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DETECTION OF PLANAR SEGMENTS IN POINT CLOUD USING WAVELET TRANSFORM

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Abstract: *In this paper we propose a new method for 3D plane segmentation and fitting from point cloud. The method is based on discrete wavelet transform. In particular, we exploit the sensitivity of certain wavelets to abrupt changes in the signal, as well as their orthonormality to linear functions to effectively recognize planar regions. The application of the proposed method is evaluated using two examples. The first example refers to a synthesized signal, and the second, real world example deals with the detection of the welding seam pose within adaptive control of robotized continuous welding.*

Keywords: point cloud, plane segmentation, reverse engineering

1. INTRODUCTION

The performances of the state of the art scanning devices [6] gave additional élan for research in the area of implementation of originally reverse engineering (RE) methods in on line manufacturing processes control. An example is the adaptive control of robotized continuous welding [5] in unstructured environment. The hardware of contemporary scanning devices is characterized by high speed and accuracy, giving usually more than sufficient raw data. However, the bottleneck for on line application of RE techniques in the process control is the data processing [1]. There are a number of very successful methods for raw 3D data registration, integration and meshing [1], and the generation of dimensionally correct polygonal mesh [7] from point cloud is standard feature of CAD systems. Nevertheless, point cloud segmentation, simplification and surface fitting still remain the most critical elements of RE software.

Segmentation and fitting of planes in point cloud attracts more research efforts than other types of primary geometry. Besides the simplicity of the planar surface, there are other mainly application driven reasons. In addition to robotized continuous welding, typical examples are: 1) on line navigation of mobile robots in unstructured environment using sensory informa-tion from laser radars [2], 2) plane recognition in architectural reconstruction [8]. Another very important outcome is that identification of planar regions in point cloud leads to significant reduction of necessary vertices making further processing of resulting mesh more efficient. There are three main streams for recognition of planar features in point cloud. They are based on 3D Hough transform, RANSAC (Random Sample Consensus) method, and region growing [2].

In this paper we propose a novel method for segmentation of planar regions from point cloud based on discrete wavelet transform.

2. DISCRETE WAVELET TRANSFORM

Wavelet transform represents one dimensional signal as a linear superposition of atomic functions - wavelets. The wavelets are obtained by translation and dilatation of a single non-periodic function - mother wavelet. In discrete wavelet transform (DWT) dilatation and translation are carried out with discrete steps. Discretization is non-uniform in time-frequency space and it provides higher time resolution for low and better frequency resolution for high frequencies. To make the DWT unique and inverse DWT feasible, the wavelets should form an orthonormal basis [3].

Multiresolution analysis (MRA) [4] had very significant impact on DWT. Besides subband filtering scheme – a fast hierarchical algorithm for execution of DWT, MRA gave efficient methods for creation of orthonormal wavelet bases. Basic MRA algorithm for DWT application can be briefly stated as follows. If a sequence of resolutions 2^{-j}, $j\in(0, -\infty)$ is taken, then each signal can be represented as the sum of its approximation at resolution J – $A_J f$ and details $D_j f$, $j\in[1, J]$ taken from it during passing from higher to the lower level of approximation:

$$f = A_J f + \sum_{j=1}^{J} D_j f = \sum_n a_n^J \phi_{J,n} + \sum_{j=1}^{J}\sum_n d_n^j f \psi_{j,n} \qquad (1)$$

In relation (1) orthonormal bases $\{\phi_{j,n}, n\in Z\}$ and $\{\psi_{j,n}, n\in Z\}$ represent family of wavelets and corresponding scalling functions, a_n^J are the approximation and d_n^j the detail coefficients, computed by above-mentioned subband filtering scheme [4]. J represents the level of transform.

There are a number of families of wavelets (Daubechies wavelets, coiflets, symmlets [3]) that form othonormal bases. All of them are compactly supported thus providing excellent time localization properties to the transform. In addition some of them have asymmetric shape and can be employed for detection of abrupt changes in signal such as edges.

Besides application in time series analysis, DWT can be performed on two dimensional signal represented by matrix **S** with dimensions $m \times n$, using the following procedure:

Step 1: One-dimensional DWT of each row of matrix **S**

Step 2: One-dimensional DWT of columns computed in step 1

Two dimensional DWT inherits all the properties of one dimensional DWT including real time applicability and sensitivity to abrupt changes.

