DeepGait: Prediction of Gait Parameters from SMPL Model

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Introduction

Assessing simple gait parameters can help subjects gain valuable knowledge about their health[1]. It can be rather difficult to get a fairly accurate assessment of these parameters without professional help, time consuming video analysis or smart devices such as a smartwatch or smartphone [2]. Our approach uses 4D humans[3] to extract a Skinned Multi-Person Linear model (SMPL)[4] that tracks the rotations of joints through time, which coupled with a neural network allows us to estimate foot contact with the ground. This foot contact along with positional data from 4D humans allows us to automatically analyze the double support time, stride length and asymmetry of a gait. This could potentially lead to early detection of various health issues, improved rehabilitation strategies, and overall better quality of life. Our research is a step forward in making advanced gait analysis more accessible to the general public.

Key points

- We use **4D humans to track poses through time**. 4D humans is a fully transformer-based model that can detect irregular as well as regular poses from videos and extract the corresponding SMPL paramaters, which is a skeletonized model of the human body trained on 3D body scans, allowing the corresponding pose parameters to be extracted.
- With the SMPL parameters, we extract the **rotation matrix of all joints from the SMPL model** and use a **Feed-forward neural network (FFNN)** to fit it to the corresponding foot-to-ground contact. This results in a curve over the video, which estimates the right and left foots contact with the ground.
- The model achieved an **93% accuracy** when measuring foot to ground contact, and using these contact points along with tracking information, we were able to **estimate double support time, stride length and stride asymmetry**.
- The result is a model that can provide gait parameters from a video with an uncomplicated setup and without relying on on-body devices such as a smartwatch or a smartphone.

Data set

Various data was collected by recording people walking from one side of the camera to the other side of the camera. While recording, the camera was held static thereby eliminating interference from camera movement. The data set consists of 24 recordings of people walking (4 men and 20 women). To track the people walking through time, we used 4D humans to extract the SMPL parameters of a person walking.

Video analysis was carried out on the data set with Logger Pro to find the *stride length*, *walking speed* and *gait asymmetry* with a reference measurement. This was done to generate a ground truth data to compare our model to. For training the model, the contact between the ground and the right and/or left foot or *double support* (both feet on the ground) was found by video analysis.

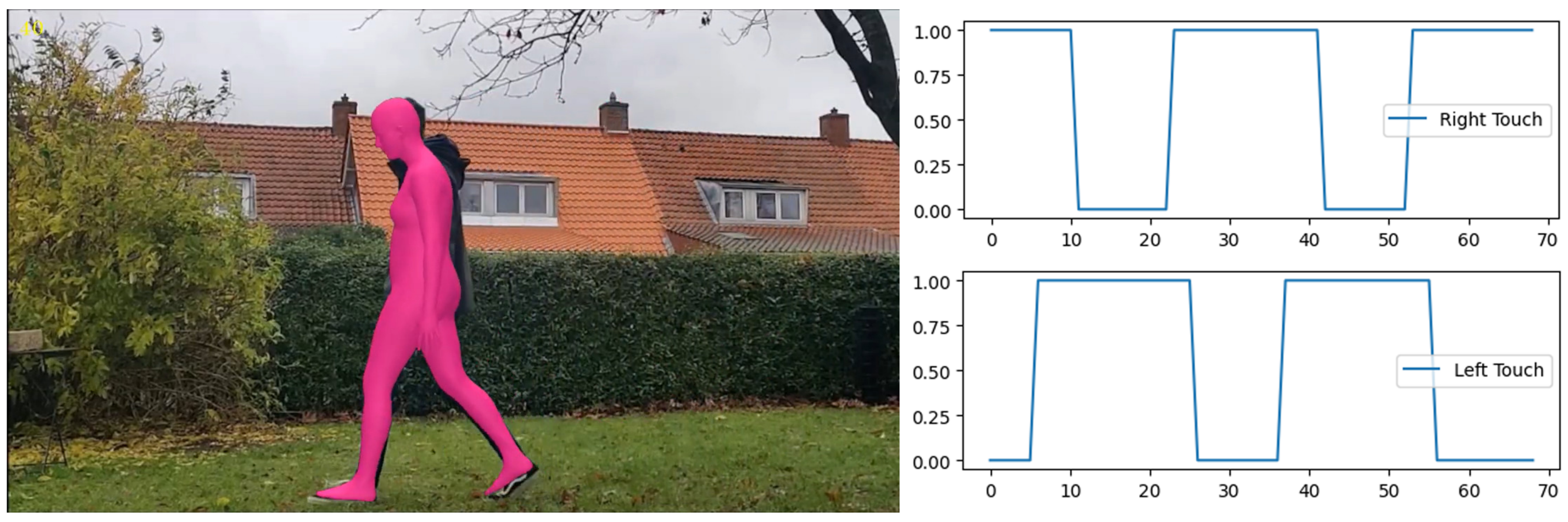

Figure 1: Ground truth for each foot's contact with the ground. The curve is binary where '1' signifies that the foot is in contact with the ground, and '0' indicates that the foot is off the ground. The x-axis represents the progression of frames over time.

