

ROAD ROUNDABOUT EXTRACTION FROM VERY HIGH RESOLUTION AERIAL IMAGERY

M. Ravanbakhsh, C. S. Fraser

Cooperative Research Center for Spatial Information, Department of Geomatics
University of Melbourne VIC 3010, Australia
[m.ravanbakhsh, c.fraser]@unimelb.edu.au

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ABSTRACT:

Road roundabouts, as a class of road junctions, are generally not explicitly modelled in existing road extraction approaches. This paper presents a new approach for the automatic extraction of roundabouts from aerial imagery through the use of prior knowledge from an existing topographic database. The proposed snake-based approach makes use of ziplock snakes. The external force of the ziplock snake, which is a combination of the Gradient Vector Flow force and the Balloon force, is modified based on the shape of the roundabout central island to enable the roundabout border to be delineated. Fixed boundary conditions for the proposed snake are provided by the existing road arms. A level set framework employing a hybrid evolution strategy is then exploited to extract the central island. Black-and-white aerial images of 0.1 m ground resolution taken over suburban and rural areas have been used in experimental tests which have demonstrated the validity of the proposed approach.

1. INTRODUCTION

The need for accurate spatial databases and their automatic updating is increasing rapidly. Road networks form key information layers in topographic databases since they are used in such a wide variety of applications. As the extraction of roads from images is still generally manual, costly and time-consuming, there is a growing imperative to automate the process. However, such a feature extraction task has long proved difficult to automate. The problem for automatic road extraction lies mostly in the complex content of aerial images. To ease the complexity of the image interpretation task, prior information can be used (Gerke, 2006; Boichis et al., 2000; Boichis et al., 1998; De Gunst, 1996). This often includes the provision of data from an external topographic database.

Roundabouts, as a class of road junctions, are important components of a road network and if modelled well can improve the quality of road network extraction (Boichis et al., 1998). However, there are only few approaches which are dedicated to this task. Boichis et al. (2000) presented a knowledge based system for the extraction of road junctions and roundabouts. The method assumed that the description of simple road junctions and roundabouts is the same in the external database, so a previous detector has to certify the presence of the circular form. A parametric Hough Transform is used for this purpose. The roundabout is reconstructed after straight parts of the connecting roads, curved parts including splitter islands, and the circulating road are extracted.

These elements are connected using geometric and radiometric continuities. In the approach, roads are treated as linear objects. Thus, elements such as the central island and the roundabout outline are not extracted, so kind of modelling does not always reflect the required degree of detail. In Fig. 1, vector data is superimposed on sample images to illustrate the problem. The image resolution is such that the roundabout's central area covers the central island and the circulating roadway. In Fig. 1b, the roundabout is represented as point object neglecting the central island and the circulating roadway. Thus, a detailed

modelling of roundabouts is needed for data acquisition purposes at large scales.

The detailed modelling of road roundabouts area objects is discussed in this paper, and an approach for their automatic extraction is proposed. This uses an existing topographic database leading to the extraction of refined roundabout data. In the following section, a model for roundabouts is first introduced. The stages of the proposed strategy are then illustrated in Sect. 3. Results from the implementation of the proposed approach using aerial imagery of 0.1 m ground resolution are presented and discussed in Sect. 4, together with an evaluation of their quality. Finally concluding remarks are offered.

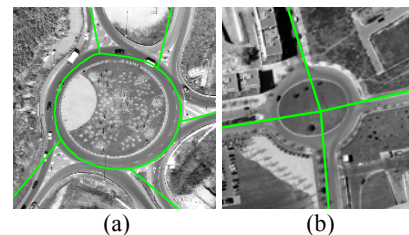


Figure 1. Superimposition of vector data on high resolution aerial images of road roundabouts.

2. ROUNDABOUT MODEL

Illustrated in Fig. 2a is the conceptual two-part model of a roundabout, the parts being the roundabout itself and the road arms. The roundabout, where road arms are connected, is in turn composed of the roundabout border and its central area where a central island is located. A road arm is a rectilinear object which is represented as a ribbon with a constant width and two parallel road edges. Disturbances such as occlusions and shadows are not explicitly included in the model.

