

# DETECTION OF BRICKS IN A MASONRY WALL

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## ABSTRACT:

Laser scanning is being increasingly applied in the documentation of buildings and archaeological sites. The documentation process sometimes involves making an inventory of bricks in walls. This paper proposes an automatic/semi-automatic segmentation method for detecting bricks in walls, in particular masonry walls. In developing the detection method the problems with detecting bricks in a 3D point cloud obtained by terrestrial laser scanning are first examined. The method starts with a 3D triangulation of a 3D point cloud obtained by terrestrial laser scanning. Associated with each point in the cloud are reflectance values and an RGB triplet. The method then uses the triangulation, reflectance and RGB triplets to effect a proximity-based segmentation. A technique for selecting ideal segmentation parameters is also proposed. The method is tested on the point cloud of three different walls and the results of the brick detection are presented. Early results are promising.

## 1. INTRODUCTION

Laser scanning is being increasingly applied in the documentation of built structures and archaeological sites. The documentation process may sometimes involve making an inventory of bricks in walls. This inventory is typically done manually and is time consuming. Because of the large size of laser scans an automation of this inventory is desirable. A first step in automating the inventory is to automate the detection of bricks in the point cloud of scanned walls. This paper proposes an automatic/semi-automatic segmentation method for detecting bricks in walls, in particular masonry walls.

The paper is divided into four parts. In the first part previous work done is discussed. In the second the problems with detecting bricks in a 3D point cloud are examined. In the third part an outline of the proposed detection algorithm is outlined. Finally, in the fourth part early results are presented and discussed.

## 2. PREVIOUS WORK

The documentation of walls may be required for such purposes as the generation of façade drawings (Henze et. al., 2005), detecting structural damage (Arias et. al., 2007, Hemmleb et. al. 2006, Lerma et. al. 2000), or the quality control of wall finishes.

Previous work done in the detection of bricks in walls is limited and mostly done by means of image processing. Typically, the objective is to detect general structural damage rather than the bricks themselves. But the classification methods used have the potential to detect the bricks as well.

Hemmleb et. al. 2006 use a multi-spectral (four bands) laser scanner system to investigate damage on walls from moisture and biological covering. The output from the multi-spectral laser scanner is two or more images in the infrared spectrum. An image contains the reflectivity at a given wavelength. Quantitative damage is assessed based on the differencing of the images.

Further digital cameras are also used. The images from the cameras are classified using cluster analysis, maximum-likelihood and object oriented techniques. Digital infrared cameras can also be used. However, Hemmleb et. al. 2006, report unsatisfying classification results from this, because of the high correlation between the infrared channels. Some of the results obtained by Hemmleb et. al. 2006 suggest that provided the surface of mortar has not suffered serious damage it is possible to detect bricks in a wall through image segmentation.

Lerma et. al. 2000, Lerma 2001 and Strackenbrock et. al. 1990 also use imagery and image processing to identify structural damage in walls.

As more 3D laser scanner data becomes available it becomes topical to study the detection of bricks in the 3D scan of a wall.

## 3. DETECTING BRICKS IN WALLS

Detection of bricks in laser scans of walls involves determining a discriminating measure between bricks and mortar, and later, extracting (segmenting) the individual bricks. Discriminating between bricks and mortar assumes that the two possess very different radiometric and geometric surface characteristics.

This section looks at the difficulty associated with detecting bricks in a wall in terrestrial laser scanner data. The problems discussed below primarily hamper the distinction between mortar and brick, and in consequence the segmentation of bricks.

### 3.1 Similar surface textures

Segmentation based on surface texture would be possible if the mortar in walls had a different texture from those of bricks. However, this is not always the case, as in face brick walls. This problem can be further complicated if the scanned points have a low accuracy or if the average point spacing of the point cloud is too large.

### 3.2 Variable depth and width of the mortar channel

Typically the mortar between bricks is indented from the surface of the bricks. This indentation is called the mortar channel. When the mortar channel is deep, brick surfaces easily stand out from the surface of the wall. In a laser scan this appears as a surface discontinuity between the points on the mortar and the points on bricks. If the mortar channel is shallow, there is no surface discontinuity between mortar and brick, and the segmentation yields segments that contain both mortar and brick, i.e., under segmentation. In masonry walls, very often bricks are packed tightly against each other and the gaps are filled with mortar. Because of this, segmentation can yield segments containing more than one brick.

### 3.3 Similar surface covering

Ideally, if bricks and mortar are made of different materials, it should be possible to segment a wall based on the rgb values (colour) of points. In practice this is not possible if bricks and mortar are covered by paint, lichen, moss or a combination. This gives bricks and mortar the same appearance or worse a patchy appearance. Another variation on this problem is when the bricks and mortar are made of the same material. For example mud walls.

