Curvature Estimation Using Machine Learning Algorithms

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Objectives

The traditional calculation of mean and Gaussian curvatures [1, 2] on 3D triangular meshes is performed geometrically for each vertex of the mesh. This process, depending on the number of vertices, can be extremely costly in terms of computational resources.

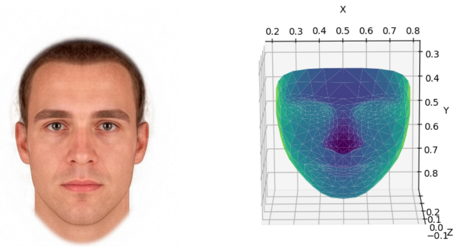
This Scientific Initiation project proposes using machine learning algorithms to estimate the mean and Gaussian curvatures on human face meshes, offering a more efficient alternative to conventional geometric techniques.

These curvatures are essential to describe the shape and details of the surface, being fundamental in applications such as facial reconstruction, face detection, and facial expression analysis. The machine learning approach aims to complement traditional methods by improving performance, making the process faster and more efficient.

Materials and Methods

The first step involved creating three-dimensional meshes from the 3D points generated by the *MediaPipe* library [3]. These meshes were used as a basis for the geometric calculation of the curvatures, which served as a reference for vertex labeling.

Figure 1: Mesh generated by *MediaPipe*



(a) Human Face (b) Resulting mesh

The mean and Gaussian curvatures were calculated for each vertex of the 3D mesh, and these values were used as labels in training the machine learning models. These labels provided a basis for the models to learn to predict the curvatures.

After the labeling phase, the main features of the meshes were extracted. These features included vertex coordinates (X, Y, Z), normal vectors, and the degree of each vertex, describing the local geometry of the mesh. These characteristics formed the input vector needed for regression models, providing the necessary data for the algorithms to learn.

With the curvatures labeled and features extracted, the training process for the machine learning models began. The feature vector, containing the geometric information of the meshes, was used as input for the models, while the labeled curvatures served as output (labels).

Results

In the initial tests, only the vertex coordinates were used as input to the models. This resulted in very poor performance, with insufficient accuracy to predict the curvatures, showing that this information alone was not enough to capture the complexity of the 3D meshes.

Afterward, the calculated features were included, which significantly improved the performance. In this regard, the models' accuracy increased notably with the new features, and the respective errors decreased. The *Random Forest*, for example, obtained the results presented in Figures 2 and 3.

Regarding the execution time, it was observed that while the geometric models had a shorter execution time for small meshes, the regression algorithms proved to be much more efficient for larger meshes, as shown in Figure 4.

Figure 2: Mean Curvature (Accuracy of 70%)

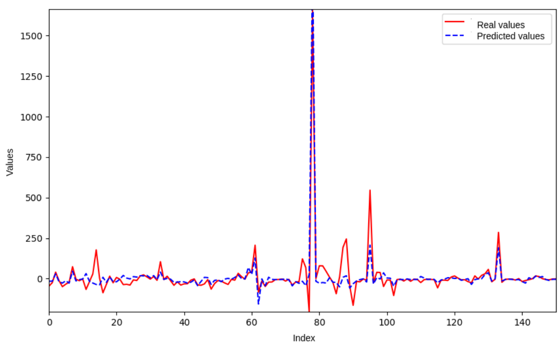


Figure 3: Gaussian Curvature (Accuracy of 90%)

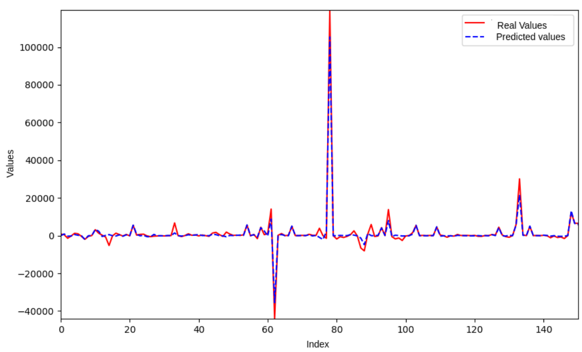
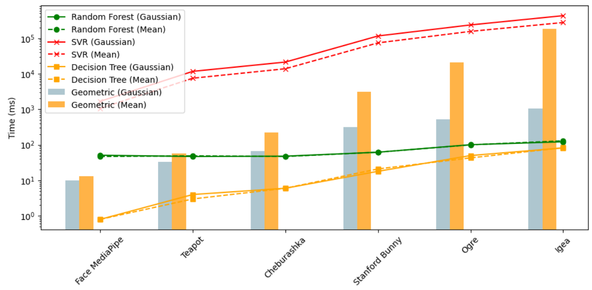


Figure 4: Comparison of execution times with the increase in the number of vertices.



Conclusions

The results of this project show that machine learning algorithms are an efficient alternative to conventional geometric techniques for estimating mean and Gaussian curvatures in 3D meshes, providing good accuracy and execution time optimization, especially in complex meshes.

Acknowledgements

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References

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[3] Lugaresi, C., Tang, J., Nash, H., McClanahan, C., Uboweja, E., Hays, M., Zhang, F., Chang, C.-L., Yong, M. G., Lee, J., et al. Mediapipe: A framework for building perception pipelines. *arXiv preprint arXiv:1906.08172* (2019).