Distinguishing between body parts: We found that the SMPL model had problems distinguishing between legs and would switch the left and the right legs if the participant was wearing black clothes. This leads to inaccurate touch estimations, where the touching leg suddenly switches as shown in Figure 2 (left). To mitigate this problem we extracted joint rotations of the joints in the legs of the SMPL model and calculating the euclidean distance between frames. Peaks with larger value than $\mu + 2\sigma$ were extracted and linearly interpolated, resulting in less leg switching, although there are limitations and it will not catch all the leg switching it is significantly better and it improved the model. The results is visualized on the graph on Figure 2 (right).

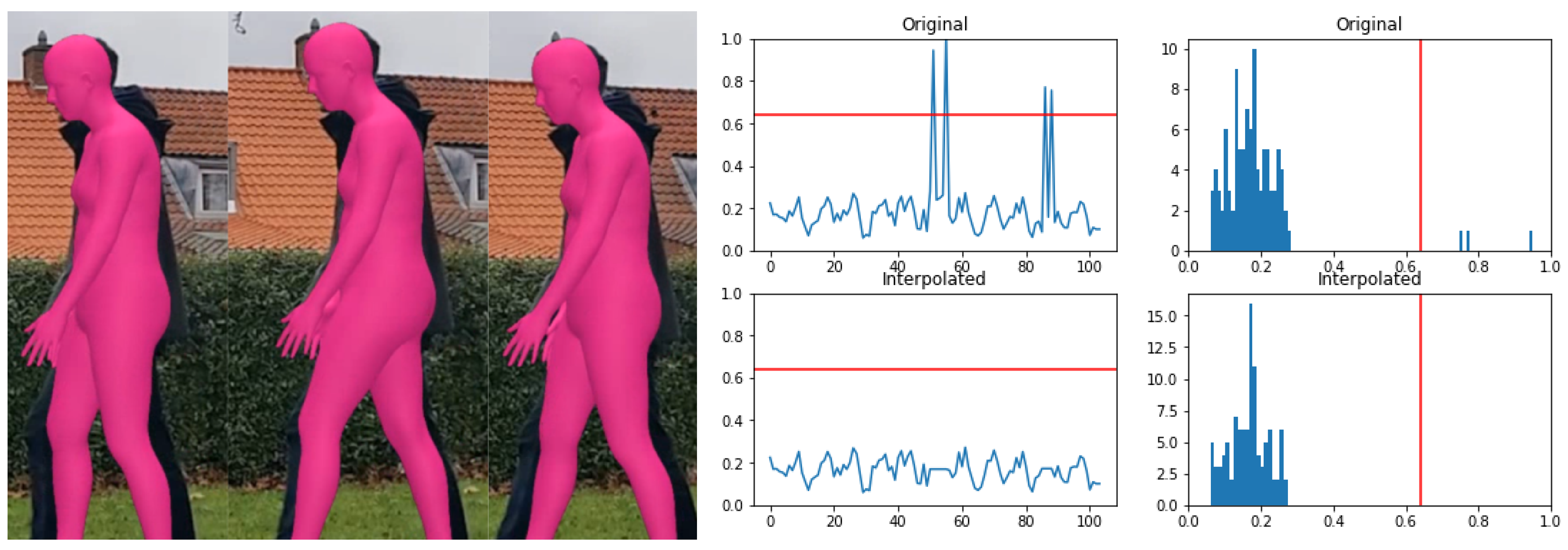

Figure 2: Unclear clothing causes legs to be switched (left)
Re-interpolation of points with leg errors (right)

We now used the outputs from the 4D humans and the manually detected ground truth to train our FFNN model.

Model

With the labeled SMPL parameter sequences, we build a FFNN with an input size at 69 (23 joints times three rotation angles) from the SMPL parameters. The model consists of one hidden layer with 64 neurons and a two dimensional output layer that describes the probability that the corresponding foot is touching the ground. This data is then used to calculate the double support time, the stride length and the asymmetry.

Model performance

With the SMPL parameters extracted from video with 4D humans, we applied the model on our test set and got an 93% foot contact accuracy. With the foot contacts estimated, we can now infer the models performance across the various gait metrics as seen in the table below, along with a baseline estimating the average values from the train set.

	MAE	STD	MAE Baseline	STD Baseline
Double Support	2.24 %	1.34%	3%	1.98%
Stride Length	13.3 cm	11.7 cm	21.6 cm	12.8 cm
Asymmetry	1.7%	1.05%	0.526 %	0.428%

Table 1: Model performance across gait metrics

As seen from table 1, the model performs quite well in estimating the double support, and stride length but struggles more with the asymmetry, since small differences in stride lengths can lead to a (compared to baseline) high deviation, since those two gait characteristics are highly correlated. Below we can see an example frame from the test set, along with the predicted (blue) and true (orange) foot contacts.

