Analysis of 4D markerless surface measurement for medical applications

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Abstract—This paper presents two new shape parameters developed for analysis of point cloud sequences captured by 4D scanners. The parameters describe local shape of body surface in a way similar to curvatures. The advantages are much shorter processing time and possibility to use with point clouds – no mesh needed.

Keywords–4D markerless scanning, shape parameters, curvatures

1. INTRODUCTION

This paper presents new shape parameters describing local features of surface as well as a new data analysis path for 4D data input. The developed shape parameters are easier and quicker to calculate than standard surface parameters, such as curvatures, but they give very similar results to the latter. The presented 4D data analysis path allows locating characteristic areas on the body surface, so called anatomical landmarks, and tracing them in time along the measurement sequence.

The article presents the general concept of the developed 4D data analysis path. The algorithms were implemented and tested on real and computer generated data representing the surface of lower limbs. Exemplary processing and analysis results are presented.

2. 4D DATA ANALYSIS PATH

In order to process 4D data a dedicated processing path has been developed (Fig. 1). Data from the measurement system comes as a time-sequence of point clouds (clouds of [x, y, z] points). For every frame (time instant) four point clouds are generated (one point cloud per one frame from every directional measurement module). First, a preliminary processing of point clouds is performed. Directional point clouds are merged and the result is interpolated in every time-frame. Next, a feature searching takes place. Maps of surface parameters are calculated, regions of interest are selected and point groups connected to desired anatomical landmarks are traced. The trajectories of traced groups may be used by an external biomechanical module to calculate the parameters of a lower limbs skeleton model. These parameters are used to support the clinician in medical diagnosis. Besides, the data generated by the biomechanical module may be used for visualization purposes.

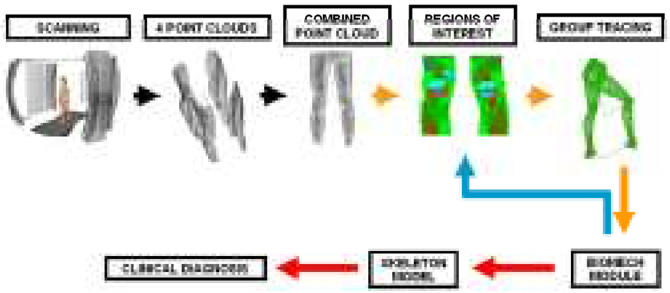

Figure 1. 4D data analysis path developed for time-sequences of 3D point clouds

3. SHAPE PARAMETERS

This chapter focuses on parameters developed to select the regions of interest related to desired anatomical landmarks.

Curvatures

Differential geometry introduces curvatures – a set of measures representing the amount by which a geometric object deviates from being flat. Curvatures – the most popular for surface analysis are mean and Gaussian curvatures – are very useful in analysis of parametric surfaces or ordered datasets, such as triangle meshes [1]. Unordered datasets, such as combined point clouds originating from 4D markerless measurement systems, need to be locally parametrized, e.g. with use of quadric patches. Unfortunately for full 3D point clouds fitting quadric patches is a time-consuming operation. For every surface patch it requires solving sets of differential equations with many parameters, where the number of parameters for a quadric patch is ten. It is worth saying that for most reliable results these patches should be calculated for every point in the 3D cloud. Besides, there are some additional issues related with discrete mathematics which make calculating of mean and Gaussian curvatures uncomfortable for full 3D point clouds. [2]

Custom Parameters C_1 and C_2

This has been our motivation to develop custom surface shape parameters which would have the same functionality for surface analysis as curvatures, yet would require less computational power to be calculated and could be applied to full 3D point clouds. In result two parameters have been developed – C_1 and C_2 [3]. The first parameter describes the convexity or concavity in the considered point, whereas the latter says whether the curvature is in this point directional or not.

Briefly speaking, the C_1 parameter describes how much the surface in the neighborhood of the considered point deviates form a plane. The C_1 values are positive for convex areas, negative for concave areas and zero for planes (Fig. 2).

Figure 2. Distribution maps of C_1 parameter over lower limbs surface (computer simulated data).

The C_1 parameter alone was not sufficient to describe the local surface shape for anatomical landmark detection. Therefore an additional parameter was developed. The C_2 parameter describes the distribution of normal vectors in the neighborhood of the considered point in a way allowing distinguishing areas of unidirectional curvature, such as cylindrical areas, and omnidirectional curvature, such as. spherical areas. The C_2 values are zero for planes and cylindrical surfaces and positive for other surface types. The highest values of C_2 are obtained for sphere and for saddle shapes (Fig. 3).

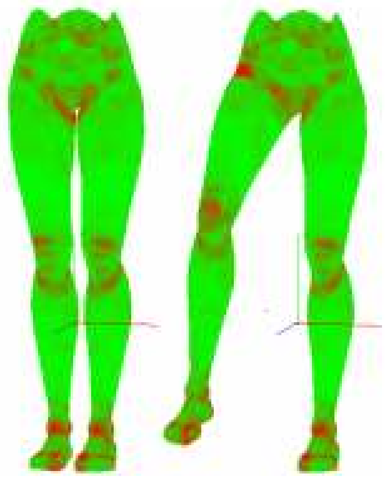

Figure 3. Distribution maps of C_2 parameter over lower limbs surface (computer simulated data)

The analysis of distribution C_1 and C_2 parameter values allows discrimination of various surface types in a way similar to used with mean and Gaussian curvatures.

4. Further Processing

The distribution maps of C_1 and C_2 are used to find areas connected with anatomical landmarks, shape of which is distinguishable on lower limbs' surface. Most anatomical landmarks, such as patella, malleoli, heel, are convex elliptic areas of high C_1 and high C_2 values. Some landmarks, such as dorsal knee part, are saddle-shaped where C_1 is close to zero and C_2 is high. The rest of leg surface has usually a cylindrical character of positive C_1 and C_2 values close to zero. Checking C_1 and C_2 values for every point in the cloud allows selecting of areas of possible interest to the operator. These areas may be traced in the whole measurement sequence producing trajectories representing the motion of desired anatomical landmarks in time (Fig. 4).

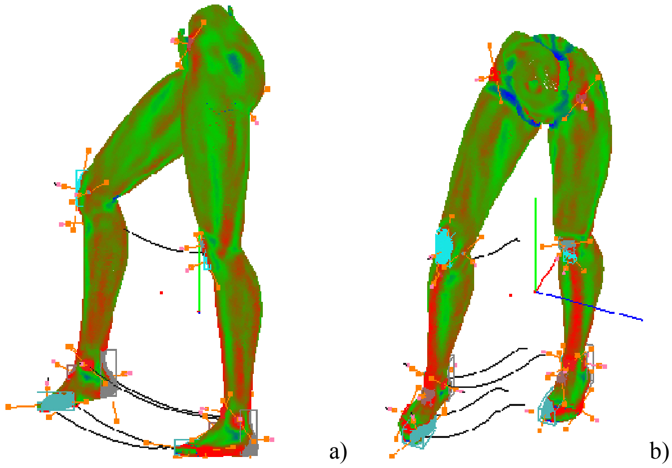

Figure 4. Trajectories showing the displacement of selected point groups for simulated data representing patient raising leg: side a) and front-side views.

5. Conclusion

The custom shape parameters C_1 and C_2 presented in this article allow analysis of full 3D surface very similar to one provided by mean and Gaussian curvature. However, the time of calculations for C_1 and C_2 parameters is approximately 15 times shorter than for curvatures what is particularly important in medical practice.

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7. References

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