3. EXTRACTION APPROACH

The proposed strategy consists of three steps (Fig. 2b). First, the topographic geospatial database is analysed and different types

of parameters for roundabouts are derived. Second, the central island is extracted using a level set approach making use of prior information obtained from the previous step. Finally, the roundabout is reconstructed using a snake-based method. The proposed approach has the aerial image, a topographic database and the road arms as input, and the roundabout border connected to the existing road arms as output. The reader is referred to Ravanbakhsh et al. (2008) or Ravanbakhsh (2008) for a description of how the road arms are extracted.

3.1 Pre-analysis of topographic database

Roundabouts are usually represented in topographic databases in one of two ways, either as an area object when the diameter of the inscribed circle is larger than the threshold (Fig. 1a), or as a point object when the diameter of the inscribed circle is small (Fig. 1b). The actual representation threshold varies in different topographic databases. This vector data is used to focus the extraction process to the image regions where roundabouts are located. Furthermore, the approximate diameter of the central island and width of the circular roadway can be initially determined (Fig. 3).

It is noteworthy that the width of the circular roadway depends mainly upon the number of entry lanes. The width of entry lanes is also derived from vector data. According to construction standards, the roadway must be at least as wide as the maximum entry width and generally should not exceed 1.2 times this width (U.S. Federal Highway Administration, 2000). In case that a roundabout appears as a point object, attributive information must be included in the topographic database implying that the node represents a small roundabout. This means that the diameter of the inscribed circle is below the threshold that has been defined in the topographic database.

3.2 Central island extraction

With roundabouts, a correct extraction of the central island helps facilitate the extraction of the outline. The reason for this is that the central island, when enlarged, influences the shape of the roundabout outline. The initial detection of the central island can then provide a good idea of how the outline appears in the image. The proposed method to detect central islands is based on level sets.

Geometric active contours were introduced by Caselles et al. (1993) and Malladi et al. (1995). These models are based on curve evolution theory and the level set method. The basic idea is both to represent contours as the zero level set of an implicit function in a higher dimension, usually referred to as the level set function ϕ , and to evolve the level set function according to a partial differential equation (PDE). It is well known that a signed distance function, a function which introduces the minimum distance from every point in a defined domain to the zero isocontour of a level set function, must satisfy the desirable property of $|\nabla\phi|=1$ (Osher and Fedkiw, 2002). The following formula has been proposed to provide the internal energy of a snake which penalizes the deviation of ϕ via a signed distance function (Li et al., 2005):

$$P(\phi) = \int_{\Omega} \frac{1}{2} (|\nabla\phi| - 1)^2 dx dy \quad (1)$$

$P(\phi)$ is a metric to characterize how close the function ϕ is to a signed distance function in a specified computational domain $\Omega \subset R^2$. The external energy is defined by

$$E_m(\phi) = \lambda L_g(\phi) + \nu A_g(\phi) \quad (2)$$

where $\lambda > 0$ and ν is a constant and the length term $L_g(\phi)$ and area term $A_g(\phi)$ are defined by

$$L_g(\phi) = \int_{\Omega} g \delta(\phi) |\nabla\phi| dx dy \quad (3)$$

$$A_g(\phi) = \int_{\Omega} g H(-\phi) dx dy \quad (4)$$

with the *edge indicator function* g being given by

$$g = \frac{1}{1 + |\nabla G_{\sigma} * I|^2} \quad (5)$$

Here, H is the Heaviside function, δ the univariate Dirac function, G_{σ} the Gaussian kernel with standard deviation σ , and I image intensity.

