INSTRUMENTED CRUTCHES FOR GAIT PARAMETERS EVALUATION

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INTRODUCTION

Most of the prototypes of instrumented crutches available in literature [1]–[3] require external motion capture devices to perform a gait analysis and to report the load applied on the crutches respect to the gait cycle. Motion capture systems with markers require a controlled laboratory with cameras, instead IMU-based systems are more transportable, but the user must be instrumented [3]. A new version of instrumented crutches, previous developed by the authors [1], allows to measure the axial forces and to detect the gait phases during a two-point assisted walking [3] thanks to the cameras mounted on the lower part of the crutches.

MATERIAL AND METHODS

The instrumented crutches allow to measure the axial forces applied with less than 13 N (P=95%) of uncertainty. They are provided of a D435I Intel Realsense camera to capture and store the depth images of the contralateral foot. The camera is placed on the lower part of the crutch and it acquires at 15 fps.

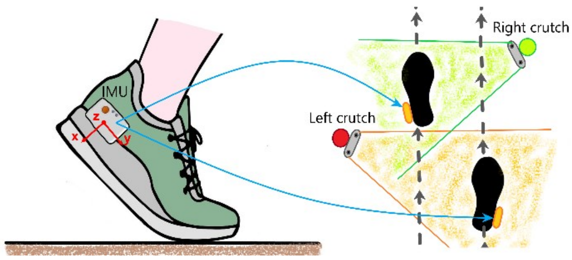

Figure 1 - IMUs placement on the feet.

To get the step phases references a set of four external IMUs are used during the tests. Two IMUs are placed on the shoes as shown in Figure 1 and an approach similar to the one used in [4] allows to extract the gait phases. Another two IMUs are fixed on the crutches to allow the data synchronization by signals comparison. The test campaign involves 13 young healthy subjects (gender: 10 male and 3 female; age: 29.3 ± 5.1 years; height: 1.76 ± 0.05 m; weight: 74.6 ± 12.5 kg). The participants are asked to perform a two-point contralateral assisted walking [3] on a flat indoor surface of 25 meters with self-selected speed. The walk is repeated at least three times and the subjects must load partial of their body weight on the crutches.

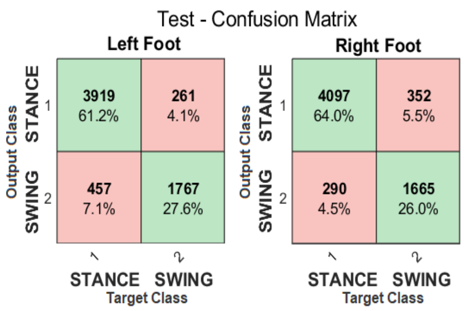

Figure 2 - Confusion matrixes of the test dataset predictions of the left and right foot.

Following the indications in [5], a neural network is trained using five percentiles of the foot-floor distances distribution of the contralateral foot framed in the depth images, hence the floor's plane parameters and the contralateral foot's point cloud must be extracted from each frame. Due to the camera orientation and the walking pattern, more objects are usually included in the point cloud: the floor, the ipsilateral foot, the contralateral foot, the contralateral crutch and background objects. Each depth frame is filtered in distance with a depth threshold of 1 meter to exclude undesired distant objects. The floor plane is easily extract using a RANSAC algorithm and the point cloud without the floor is then passed to an iterative k-means clustering to separate each element. Since the contralateral crutch's point cloud, if it is present, is the farthest element from the camera, the clusters of the contralateral crutch should be composed by few points. An empirically threshold of 3000 points is chosen to remove all the clusters under this value. The remaining clusters should belong to the ipsilateral and contralateral feet. The cluster with the maximum distance of the centroid from the camera is selected as the contralateral foot's point cloud. For each point the point-plane distance is computed and five percentiles are extracted from the distribution. Since during the two-points walking pattern a swing phase of the contralateral foot imposes a stance phase in the ipsilateral foot, the percentiles extracted by both the crutches are useful to predict the step phases. To take advantage of the chronological sequence of the recorded frames a Neural Network with three fully connected layers is trained passing the percentiles from the i-9 frame to the i+9 frame from both the crutches (PCA enabled with 95% of explained variance). 10 random subjects (81% of the dataset) are used to train the model and the other 3 subjects are included in the test.

Table 1 - Intra-subject comparison of gait parameters.

Foot side	***Stride time [ms]***		***Stance time [ms]***		***Swing time [ms]***		***Cadence [step/min]***	
	mean	***RMSE***	***mean***	***RMSE***	***mean***	***RMSE***	***mean***	***RMSE***
left	1708	64	1164	87	544	61	33.2	1.7
right	1707	83	1167	78	541	44	33.3	1.5

RESULTS AND CONCLUSION

In Figure 2 the confusion matrixes of the test show a general accuracy about 90% for both the side. In Table 1 reports an intra-subject comparison among the predictions and the reference (IMU-based gait detection) results computing the root mean squared error (RMSE).

The presented instrumented crutches measure the load applied with respect to the gait cycle during a two-point assisted walking. Thanks to the depth cameras mounted on the lower part of the crutches the gait analysis is performed without other external devices. Good accuracy in step phases detection (~90%) is obtained and the gait parameters as cadence and stance, swing and stride time are well estimated. It is not more necessary to set thresholds based on the walking behavior of subjects to properly filter depth images, as was done in the previous version of the algorithm [5]. The database should be expanded, also including subjects with walking disorders. Differents gait pattern should be investigated to cover more rehabilitation approaches.

ACKNOWLEDGMENT

This project has received funding from the European Union's Horizon 2020 research and innovation program, via an Open Call issued and executed under Project EUROBENCH (grant agreement N° 779963).

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