AUTOMATED SHACK RECONSTRUCTION USING INTEGRATION OF CUES IN OBJECT SPACE

Emmanuel P. Baltsavias
Institute of Geodesy and Photogrammetry
Swiss Federal Institute of Technology (ETH)
CH-8093 Zürich, Switzerland
tel./fax: +41-1-6333042/6331101
manos@geod.ethz.ch

Scott O. Mason
Department of Geomatics
University of Cape Town (UCT)
Rondebosch 7700, South Africa
tel./fax: +27-21-6503574/6503572
mason@engfac.uct.ac.za

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ABSTRACT:
The improvement of living conditions in informal settlements (IS) is one of the most complex and pressing challenges facing developing countries. In this paper we report on progress towards the automated generation of geospatial databases of IS from large scale, low cost, digital still-video imagery. We focus on shack extraction as the predominant data requirement. In contrast to western residential environments where many structures are geometrically complex yet texturally regular, sample studies in IS suggest that up to 90% of shacks are approximately rectangular in shape with a flat roof, but texturally complex due to the diverse construction materials. We present a strategy for automating the detection and extraction of these structures from digital still video Kodak DCS460c imagery. Experiences and problems associated with this imagery are outlined. Preliminary results for different cues are discussed. Central to this strategy is the integration of cues in map (object) space. First experiences suggest that a framework based on attributed contours, 2.5D blobs derived from digital surface models and extracted shadows will suffice for modelling shack outlines plus a representative height.

1. INTRODUCTION
Informal settlements (also known as “squatter settlements” or “shanty towns”) may be defined as dense settlements comprising communities housed in self-constructed shelters under conditions of informal or traditional land tenure (Hindson and McCarthy, 1994). They are a common feature of developing countries (DC) and are typically the product of an urgent need for shelter by the urban poor. As such, they are characterised by a dense proliferation of small, make-shift shelters built from diverse materials (e.g. plastic, tin and asbestos sheeting, wooden planks), degradation of the local ecosystem, e.g. erosion, poor water quality and sanitation, and severe social problems. A UNCHS global report on human settlements in 1986 pointed out that between 30 and 60 percent of residents of most large cities in DC live in IS. South Africa is not spared this situation. In the Cape Town area alone there are estimated to be some 120 IS.

In the first world developments towards technologies for reconstructing 3D models of urban environments are driven by applications such as architectural planning, illumination design and even virtual tourism (Mason and Streilein, 1996). Spatial models of IS, in contrast, are required to support efforts to improve living conditions. Applications in which spatial data play an important role range from monitoring IS growth at the regional level to the management of individual settlements, to shack counting for electoral boundary determination, the generation of GIS/CAD databases of IS infrastructure (huts, tracks, water outlets, etc.) for service upgrading, soil and ground water quality evaluation for environmental quality assessment, and settlement upgrade scenario modelling. With the exception of settlement upgrading, requirements for spatial models of IS emphasize less the need for positional and object modelling accuracy and more completeness of records in the face of highly dynamic environments. In all cases, integration of a complete settlement spatial model with socio-economic data in a GIS environment is considered a major facilitating factor towards improved IS management (Mason and Rüther, 1997).

To date, the spatial modelling of IS has been carried out using conventional, mostly photogrammetric, mapping techniques. Numerous authors and agencies have promoted mapping methods better suited to the low-cost/low-tech DC situation, e.g. small-format aerial imagery. The UNCHS (1995), in particular, has developed the Visual Settlement Planning (ViSP) IS mapping and planning methodology based on PC-based GIS tools using data manually digitised from scanned medium-format aerial imagery. The objectives of the UrbanModeler project in the Department of Geomatics, University of Cape Town, are to improve upon manual methods with the development of reliable methods and computer-based tools for automated settlement mapping. The research reported here stems from collaborative research between UCT and ETH Zurich.

This article outlines the needs and complexities of generating spatial models of IS. It reports on first experiences in
developing a strategy for automated shack extraction. Key features of this strategy are its operation in object space enabling integration in a desktop GIS environment and the use of low-cost digital aerial imagery. Experiences in using the Kodak DCS460c camera for mapping are reported.