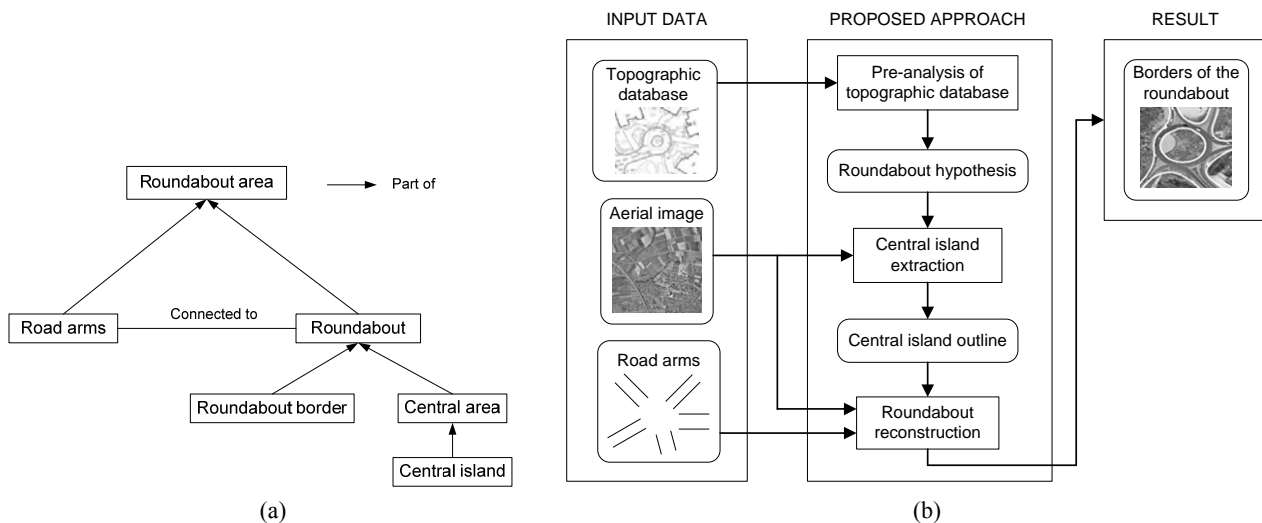


Figure 2. (a) Roundabout model and (b) workflow of roundabout extraction.

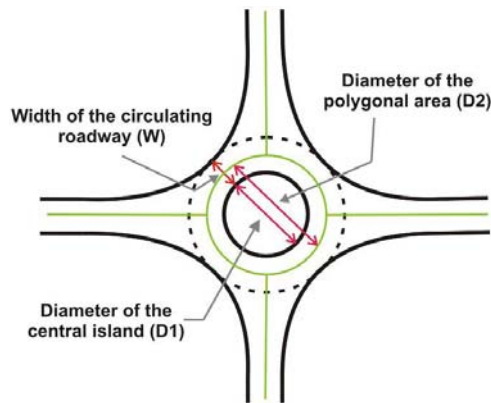


Figure 3. Schematic illustration of the relationship between roundabout geometric parameters. Vector data is in green.

The resulting total energy function can now be defined:

$$E(\phi) = \mu P(\phi) + E_m(\phi) \quad (6)$$

where $\mu > 0$ controls the balance between the first and second term. The evolution equation of the level set function is then obtained via calculus of variation (Courant & Hilbert, 1953) and application of the steepest descent process for minimization of the energy functional equation (Li et al., 2005) as

$$\frac{\partial \phi}{\partial t} = \mu [\Delta \phi - \text{div}(\frac{\nabla \phi}{|\nabla \phi|})] + \lambda \delta(\phi) \text{div}(g \frac{\nabla \phi}{|\nabla \phi|}) + v g \delta(\phi) \quad (7)$$

For all examples of central island detection, the same set of control parameters, $\lambda=4$, $\mu=0.13$, $\nu=2$ and the time step $\partial t=2$, were tuned for the evolution equation (Eq. 7).

Since either evolution type alone, shrinking and expansion, has its own limitations, a hybrid evolution strategy is employed. For instance, in case of only shrinking curve evolution, vehicles on the circulating roadway, and in case of only expansion curve evolution, structures inside the central island, can block the motion of the curve toward the central island's border. Using a hybrid evolution strategy overcomes various kinds of disturbances often present inside and outside the central island.