The above problem might be overcome by acquiring multi-spectral images of a wall.

### 3.4 Discontinuities in brick surfaces

Segmentation assumes that a surface discontinuity only exists between the surface of mortar and bricks. Bricks in a masonry wall sometimes have surface discontinuities within them. This leads to an over segmentation which may then complicate the detection of whole bricks.

### 3.5 Surface lighting

Depending on the lighting parts of bricks and mortar may be in shadow or highlighted. This complicates the segmentation of a wall based on the shading/brightness of objects. Furthermore, it complicates segmentation based on rgb, since brightness is embedded in the rgb components. Converting rgb values to hsv (hue, saturation and value) should help to untangle the effect of the variability of surface lighting from the hue.

Preferably a wall should be scanned under diffused illumination as available on a cloudy day. However, this may not always be possible.

### 3.6 Variable resolution of point cloud

Choosing the parameters of segmentation assumes that the local geometric surface characteristics of brick and mortar surfaces is uniform throughout the point cloud. In practice this is not the case for the following reasons:

- The edge of a scan will have a lower resolution than the centre of the scan,
- The overlap area of two or more scans will have a higher resolution than other areas of the scan.
- Objects at different distances from the scanner will have different scan resolutions, as shown in

- Figure 1. This applies to walls that are embedded, i.e., walls at different distances from the scanner.

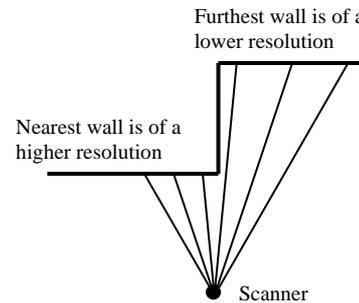


Figure 1 Variable resolution caused by walls at different distances from the scanner.

The above complicate the selection of optimum thresholds for segmentation criteria. One possible solution to this problem is to apply different thresholds optimised for local point cloud resolutions. Alternatively, a single threshold can be used and local segmentation criteria can be weighted based on local point cloud resolution.

## 4. PROPOSED DETECTION ALGORITHM

The proposed solution is based on weighted proximity segmentation. The method works on the assumption that the mortar channel is reasonably deep and wide (at least two points).

The method is designed to work on a 3D point cloud. This is necessary because the point cloud of a wall is typically composed of more than one scan. The sequence of steps in the algorithm is outlined in the following subsections.

### 4.1 Pre-processing

The rgb value of all points is converted to hsv. As mentioned in section 3.5 this is done to untangle the effect of surface lighting from the hue.

### 4.2 Triangulation

The point cloud is triangulated using a 3D Delaunay triangulation, see Figure 2(b). The triangulation is stored in a graph  $G(V, E)$ . The points in the point cloud are given by the set  $V$  and the edges of the triangles by the set  $E$ . The graph is used as a data structure to search point neighbourhoods and effecting the connected components (explained in section 4.5)

### 4.3 Point attributes

Radiometric and geometric attributes are associated with each point. The radiometric attributes include the intensity, hsv triplets, and functions of the intensity and hsv of neighboring points. Geometric attributes include the statistics of the Euclidean distance to the  $N$  nearest points, and the normal at a point.

### 4.4 Edge attributes

From the point attributes edge attributes are determined. These attributes represent the strength of the connection between

connected points in the graph. Desirably, the strength of the edges connecting points in the bricks and the points in the mortar should be weak. Conversely the strength of brick-brick edges and mortar-mortar edges should be strong. Some possible schemes for determining the edge strength,  $E_s$ , of an edge with end points  $V_i$  and  $V_j$ , are:

- $E_s = V_{iA} + V_{jA}$ : the sum of the end point attributes,
- $E_s = V_{iA} - V_{jA}$ : the difference of the end point attributes,
- $E_s = V_{iA} * V_{jA}$ : the product of the end point attributes,

$V_{iA}$  and  $V_{jA}$  are the attributes of end points  $V_i$  and  $V_j$ .

#### 4.5 Segmentation - connected components

The graph  $G$  is filtered to remove the weak edges, i.e., edges whose strength is below a user defined threshold. The result of the filtering is a graph  $G_f$ . Filtering the weak edges leaves edges that connect brick-brick points and mortar-mortar points, see Figure 2(c) and (d). Therefore, all points in the same brick should be interconnected by at least one edge. A connected components analysis of  $G_f$  yields components (sub graphs) that represent the bricks, see Figure 2(e).