2. INFORMAL SETTLEMENT SPATIAL MODELLING REQUIREMENTS

2.1 Image Analysis Tasks

Given the dynamics of IS, their density and the type and quantity of spatial data required for their management, imagery is clearly a major source of data. The roles of imagery and image analysis in supporting these applications include:

- Detection of settlements, e.g. regular satellite-image based control of urban areas.
- Detection of infill and monitoring of change in settlement boundaries, density etc.
- DTM (Digital Terrain Model) and DSM (Digital Surface Model) generation.
- Ground cover classification for environmental quality assessment.
- Detection of shacks, e.g. shack counting in support of social surveys.
- Detail settlement mapping including the extraction of shacks, other buildings, tracks, services in support of geospatial model generation.
- Reconnaissance and response to emergencies.

In addition to these modelling roles image media can play a key role in communicating spatial information to IS residents. In South Africa at least, perceptions of space and spatial relations differ markedly between African and European cultures. For example, abstractions such as line maps are often not well understood.

In this work we focus firstly on the task of rapid “first time” settlement mapping. A second, and in the long term more important thrust, is the detection and updating of change in IS geospatial models. The ability to accurately monitor the dynamics of an IS is critical in ensuring informed decision-making. We focus initially on the detection and extraction of shacks from digital aerial imagery given that shacks are the primary spatial unit in IS and constitute the link between the spatial and the non-spatial information (socio-economic data are usually collected at shack level).

2.2 Image Sources

Detailed mapping of IS has traditionally been carried out photogrammetrically using large-format aerial photography. Data is compiled using analogue or analytical (depending on local technology resources) methods, i.e. manually, labour-intensive and hence slow, requiring considerable expertise and expensive equipment. These methods are uneconomical over the relatively small, if dense, areas covered by IS, particularly for frequent updating. Alternative imaging sources and rapid mapping techniques are therefore needed.

Of low-cost imaging devices, digital cameras are preferred due to the direct capture of digital data. Currently, however, these cameras do not match their analogue counterparts in resolution. Moreover, slow image download rates can lead to more complex flight planning. Multiple runs of individual strips are needed to provide for overlapping imagery at large image scales. Nevertheless, because the areal extent of many IS is moderate, these limitations can be practically overcome in a large number of situations, e.g. as was demonstrated in a mapping campaign of the Marconi Beam settlement using a Kodak DCS460c digital camera (Mason et al., 1997). We briefly report these findings below along with further investigations into image quality.

Based on practical experiences desirable characteristics of imagery for IS detail mapping which influence the interpretability of IS scenes and provide useful cues for automated feature extraction include:

- Large image scale and high resolution. The minimum ground pixel size in digital imagery should be in the order of 0.5m. Finer resolution is needed for reliable mapping of communal toilet facilities, services such as water outlets, etc.
- Colour imagery is preferred to improve interpretability.
- Flying times should be chosen to ensure strong shadows. Shadows are useful in manual scene interpretation as well as in automated shack extraction (see Sec. 5.6).
- Nadir stereo imagery with high overlap is required for DSM generation.

Ground control is somewhat problematic given that signalisation materials are likely to be rapidly converted into roofing. Roof corners of shacks are often suitable and can be rapidly coordinated using kinematic GPS fixing. This must be performed immediately after flight to avoid gross errors introduced by shacks “renovations”. More substantial buildings, e.g. community halls, are therefore preferred.

3. APPLICATION OF STILL VIDEO CAMERAS FOR SMALL AREA MAPPING

The Kodak DCS460c is a digital still video camera with a standard Nikon N90 SLR camera body. A six million pixel (3060 x 2036) CCD chip is positioned in the film plane of the camera. Its dimensions are 27.6mm x 18.4mm with a pixel size of 9µm x 9µm. As CCD sensors are inherently monochromatic, special filters are needed to separate specific spectral bandwidths. The colour chip (indicated by the “c” in DCS460c) records visible radiation in the three bands red, green and blue. Kodak use their patented filtration pattern of the individual CCD elements, providing alternate red, green and blue in a special sequence, i.e. each pixel records either red, green or blue. The image in DCS format is interpolated using a Kodak interpolation algorithm to produce a 36-bit colour image (12-bits per
colour). During the process of converting the image from Kodak DCS format to one of the standard image formats, e.g. TIFF, the image is reduced to 24-bit colour. This gives a nominal uncompressed size of 18.6 Mb.