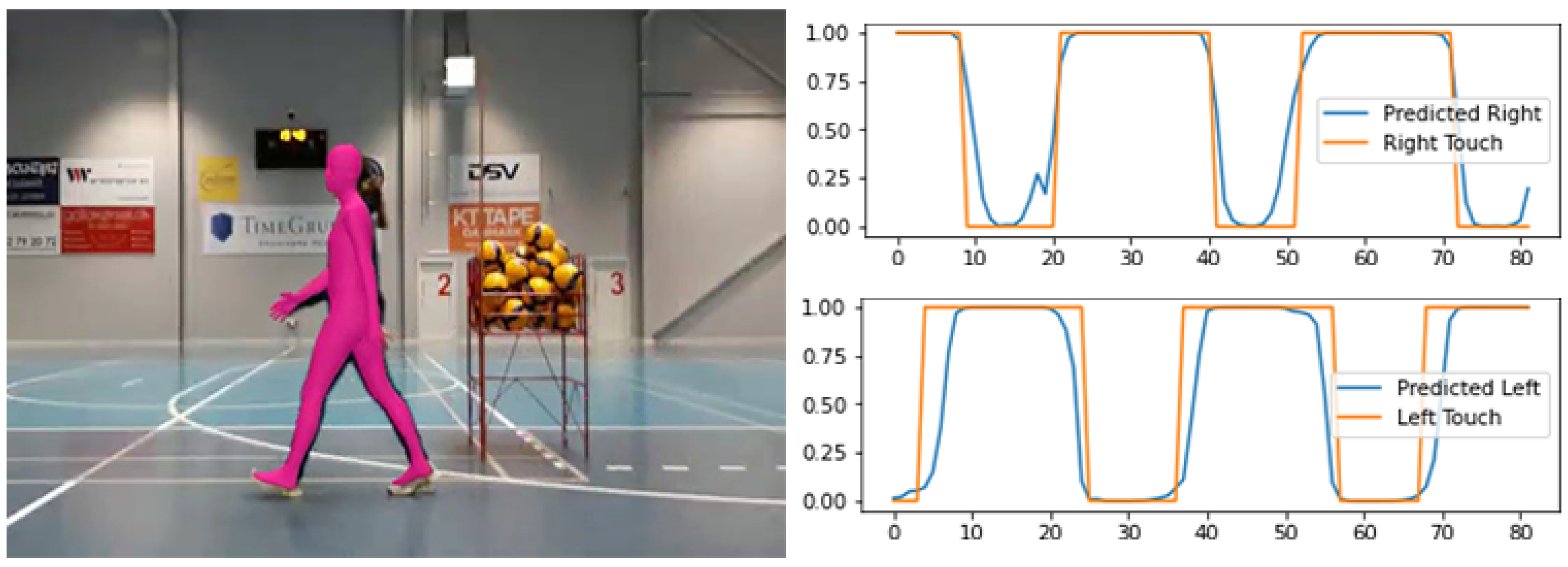

Figure 3: Example of data, predicted Double support: 24.4%, actual: 26.8%, predicted stride length (l/r) in cm: 171/166, actual: 187/187, touch accuracy: 92%

As expected from the results, the touch accuracy here is very accurate at 92%, however the stride length and gait asymmetry vary quite a bit from the expected range, which will be discussed below in the problems/model fails section.

Problems/model fails

- **Difference in stride length and asymmetry:** For estimating the length of the strides, we use the position of the SMPL model in space. It is possible that 4D humans has difficulties estimating whether its a larger person further away or a smaller person closer, which could lead to deviations in the change of position. A possible workaround for this might be moving to Simultaneous Localization And Human Mesh Recovery (SLAHMR)[5], that detaches camera and actor movement. This would also allow us to use a moving camera instead of relying on a static one.
- **Full body in frame:** As the 4D humans fit a SMPL model it gets confused if the entire body of the subject is not in the video. As illustrated in Figure 4 the model shows both legs are in the frame when in reality there is only one leg.

Figure 4: 4D humans fitted to edge of frame produces inaccurate SMPL representation

- **Stress test:** The model is only trained on people walking on a flat surface therefore stress tests were done to see how well the model performed. Test were done where an individual was walking up- and down stairs, running and doing jumping jacks. Results showed that the model accuracy was 82%, 75%, 83% and 53% and a baseline accuracy at 48%, 53%, 52% and 56%, respectively.

Conclusion and future works

Using 4D humans to extract SMPL parameters from a video, we have applied a neural network to estimate right and left foot contact, double support, stride length and stride asymmetry. For estimating touches, we received an accuracy of 93%. Using this to estimate the gait parameters, we got a mean absolute error of 2.24% for double support, 13.3 cm for stride length and 1.7% for stride Asymmetry. Estimating Asymmetry was more error prone due to it being affected alot by small changes in stride length, and we foresee that using SLAHMR instead of 4D humans will improve tracking quality, reducing the magnitude of the problems, as well as allowing for a dynamic camera to better capture more space requiring movements like running.

References

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