2. APPLICATION OF DWT IN RECOGNITION OF PLANAR REGIONS

Besides suitability for detection of abrupt changes (e.g., edges) in signal, there is another property of some wavelets that is crucial for the application at hand. Namely, the wavelet db2 from Daubechies family (db wavelets) has 2 vanishing moments:

$$\int x^2 \psi(x) dx = 0, \quad n = 0, 1, \ldots N-1 \qquad (2)$$

where ψ denotes the wavelet. This means that the db2 wavelet is orthogonal to the first degree polynomials 1, x and that the signal after DWT application will be approximated by linear function. Consequently the detail coefficients in the areas of the signal that are well approximated by first degree polynomial will be close to zero. On the other hand, in all nonlinear areas, the detail coefficients will be high. Besides, on the transition between two linear segments with different inclination there will be abrupt change in signal. Since db2 is highly asymmetric wavelet, it will be sensitive to this change and the level of detail coefficients at the connection of two linear segments will be high.

For the illustration of the given observations, Fig. 1 presents one level decomposition of a synthesized signal using db2 wavelet. Signal (Fig. 1a) consists of four linear and one conic section segment. The details of the signal at the first level of DWT using db2 wavelet are presented in Fig. 1b. It can be seen that details equal zero in all areas in which signal is constant or linear, while it differs from zero in areas that correspond to circular segment. The boundaries between segments represent abrupt changes in the signal and DWT detects them - detail coefficients differ from zero. This information is very useful for segmentation of adjacent linear segments. Besides sensitivity to abrupt changes, 2D DWT inherits the orthonormality to polynomial surfaces from one dimensional DWT, as well.

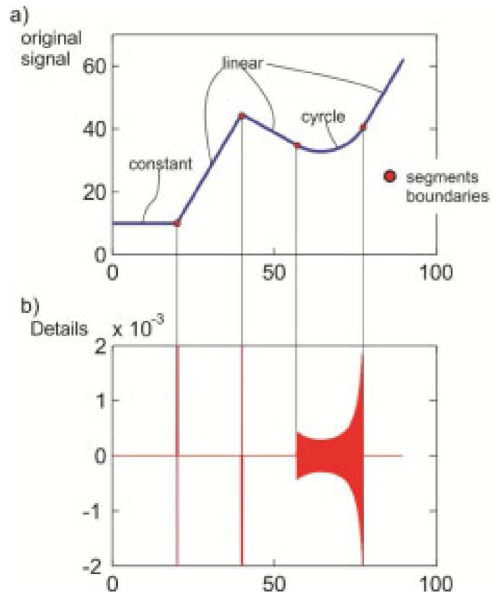

Fig. 1. Sensitivity of db2 DWT to abrupt changesand higher order polynomials – 1st level details

For the illustration of application of 2D db2 DWT in segmentation of planar regions, we used a synthesized surface that consists of four planar and one cylindrical segment (Fig. 2a). The detail coefficients of 2D db2 DWT at the first level of transformation of the selected surface is given in Fig. 2b. As expected, the details equal zero in points that belong to planar segments. The only exceptions are the points at the surface edges - this information will be used for the segmentation of adjacent planar regions (Fig. 2c). Simple tresholding of the details (Fig. 2b) leads to generation of binary 2D matrix (binary image) which contains one connected object for each planar segment in processed surface (Fig. 3a). Using well known procedure for detection of connected components in 2D binary image, the planar segments are recognized and segmented (Fig. 3b). After segmentation, since all data that belong to one segment are sampled from single plane, we can apply least squares regression for computation of plane parameters. The detected planar segments are shown in Fig. 2d.