3.1 Photogrammetric Limitations

A number of characteristics of the digital cameras in general, and the Kodak DCS460c in particular, limit the DCS460c's practical and economic use for photogrammetric mapping operations to small areas. These include:

- Limited format size compared to large and medium format cameras. To achieve the same ground area coverage at equivalent resolution and scale as a standard aerial photograph, in the order of 277 DCS460c images are required.
- Slow readout speed, making repetition of the flight lines necessary in order to achieve sufficient overlap.
- Large lens distortion (200µm at the format edge for the 28mm lens tested) and other systematic errors.
- Poor radiometric quality due to the colour mosaic filter (artifacts, high noise, especially in blue and less in red channel), as exemplified in Figure 1.

Problems of the Kodak DCS460c colour interpolation algorithm were noted particularly at strong intensity discontinuities resulting in shifts in the location of edges between the three colour bands. These effects are insignificant in most IS applications but may be critical in high accuracy applications.

3.2 Mapping Potential

From ten acquired images, six DCS460c images at 1:18500 scale providing between 60% and 90% overlap over the Marconi Beam settlement were chosen for aerotriangulation. A set of twenty-one well-defined roof corner points distributed around the settlement were coordinated with static GPS to an accuracy of around 0.1m in both planimetry and elevation to serve as control and as check points in determining the external accuracy of the triangulation. An additional eleven roof and a few well-defined ground features such as painted road markings were selected as tie points. A free network bundle adjustment gave precision measures of 0.2m in planimetry and 0.74m in elevation. External accuracy tested on GPS coordinated points such as shack corners gave RMS results of 0.4m in X, 0.74m in Y and 0.46 in Z.

Two tests were carried out to test the potential of stereomapping accuracy for 80% (case A) and 60% (case B) overlap. Free network adjustments were performed in both cases due to poor control point distributions within the overlap areas. Internal precision estimates of around 0.15-0.2m in planimetry and 0.6-0.7m in elevation were confirmed by the RMS errors between the GPS and triangulated coordinates of the check points. These results are significantly better in planimetry than the 0.4m suggested by simulations. This can be primarily attributed to the larger number of ground points used in the adjustment and the greater elevation range in these points than the ones used in the simulations. The better results achieved in A over B can also be explained by the greater number and improved distribution of points used in the adjustment (23 versus 13) leading to stronger external orientation fixes.

These accuracies suffice for most IS detail mapping applications including shack and road delineation and infrastructure inventorying. One exception may be digital terrain modelling in cases, such as in Cape Town, where very flat terrain and the danger of flooding require higher elevation accuracies, e.g. for flooding analysis. Further testing of the DCS460c for IS mapping is being carried to verify the results under a range of conditions.

![Figure 1. Example of noise and artifacts introduced by DCS460c colour interpolation.](image)
4. AUTOMATED SHACK EXTRACTION STRATEGY

Unlike residential environments in developed countries development patterns in IS do not follow regular design codes but are subject to a complex interplay of natural (terrain, environmental), social (population pressures), historical and political forces. It is therefore impossible to define a narrow contextual description. In this Section we first investigate shack characteristics with view to the identification of reliable extraction cues and use these to formulate a strategy for automated shack extraction.

4.1 Shack Characteristics

IS are typically characterised by a mix of primarily informal and a few formal buildings (play schools, community centres). The majority of buildings are shacks with the following properties:

- Single-storied structures with flat and near-horizontal roofs. A small percentage of shacks are multi-storied and/or hip-roofed.
- Simple geometry. A study of shack shape typology in the Marconi Beam settlement in Cape Town showed that 85% of shacks are 4-sided and 11% 6-sided. Deviations from rectangularity up to 30 degrees are, however, not uncommon.
- Small shack have dimensions around 4m x 4m with roof heights between 2 - 2.5m. Other structures, such as toilets, are smaller.
- Constructed from diverse materials (e.g. plastic, iron sheeting, timber) with variable textures and colours even for a individual shack.
- Often very densely built, e.g. 2 - 3m separation.
- Situated in variable contexts although commonly characterised by a general lack of vegetation.