Often before the curve evolution begins, a pre-processing step is necessary to remove some fine features that might hinder the curve motion. First, a morphological closing operator is applied in order to remove dark spots and subsequently the opening with the same structuring element (disk structuring element; size=2) is performed to eliminate small bright features followed by Gaussian smoothing (Fig. 4c).

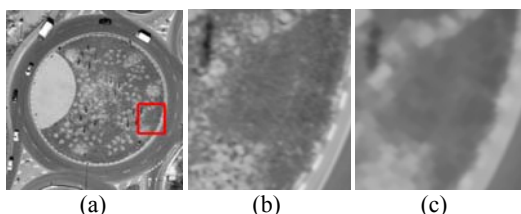


Figure 4. Pre-processing sequence: (a) Original image, (b) cut-out marked by the red box in (a), and (c) pre-processed result.

Shown in Fig. 5 is the first sequence for island extraction, when shrinkage curve evolution is applied. After the vertices of the polygonal area identified as a roundabout object in the

topographic database are located, the polygon is enlarged so that its increased area is one-tenth more than its initial area (Fig. 5a), thereby making sure that the new polygon is located outside the central island. Subsequently, shrinkage evolution begins through use of level sets. Among the obtained closed curves in Fig. 5b, the one with the largest area is selected as the initial guess for the island (Fig. 5c). This island candidate is subject to further processing.

Next, the initial polygon obtained from vector data is made smaller so that its area is reduced by half (Fig. 5a). Subsequently, expansion curve evolution occurs (Fig. 6a). The largest resulting closed curve is most likely the desired solution due to the fact that the island is the largest object within the computational domain. This closed curve, however, can often not be regarded as the island because many disturbing features such as trees and various structures exist inside the island. This can block the motion of the evolving curve towards the island boundary. Leakages are therefore created at some points along the boundary of disturbing features where zero level curves have stopped in order to pass over them.

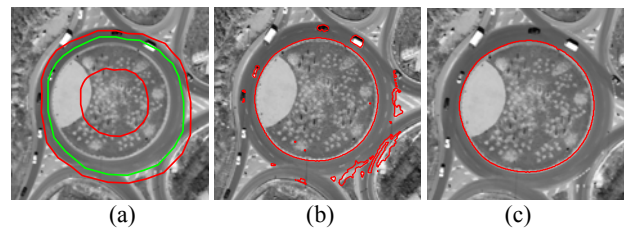


Figure 5. First sequence for island extraction: (a) Polygonal vector data (green) and its enlarged and reduced forms (red), (b) shrinking curve evolution result after 1335 iterations, and (c) the eventual result of shrinking evolution.

With the assumption that disturbing objects inside the island do not contain smooth boundaries, cubic spline approximation is carried out to provide leakages (Fig. 6b). Subsequently, expansion evolution and spline approximation are repeatedly carried out (Fig. 6c) until no change in the position of the curve is reported. Again, the largest closed curve is regarded as the island (Fig. 6d). Now that the results of island detection from the iterative expansion and shrinkage curve evolution have been obtained, the image positions of the resulting curves are compared and those points which are close to each other are selected, thereby eliminating curve positions that are not located on the island boundaries. The selection of points is based on their closeness in such a way that points having a distance below a certain threshold are selected. The final result is obtained when an ellipse is fitted to the selected points.

When a roundabout appears as a point object in the topographic database (Fig. 1b), the same hybrid evolution strategy is used but with a different initialization because the diameter of the inscribed circle is known to be below a given threshold, but how small it is is unknown. This brings some limitations for the shrinkage curve evolution. In order to apply the shrinkage evolution, the initial zero level curve must be placed outside the island. Since the approximate diameter of the inscribed circle is unknown, three successive circles are defined (Fig. 7a), on each of which the shrinkage curve evolution is carried out separately. The diameter of the circle interior to the central island is 10 m and the diameters of exterior circles have an interval of 3 m. The results of shrinkage evolution on each initial curve from the largest to the smallest circle are depicted in Figs. 7b, c and d. In the next step, the iterative expansion evolution is carried out

similarly to the method described earlier with the exception that the initial curve is defined as a circle around the roundabout node so that it must be placed inside the island (Fig. 7a).