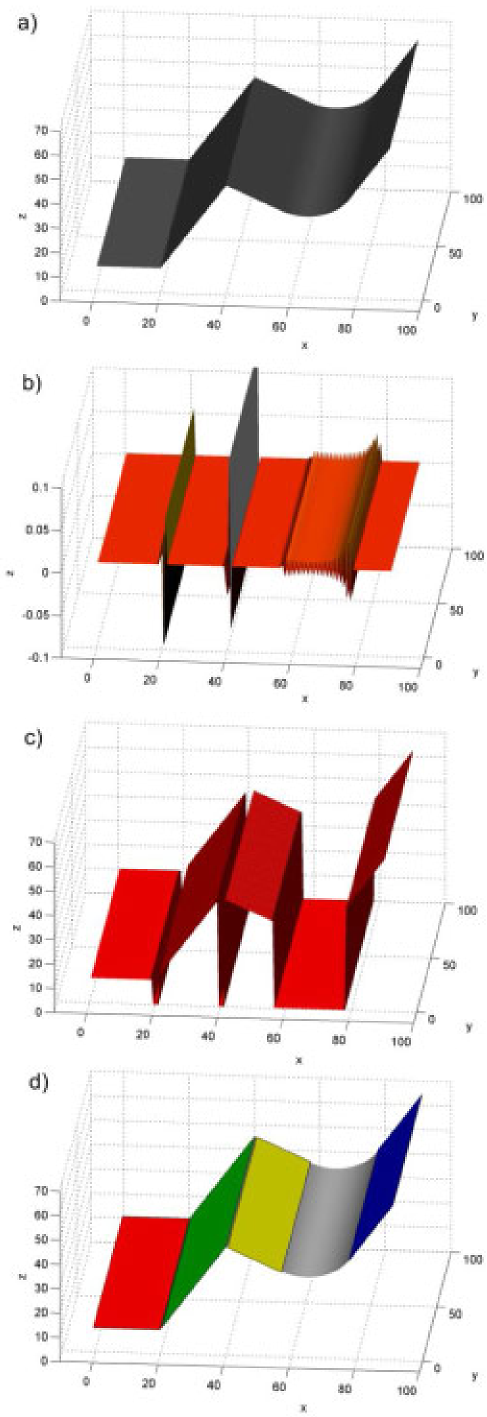

Fig. 2. Application of methodology to synthesized 2Dl signal

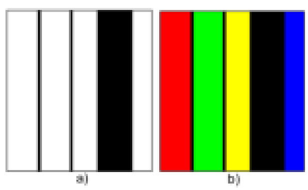

Fig. 3. a) 2D binary image; b) recognition of connected regions

3. A REAL WORLD EXAMPLE

In the scope of diversified manufacturing, adaptive control of robotized continuous welding in unstructured environment represents a significant issue. During continuous welding of the assemblies, there exists a significant discrepancy between assumed/ predefined and real pose of the seem due to the different errors that come from imperfections in semi-finished products dimensions, errors in assembly part's positioning, thermal deformations introduced during previous phases of welding, etc. Existing contact systems for detection of seem position are time expensive and have poor influence on production system's efficiency. Introduction of alternative, fast methods based on scanning devices (e.g., structured light sensors) is more than welcome. Nevertheless, the online application of scanning devices in this area demands a fast algorithm for plane segmentation and fitting. For the given reason, we have chosen the detection of the seam in corner joint as a real world example in this paper.

During experiments (Fig. 4), two metal sheets were placed in the fixture in such a way to create a corner joint. The digitization of the sheets is carried out using ATOS Compact Scan 3D scanner, and unstructured 3D mesh is generated (Fig. 5a). To employ described procedure for detection of planes, we had to create a regular point cloud from scattered points. We used an algorithm similar to z buffer algorithm along with the representation of mesh triangles in barycentric coordinates. The resulting regular point cloud is shown in Fig. 5b. After the application of wavelet based procedure, the planar regions shown in Fig. 5c are recognized. Since dealing with real world data, the threshold applied to DWT details was set to 0.002 The seam is detected as planar segments cross-section. As can be observed from Fig. 5, our procedure is insensitive to the missing data in point cloud.