A lack of regularity in most shack properties implies that many of the vision cues commonly used in building extraction in other domains are less reliable for use in IS reconstruction. For example, geometrical constraints such as parallelity and orthogonality cannot be strongly imposed. Similarity measures such as those based on photometric and chromatic attributes, as used in Henricsson et al. (1996) will also be less reliable due to mixed building materials.

4.2 Considerations

The following considerations apply in developing a strategy for shack extraction from large-scale aerial imagery.

- Automation. Recognising that full automation is not attainable we aim to reduce the complexity of the shack reconstruction task by concentrating on classes of shacks most likely to be extractable and embedding the strategy in an interactive environment.
- Initial focus: "first time" mapping.
- Shack modelling: 2D roof outline and a representative height.
- Low-cost image acquisition: small format film, still video CCD, and standard & digital video are preferred for practical reasons. The desirable image characteristics listed in Sec. 2.2 are assumed.
- Integration in a desktop GIS environment. This should enable exploitation of standard functions for the I/O, management, spatial analysis, editing, visualisation and fusion of hybrid data. It also aims at enhancing the accessibility of developed tools to end users. To this end, the GIS software should be low-cost, a market standard and expandable. Stereo display should not be a requirement for data extraction, although it may be desirable for supporting interpretation.
- Simplicity. Accessibility to low-skilled operators is required, ideally enabling settlement residents to be trained in its use. This would bring the advantage of exploiting local knowledge to the system.

Integration in a desktop GIS environment implies performing shack extraction in object space. Orthoimages therefore form the image source employed. The advantage of object space reconstruction is that all geocoded sources of information, e.g. from earlier mapping epochs, can be directly exploited. Moreover, as desktop GIS nowadays support orthoimages and polygon data capture tools, interactive data capture functions already exist and can be built upon. We base our work on the PC Arc/INFO and ArcView desktop GIS products. We are integrating our shack extraction functionality into these tools using AMLs and Avenue scripts. PC-based Erdas Imagine is used for image processing tasks such as multispectral classification.

4.3 Shack Extraction Strategy

Based on the above-mentioned considerations the strategy for shack extraction shown in Figure 2 is proposed. This strategy is based on the following principles:

- Automate extraction of the simplest shacks, e.g. 4-sided shacks. As this is the most common shack form reliable automated extraction of a high percentage of this class of shacks should deliver improvement in the efficiency of geospatial database generation. This can be integrated into a operational environment as follows. If complicated shacks are first manually measured the search space for remaining simple shacks is reduced. The a priori knowledge of the number of sides of remaining shacks can be exploited in the reconstruction, especially in the grouping of edges to detect the hut outline.
- Multiple cues (e.g. edge contours, shadows, DSM etc.) are fused in a two-step procedure of shack detection followed by shack extraction.
- Manual support for the automated procedure, e.g. for complicated roofs and/or where cues are inadequate, is accommodated in the shack extraction step.

The shack reconstruction strategy assumes the existence of a detailed DTM of the area being modelled, e.g. derived from an earlier conventional photogrammetric survey. This assumption, which has wide validity given that the terrain...
is stable over time and IS development will have limited impact on it, enables image analysis to focus on orthoimages derived from the DTM. This has the advantages of simplifying the integration of cues from multiple sources (which can be derived directly from the orthoimages, e.g. classification results and shadows) and the output is in a form suitable for direct dissemination to planners, etc. Results from automated shack extraction procedures may be overlaid on the orthoimages and shacks corrected in manual fashion. The overlay capacity is of particular advantage in IS update mapping; only changes to previous epoch shack outlines need to be mapped.

**5. EVALUATION OF INFORMATION SOURCES**

**5.1 Test Imagery**

One of the goals of this work is to evaluate low-cost imaging sources for IS mapping. A test data set was derived from a stereopair of DCS460c imagery from the pilot study referred to in Sec. 2.2. Ground truth for this set was produced by manual shack measurement in the orthoimages in ArcView 3 (see Figure 3). It was measured monoscopically in one of the orthoimages although in some difficult...
cases viewing with a Leica DVP stereoviewing system was used. Note that inaccuracies in the planimetric positions of shacks extracted from single orthoimages due to their non-inclusion in the DTM are insignificant for most IS applications.

