An Exploratory Study of Body Measurements Prediction using Machine Learning and 3D Body Scans

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Keywords: machine learning; 3D body scans; body measurements.

3D body scanning has fundamentally enhanced the accessibility of body data available to ergonomics, product developers, and apparel designers (Kershaw, 2013). Most 3D body scanning systems have software that automatically derives measurements from body scans based on pre-determined landmarks, such as the AnthroScan software for Human Solutions 3D scanning systems (Human Solution, 2018; Ashdown, 2020). The landmarks for the automatic measurement extraction process are usually pre-defined using standards (e.g., ISO International Standard, 2017) and programmed into the software (Ashdown, 2020). The automatic measurement extraction from 3D body scans outperforms manual measurements in speed, efficiency, and repeatability (Ashdown, 2020; Kershaw, 2013;). However, there can be a large amount of missing data from automatically extracted measurements from 3D body scans, because of the scan posture, occlusion, and the automatic measurement extraction process (Pleuss, 2019). This could result in incomplete datasets. Besides, past researchers have also documented the inherent difficulties in extracting measurements at the crotch and armpit areas from 3D body scans (Sobhiyeh et al., 2019;). Currently, researchers must resolve those issues by going into each scan file, cleaning the data, placing landmarks, manually taking missing measurements, and adding the measurements back into the dataset. This process is time-consuming and labor-intensive and can change body measurements, and could also introduce measurement problems downstream. Therefore, manual correction is impossible for large-scale anthropometric studies where thousands of scans are collected.

Bishop (2006) defined ML as the development of algorithms that learn from data or experience for making predictions. Recently, there has been increasing use of Machine Learning (ML) in predicting biological information based on body measurements (Costa et al., 2018; Son & Kim, 2020; Rativa et al., 2018), as well as in clothing-related research such as body shape classification and prediction, body measurement prediction, clothing size and fit prediction, and clothing styles recommendation (Costa et al., 2018; Liu et al., 2017a; Liu et al., 2017b; Lu et al., 2021; Markiewicz, et al., 2017; Song et al., 2017; Wang, Lee, Bavendiek, & Eckstein, 2021). It has been reported that the ML predictions were significantly more accurate than that obtained with conventional statistical methods such as linear regression in most situations (Miguel-Hurtado et al., 2016; Rativa et al., 2018;). However, even though some ML methods have been used for body measurements prediction, it is unclear what ML methods are the most suitable for this task. Therefore, this project aims at exploring if ML is a potential tool for filling missing body measurements based on available body measurements extracted from 3D body scan datasets.

Method

After obtaining IRB approval, the researchers first 3D body scanned 245 participants living in a mid-western city in the United States between the ages of six to 75. Then, based on the literature review and the researchers' practice, they identified critical body measurements for apparel product development and extracted them from each of the 245 3D body scans using the automatic measurement extraction function in AnthroScan software. In the cases of missing measurements from usable scans, the researchers experimented with various ML models and then selected the Support Vector Regression (SVR) model over other models for its superior performance for body measurements prediction. The SVR model used known body measurements as training data for predicting missing body measurements.

Mean Square Errors (MSEs), which are average squared differences between predicted measurements and actual measurements, were used to assess the ML prediction accuracy. The lower the value of MSE, the more accurate the prediction is. An MSE less than 0.25 usually indicates good prediction accuracy (James, Witten, Hastie, & Tibshirani, 2013). To thoroughly test the performance of SVR for recovering various categories of missing data, a stochastic sampling was applied by splitting the training and testing data subsets. Therefore, the reported MSEs in the current study are averaged across 50 different random samples.

Results and Discussion

Wrist Circumference had the most significant number of missing automatically extracted measurements (33%) followed by Bust to HPS Distance, Arm Length, Elbow Length, Biceps Circumference, and Elbow Circumference. Each of these four measurements following Wrist Circumference had 20-26 missing values. This finding indicates that 1) the missing data points at the inner side of arms and hands due to occlusion could cause issues in the automatic extraction of relevant measurements from 3D body scans, and 2) the automatic measurements extraction function, including the definitions and landmark placements, of the above mentioned six body measurements in AnthroScan needs improvement. This finding echoes existing finds (Sobhiyeh, et al., 2019;).

The SVR prediction results demonstrated outstanding potential for predicting missing body measurements. First, all the six above-mentioned body measurements, which tended to experience missing data, were well predicted by our SVR model with MSEs much smaller than 0.25. The MSEs are 0.149 for Bust to HPS Distance, 0.160 for Arm Length, 0.145 for Elbow Length, 0.064 for Biceps Circumference, and 0.145 for Elbow Circumference. Besides, 90% of the automatically extracted body measurements were well-predicted with MSEs smaller than

0.25. Third, although the MSEs of Mid-Armhole to Waist Length, Inseam Length, and Upper Thigh Circumference were larger than 0.25, they are still considerably low when compared with previous studies (Liu et al., 2017a; Liu et al., 2017b). Therefore, the current study suggests, in large-scale studies, using ML methods for predicting measurements, particularly missing and difficult-to-extract measurements at the armpit and crotch areas could be of great potential. However, this requires certain preparatory work, such as preparing high-quality training datasets and training/tuning ML algorithms. More future research is necessary in this area.

Conclusion

Based on 245 sets of 3D body scans, the current study is a pioneering work investigating the potential use of SVR model for body measurements prediction in anthropometric and on-body product-related studies. SVR was particularly useful in filling missing body measurements, which were not successfully retrieved from 3D body scans using automatic extraction functions. Thus, this study proves that SVR could dramatically increase the usability of 3D body scans datasets and reduce the time-consuming and labor-intensive work of body measurements extraction from 3D body scans, with the notable exception of hard-to-measure areas around the armpit and crotch.

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