#### 4.6 Component counting

The connected components analysis will yield components of varying sizes. Some of these components are invalid. Invalid components are typically small and are to be rejected. The definition of an invalid component is user defined. A count of the number of valid components is kept. This count is used in the next step to seek the optimum segmentation parameters for a wall.

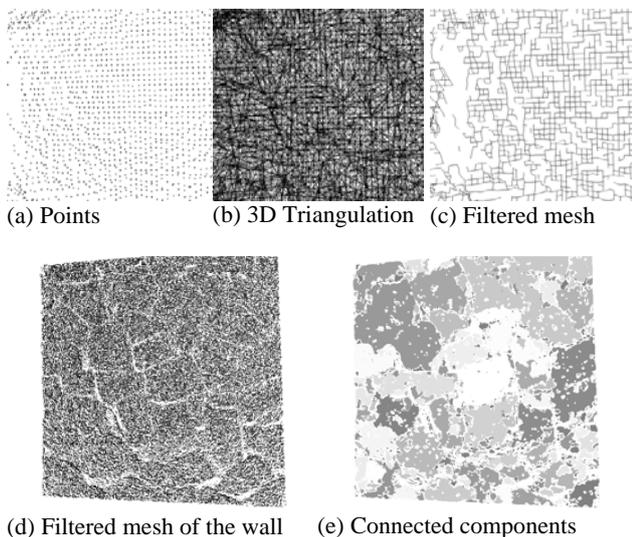


Figure 2 Real examples of typical results at key steps in the algorithm. In this example the wall is over segmented. The reason for this over segmentation is explained in the discussion on the results for wall 3 (section 5).

#### 4.7 Mode seeking

The segmentation and connected components is run several times with different thresholds on the edge strengths. At each

segmentation the number of valid components is counted. The component counts are graphed against the edge strengths, Figure 3.

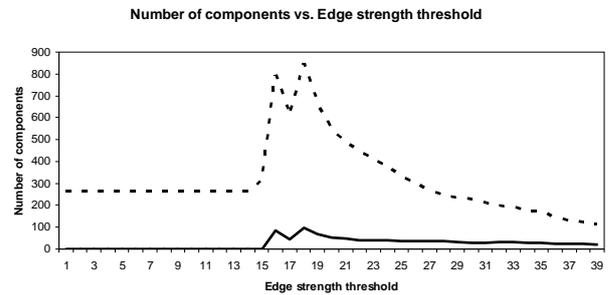


Figure 3 The distribution of the edge strength threshold against the number of components generated with a point count less than a specified number. The solid curve shows valid components with a point count of 20 or more points and the solid curve shows valid components with a point count of 40 or more points. It can be seen from the solid curve that the number of components drops sharply as fewer invalid components are counted. Notable about the graph are the two peaks. The data set for this result has two walls at different distances from a scanner. The two peaks represent the optimum edge strength threshold for each wall.

The graph in Figure 3 is used to select the optimum edge strength threshold for the final segmentation. A very large edge threshold will lead to the removal of many edges and hence an over segmentation. Many of the components obtained at this large edge threshold will be small and will therefore be invalid. Therefore, a small component count will be obtained. Conversely a very small edge threshold leads to an under segmentation as fewer edges are removed. Therefore, the component count at very small edge thresholds will also be small. The edge count should peak when there is an optimum segmentation. If a point cloud contains walls at different distances (depths) from the scanner, then several peaks will be obtained. The number of peaks will be equal to the number of depths in the scan. The critical part of this step is selecting a suitable point count for invalid edges.

### 5. EXPERIMENTS

The point clouds used in the tests are from two different walls at the University of Cape Town. Wall 1 is a typical face brick wall. Wall 2 is a masonry wall with fairly large and irregularly stone bricks. Wall1 and wall 2 are scanned at a resolution of about 3 mm and 5 mm respectively.



Figure 4 Walls used in the tests.

The walls were scanned on a cloudy day to ensure as much diffused illumination as possible. However as shown in Figure 4 this was not entirely successful. Walls 1 and 2 contain shadows thrown by a nearby tree and a nearby pillar respectively.

### 5.1 Wall 1

The mortar channel in Wall 1 is about 10 mm deep. Each brick is 220 mm wide and 70 mm high. At an average point spacing of 3 mm this yields about 2000 points per brick. Therefore, invalid bricks, i.e., incorrectly segmented bricks should have a point count considerably less than this. A value of 750 (slightly less than half a brick) was used in the tests. The rgb triplets of each point was first converted to hsv, see Figure 5. The following point attributes were used, Hue, Saturation, Value, intensity and mean distance to neighbouring points.