5.2 Multispectral Classification and Shadows

The potential of multispectral classification to support man-made object (MMO) extraction in digital imagery is well-recognised, however to date it has found only limited application. For example, Henricsson et al. (1996) show that for residential scenes the spectral signatures of vegetation and MMO features in scanned false-colour IR imagery are distinct enabling reliable classification into foreground and background. In IS, however, the “background” is largely bare ground which is spectrally similar to many shack materials in RGB as well as in false-colour IR imagery.

Figure 4 illustrates the results of multispectral classification on the test imagery (see Li et al. (1997) for a more detailed analysis). Note that in the test area there was an almost complete absence of vegetation, especially trees. Figure 4a shows a scattergram of the two bands after principal component analysis (PCA) on the original enhanced RGB imagery. The ellipsoids represent the $2\sigma$ variance of 5 object classes about their mean values. These classes were derived from a process of unsupervised classification to determine 10 statistically separable classes followed by merger of these classes into 5 identifiable object classes (shadows, ground and three types of shack roofs: dark, medium and bright) in a supervised classification step. The denotation of the roof classes reflects the fact that their spectral distinction lies more in differing luminance than in chromatic variation. Figure 4b illustrates the result of merging the 3 shack (light) and 2 non-shack (dark) classes. Examination of this result reveals the difficulties of shack-ground separation. Shack hypothesis generation based on multispectral classification alone leads to an unacceptable number of false alarms. Similarly, many shacks are partially classified as ground. Nevertheless, in some cases classification results could be used as an additional criterion (vote) in ambiguous cases.

5.3 Shadows

The scattergram in Figure 4a suggests that the class shadows is largely distinct of other object classes. This is confirmed by Figure 4c showing the result of multispectral classification of the image in Figure 3a into shadows and non-shadows. An equivalent result can be achieved from segmentation of grey level images. Importantly, with few exceptions the shadows have been reliably classified. This result presents a number of shack detection and extraction possibilities, particularly when combined with a digital surface model. These are detailed below.

5.4 Digital Surface Model

Dense DSMs have been shown to be useful in both the detection of buildings, i.e. as blobs on the terrain, and in building reconstruction (Baltsavias et al., 1995; Henricsson et al., 1996). Note that DSMs cannot be used for orthoimage generation due to smearing effects resulting from the imprecise modelling of MMOs. For these investigations DSMs were generated using an implementation of Geometrically Constrained Least Squares Image Matching. Exterior and interior orientation values were adopted from the triangulation study reported in Mason et al. (1997). A number of different tests were conducted using combinations of preprocessing (none, Wallis filtering and median filtering) and match point selection (image grid and points selected using an interest operator). Best results were obtained using a dense image grid on the Wallis filtered images (see Figure 5a).

Blob detection using the DSM was performed in two steps: (1) by producing the normalised DSM, i.e. DSM minus DTM; (2) thresholding of the normalised DSM at 1.5m. This threshold was chosen so as not to exclude the lowest shacks accounting for some smoothing in the DSM peaks, but to exclude possible surface features, such as...

cars. Figure 5b shows that all shacks have been at least partially included in the extracted blobs. It is evident, however, that many shack blobs are connected, thus leading to difficulties in individual shack detection. This problem can be significantly reduced by elimination of blob regions that overlay shadow regions. Figure 5c shows the result of masking the DSM blobs in Figure 5b with the shadows in Figure 4c. The shadow-refined shack blobs can be used to hypothesize shacks. Cleaning of this result is required to remove small, non-shack objects. Verification of blobs as shacks, e.g. using image texture measures (see Balt savias et al., 1995), would need to be employed in areas where vegetation exists. It is important to note that the (coarse) delineation of shacks by the resultant 2.5D blobs suffices as an end result for many IS applications, including shack counting.

