors interactively, it is recommended that improvements be made to the eye location algorithm to minimize measurement error on this critical variable. At the same time, the number of variables measured should be increased to meet the needs of the pilot selection process. These additional variables are: bideltoid breadth, waist depth, and hip breadth.

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List of symbols/abbreviations/acronyms/initialisms

CF	Canadian Forces
DND	Department of National Defence
DSSPM	Director of Soldier Systems Program Management
DRDC	Defence Research and Development Canada
ICESS	Intelligent Clothing and Equipment Sizing System
LF	Land Forces

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(U) anthropometry, BoSS XXI, body scanner, pilot selection

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