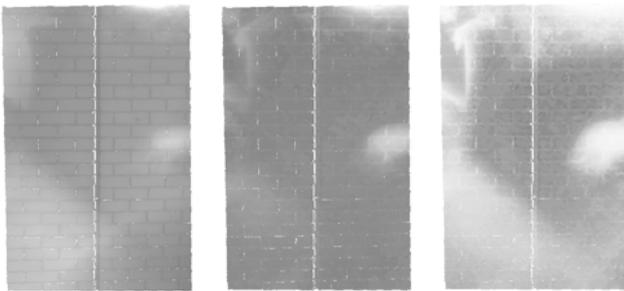


Figure 5 Point hue (left), saturation (middle) and values (right) of wall 1. The value component suffers the most from the shadow (dark area) cast by the tree.

The edge strength was computed as the product of the point attribute at both edges or the length of the edge. Attribute difference was also tried, but the attribute product provided the best discrimination between brick and wall points. Once the edge strengths had been set the edges with a value below a given threshold were removed. The best value for the threshold was obtained from the mode seeking technique described in section 4.7.

As shown in Figure 6 the segmentation is most successful when edge length is used as the edge strength criteria. This is helped by the fact that the mortar channel is both deep and wide and the scan resolution is fairly high. The results of the hsv segmentation are fairly similar with the value segmentation possibly performing worse than the hue and saturation segmentations. The hsv segmentations yield at least 5 over segmentations on the left side of the wall. This is because the segmentations were optimized for the right side of the wall.

In Figure 7 is shown the means by which the optimum threshold is selected. In this example invalid segments have a point count of 750 or less, and the edge strength is based on edge length. The images show the segmentations at different points on the graph. Note that as expected the optimum result occurs near the peak of the curve.

### 5.2 Wall 2

Wall 2 presents a more difficult problem and is typical of the brick detection problem trying to be solved. The mortar channel is both shall and narrow. Moreover the granite bricks are of different shapes and sizes. Here invalid bricks were chosen as

containing a 750 points or less. The rgb triplets of each point was first converted to hsv, see Figure 8.

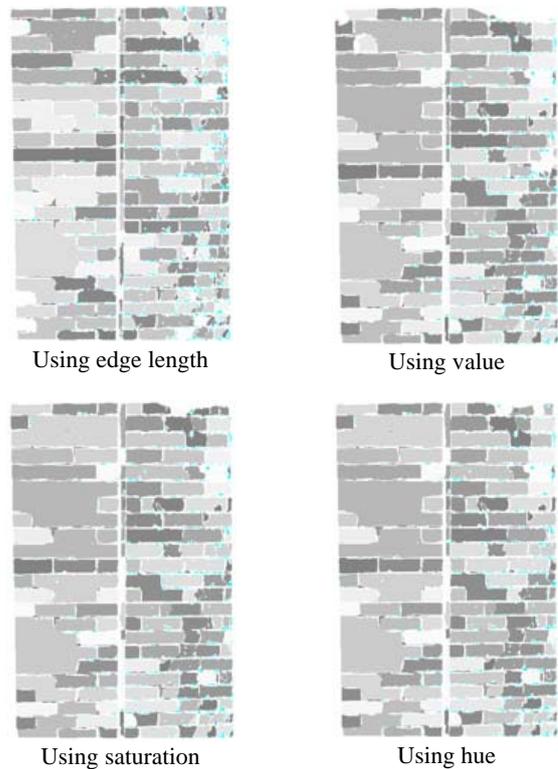


Figure 6 Segmentation using different edge strength criteria.

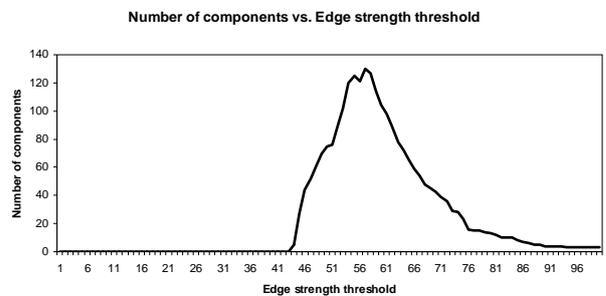
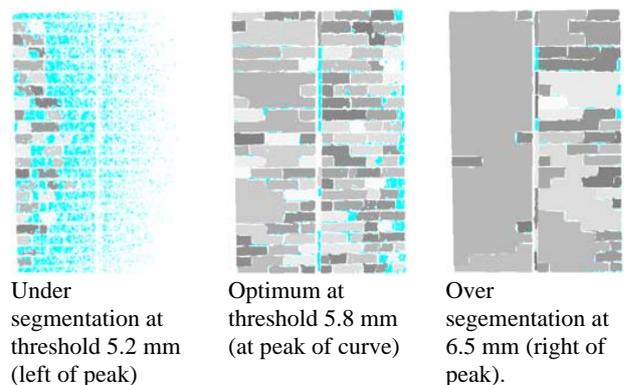


Figure 7 Selection of threshold for segmentation.