5.5 Attributed Contours

Edge contours are required in shack reconstruction (cf. Figure 2) for precisely delineating shack boundaries. Related work has shown that in formal urban environments edge contour attributes such as photometry and chromaticity can be successfully employed to connect image contours (edges) for generating object surface hypotheses (Henricsson et al., 1996). We have used Henricsson's approach to extract contours and characteristic points as well as their respective attributes. Figure 6 shows the (partial) result of contour extraction in the pair of enhanced orthoimages used in the test data set. Many shacks are not completely delineated by contours, especially when the ground-roof contrast is low. Subsequent 3D matching of straight edges and a coplanar grouping would face problems due to the fact that many roof edges are close to each other and at approximately the same height. Moreover, many roofs exhibit strong internal edge contours at boundaries between different materials. These pose difficulties for reliable automatic extraction of shack boundaries in the absence of other cues. Edge contours at roof-shadow interfaces are, however, almost without exception reliably extracted in both orthoimages (cf. Figure 6).

5.6 Shack Delineation

We now consider the fusion of shack detection results with the extracted attributed contours for shack delineation. While the results of fusing shadow data with DSM blobs
are promising for shack detection, we cannot assume that all individual shacks will be accurately separated, e.g. where shack density is very high blobs may contain multiple shacks, nor that the blob boundaries will accurately delineate shack boundaries at their non-shadow borders. The fusion of shadows with edge contour data presents possibilities for automated and semi-automatic shack extraction. The high contrast between most shack roofs and shadows means that contours defining these interfaces are generally strong and well-defined. In general, these roof-shadow contours can conceivably be used to: (1) verify 3D blobs; (2) refine blob boundaries; and (3) in some cases where blobs are merged to delineate separate adjacent buildings. They can also be employed to hypothesize missing contours, e.g. to guide contour extraction procedures in revisiting local image regions.

Most importantly, however, shadow edges can provide the crucial starting point for edge grouping and automated shack extraction.

Two cases for automated shadow contour-based shack extraction are proposed in Figure 7. In Figure 7a two sides of a shack are delineated by shadow contours. These two contours can be used to generate a bounding parallelogram for the 4-sided shack. Note that the shadow direction can either be given manually for a scene or computed automatically from the time and date of image acquisition. Additional contour information can then be used to refine the parallelogram approximation (Figure 7b). Weak constraints on shack dimensions and contour parallelity and rectangularity can be used to limit the search space. The second case occurs when only one shack side is delineated by a shadow contour (Figure 7c). The DSM blob, the contours and knowledge about min/max shack dimensions are still used to hypothesize one or more bounding parallelograms. In this case, however, there is greater uncertainty in using the extracted contours to refine the delineation. Additional information such as the classification result and edge groupings based on attributes (primarily length, straightness, orientation and to a certain extent colour) may be used to generate hypotheses (Figure 7d). Where automatic extraction fails in the above mentioned cases, we propose user interaction in the form of pointing to one of the ill-defined corners in the parallelogram as a simple and rapid method to narrow the range of hypotheses to a single satisfactory delineation.

6. FIRST RESULTS

6.1 Shack Delineation from DSM Blobs

As noted above, the DSM blobs constitute coarse delineations of shacks per se. One difficulty in dense areas is that shack blobs are merged. One approach to separating blobs is morphological processing. The erosion operator can be applied to remove thin connections between blobs, albeit not without eroding true blob boundaries (a problem for small shacks) and widening holes in blobs. Dilation can be used to (partially) recover such problems. In Figure 8a the results of morphological processing of the DSM blobs shown in Figure 5c are given. This processing was carried out in ArcView using the focal minority and focal maximum functions for erosion and dilation, respectively. This raster data was converted to polygon form with generalisation of the boundaries, as shown in Figure 8b. In total 66 shacks were hypothesised from the DSM blobs of which 3 are errors of commission (created by walled but unroofed structures). All 81 shacks in the ground truth were hypothesised by a blob, at least to some extent, noting that shacks densely situated were represented by a single hypothesis. Of the total shack floor coverage of 2400m² (mean shack area 30m²) 1605m² were correctly covered, i.e. 67%.