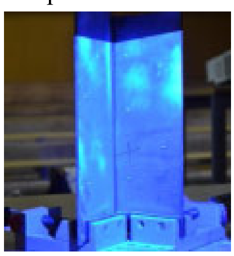

Fig. 4. *Expermental setup*

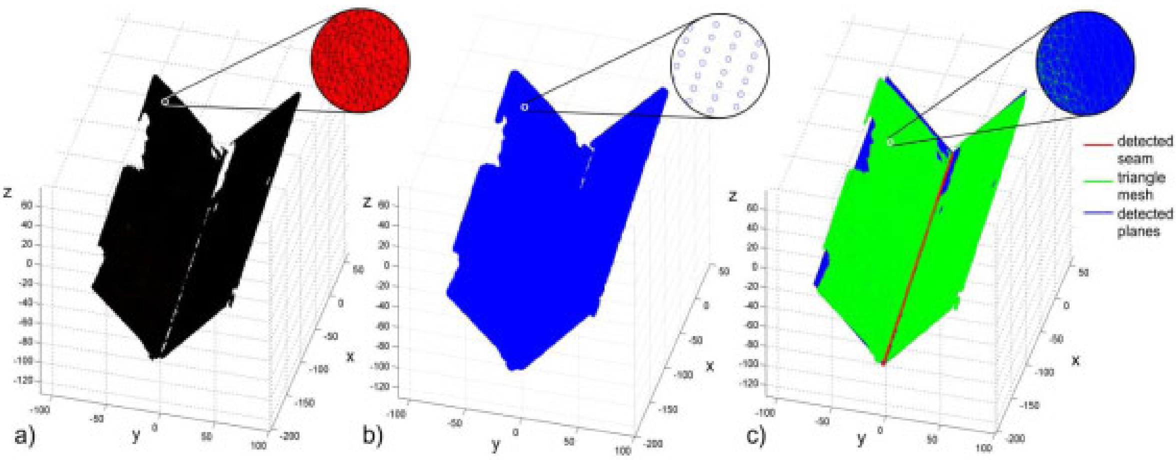

Fig. 5. *Real world example – welding seam detection from scanned point cloud*

4. CONCLUSION

In this paper we have introduced the method for segmentation of planar regions from point cloud using DWT. The presented method gives fast, one-pass algorithm that is suitable for detection of multiple planar regions in the cloud[1]. It is not subject to the trade off between execution velocity and the accuracy of the plane parameters present in Hough transform. In addition, our method is insensitive to missing data.

The main drawback of the algorithm is that it requires regular point cloud at input. For overcoming this issue, we have used the derivative of z buffer algorithm for scattered point cloud structuring. However, it should be noted that a large number of scanning devices outputs regular point sets.

The future work will address the segmentation of other, more complex surfaces (e.g., quadrics).

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REFERENCES

[1] Bi Z. M., Wang L., Advances in 3D data acquisition and processing for industrial applications, *Robotics and CIM*, Vol. 26, pp. 403-413, 2010

[2] Borrmann D., Elseberg J., Lingemann K., Nuechter A., The 3D Hough transform for plane detection in point clouds: a review and a new accumulator design, *3DR Expresss*, Vol. 2, Art. 32, 2011

[3] Daubechies, I., Ten Lectures on Wavelets, *CBMS-NSF regional conference series in applied mathematics*, Vol. 61, SIAM, Philadelphia, Pennsylvania, 1992

[4] Mallat, S., G., A Theory for Multiresolution Signal Decomposition: The Wavelet Representation, *IEEE Transaction on Pattern Analysis and Machine Intelligence*, Vol II, pp. 674-693, 1989

[5] Petrović P. B., Hodolič J., et al., Intelligent robotic systems for extremely diversified production–TR35007, *38. JUPITER Conf.*, Belgrade, pp. UR.49-UR.66, 2012 (In Ser.)

[6] Savio, E., De Chiffre, L., Schmitt, R., Metrology of freeform shaped parts, *Annals of the CIRP*, 56/2, pp. 810-834, 2007

[7] Schall O., Samozino, M., Surface from Scattered Points: A Brief Survey of Recent Developments, *1st International Workshop towards Semantic Virtual Environments*, Villars, Switzerland pp. 138-147, 2005

[8] Tarsha-Kurdi, F., Landes, T., Grussenmeyer, P., Hough transform and extended RANSAC algorithms for automatic detection of 3d building roof planes from lidar data, *IAPRS*, Vol. 36, pp. 407-412, 2007

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[1] Note that RANSAC algorithm demands a significant number of iterations in presence of multiple planes, while region growing methods are very sensitive to seed selection.