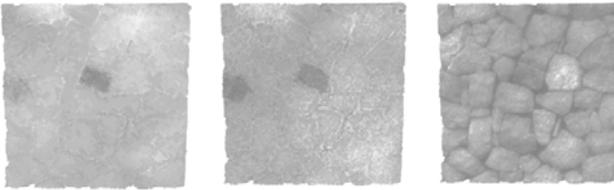


Figure 8 Point hue (left), saturation (middle) and values (right) of wall 1. The masonry wall is made of tightly packed granite stones, hence the hue and saturation components have almost uniform shading through out, except for two of the stones. As expected the value component (representing the distribution of light on the wall) contains more information.

Point and edge attributes were computed as in wall 1. The segmentation of the wall using the edge length and value is shown in Figure 9.

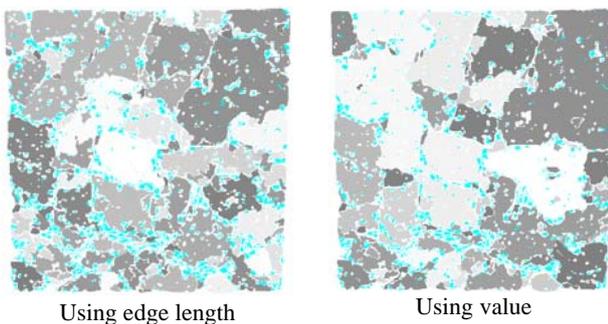


Figure 9 Segmentation using edge length and value as edge strength criteria

The two results are fairly similar. The most notable aspect of the result is that there is a lot of under segmentation within and on the edge of the bricks. It is suspected that these are caused by depressions/ protrusions on the surface of the bricks that cause discontinuities or cast shadows. This however needs to be further tested. Wall 2 shows the difficulty of segmenting tightly packed masonry walls. Nonetheless, while the segmentation is not good enough for a brick reconstruction, a visual comparison with the value image in Figure 8 and the segmentation result in figure 9 suggests that it is good enough for the purposes of detection.

### 5.3 Discussion

From tests carried out, the proposed general algorithm works if the mortar channel is deep enough to cause a discontinuity between the surface of the brick and the mortar and the scan is dense enough to capture the mortar between bricks (at least three points). Variable resolutions in the scan present the greatest challenge as they make the selection of a segmentation threshold difficult. Because of this it is best to detect bricks in single scans, to avoid the dense overlaps that are caused by the overlapping of two or more scans.

Experience from several tests indicates that the problems attendant with every wall is different. Lighting conditions will vary, the material of both mortar and brick vary, the texture of the mortar and brick are not the same between walls. Furthermore the resolution of scans will also vary. Thus, a semi-automatic detection approach may be better than an automatic one.

## 6. CONCLUSIONS

Laser scanning for the documentation of walls is done primarily for the purposes of generating façade drawings, assessing structural damage and quality control during and after construction. However, detecting individual bricks should allow for greater enhancement and intelligence in these activities. For example, if the bricks in a wall are of a uniform size then detected misshapen bricks will hint at defects (such as cracks) in a wall. Furthermore, the deformation analysis of a wall can be done based on a brick by brick comparison as opposed to current techniques that use targets or surface matching.

A semi-automatic algorithm and tool was developed and experiences during its development showed that the bricks in a wall can be detect fairly quickly and with a high level of accuracy. The development of the proposed algorithm is still in its early stages. Greater testing of suitable point and edge attributes need to be done. For example a shortcoming of the algorithm is that it does not use the normal at a point. Using the normal at a point in the computation of edge attributes will enhance the detection of discontinuities between bricks and mortar. As is, the algorithm is still naïve. More testing is required to improve the algorithm. But the results obtained thus far are encouraging.

Segmenting embedded walls is complicated because the walls at different depths will contain points at different resolutions. To overcome the problem of segmenting embedded walls an optimum threshold selection technique has been proposed. The technique has the potential for wider application in segmenting other types of point clouds.

## ACKNOWLEDGEMENTS

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