6.2 Shack Delineation from Shadow Edges

First results with shack hypothesis generation from shadow contours are shown in Figure 9. The method shown in Figure 9 was partially implemented (thusfar without user interaction for defining the missing polygon point) in the ArcView environment. First, a set of shadow contours were selected by querying the photometric attributes of the set of contours derived with Henricsson’s method for those with significant contrast between their left and right support regions. An examination of this result given in Figure 9a shows that most free standing shacks are described, at least partially, on two sides by shadow contours. An interactive routine was developed for generating parallelograms from pairs of these contours. The user marked shack corners in the orthoimage with a single mouse click. Where two shadow contours (on an active but not visible ArcView theme) lay within a small support

Figure 7. Shack delineation (description in text).
region of the corner (radius < 1.0m), the parallelogram was defined by:

- The point of intersection of the contours, or vertex if they were joined.
- The two extreme points defining the two contours.
- A fourth point computed to complete the parallelogram.

The results are shown in Figure 9b. Only a small percentage of the shacks have been accurately delineated by this method; a larger set have been partially delineated. A number of blunders have also occurred. Inspection of the results reveals a number of problems with this simplistic approach:

- The contour extraction algorithm often breaks roof edges into sets of short contours. In such cases, contours need to be merged into longer lines in order to produce complete boundaries.

- Some shack corners have more than two contours in their vicinity. An intelligent decision needs to be made which two comprise the hypothesis. Near-rectangularity suffices as criterion in many cases but not all. This problem occurs very frequently when all extracted contours are used.

- The presence of shadow contour cannot be relied upon when shacks are very dense (e.g., see upper right hand corner of the test area in Figure 9b).

- The setting of appropriate photometric attribute thresholds for shadow/non-shadow decision-making is somewhat arbitrary.

The first two problems can be partially attributed to changes in texture along roofs. We are currently investigating solutions to these issues. It is useful to note that of the partially completed shacks, most could have been accurately delineated with the interactive definition of the closing point by the user.
7. DISCUSSION AND OUTLOOK

A strategy for shack detection and delineation from high resolution still video imagery has been presented. Central to this strategy is the integration of cues in object space. Different cues and their importance for shack reconstruction have been discussed. Preliminary investigations suggest that shack detection can be automatically performed by fusing shadow data with the 2.5D blobs derived from segmentation of a normalised DSM. These "refined" blobs suffice for a coarse delineation of the individual shacks (if they are not attached), a result which is sufficient for many IS applications (e.g. shack counting). For applications requiring more precise shack delineation we propose using the well-defined edges associated with shadows and other cues to hypothesize shack parallelograms and finally refine them. In difficult cases, user interaction in the form of a single pointing to define a shack corner is foreseen. Emphasis is initially placed on the extraction of geometrically simple 4-sided shacks either automatically or with minimal interaction as these constitute the majority of structures in IS.

In both shack detection and extraction this strategy relies on the presence of shadows in the imagery. To this end, the imagery is best acquired under bright conditions with strong sun inclination angles. We assume that, due to the uniformity of shack heights and general absence of vegetation in IS, shadows on roofs are rare (this does not always hold for some IS in tropical countries). A number of cases exist where difficulties in using shadows will occur. Dark roofs may not produce strong shadow contours. Dark materials at roof edges may lead to incorrect parallelogram hypotheses and shape irregularity.

Further investigations are required to verify the use of DSM blobs for shack detection, including:

- Reliability of DSM generation in dense settlements.
- Appropriate methods for cleaning the shadow-refined DSM blobs to remove extraneous blobs.
- The sensitivity of the strategy to the (DSM-DTM) threshold.
- Use of multispectral classification results in supporting blob definition.
- Use of blobs to predict the number of sides and approximate shape of shacks.

A 2.5D modelling of shacks is supported by the proposed shack reconstruction strategy. Currently, shack ground plans are inferred from their roof boundaries in a single orthoimage. In future, the fusion of edge contour results from orthoimages of stereopair (cf. Figure 6) will be investigated as a means of resolving (some) ambiguous cases, such as those occurring when only one shack side is defined by shadows. Future work will also include handling of shacks with more than 4 sides, as well as updating of existing shack models.

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