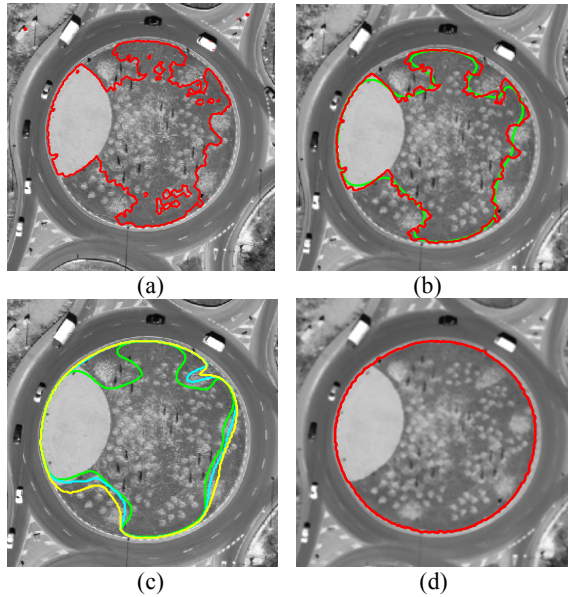


Figure 6. Island extraction: (a) Expansion evolution result after 1330 iterations, (b) selected curve (red) and approximated cubic spline (green), (c) other curves resulting from iterative curve evolution, and (d) eventual result of expansion evolution.

The diameter of the circle needs to be less than the threshold which dictates whether islands are regarded as point or area objects in the topographic database. By experiment, it is safer to define a circle with a diameter as one-third of this threshold. The expansion result is compared with each group of shrinkage results separately, and points that are close enough to each other are selected. These points are candidates for ellipse fitting. The fitting result for a case with the highest number of points is more likely to produce a correct result of island extraction (Fig. 7f).

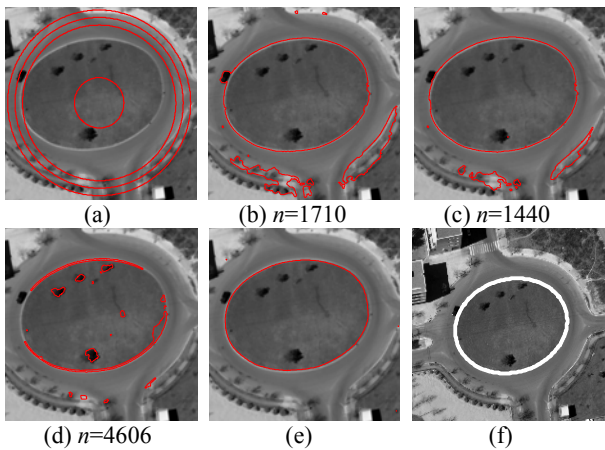


Figure 7. First sequence for island extraction: (a) initial successive circles, 3 located outside central island for shrinking evolution and 1 inside for expansion curve evolution; (b), (c) and (d) results of the shrinking evolution for exterior circles from large to small (n denotes iteration number); (e) result of iterative expansion evolution to interior circle; (f) final result.

Extracted central islands are verified using the existing information derived from the topographic database. When a roundabout appears in the database as an area object, as shown in Fig. 3, the diameter of its central island ($D1$) obtained from the extraction process must only differ from that obtained from vector data ($D2$) by a small amount. In an ideal situation, the difference (ΔD) corresponds to the width of the circulating roadway (W), i.e. $W = \Delta D$. In practice, due to the imprecise digitization of roundabouts, polygonal vector data do not always lie on the middle axis of the circulating roadway, but somewhere within its area. Therefore, ΔD is expected to be within the range of 0 to $2W$, i.e. $0 < \Delta D < 2W$.

In the case where a roundabout appears as a point feature, the diameter of the extracted central island must fall within a predefined range whose highest value is the threshold below which a roundabout is regarded as a point object and whose lowest value is the minimum possible diameter for a central island.

3.3 The Snake Model for Roundabout reconstruction

The snake model, or parametric active contour method (Kass et al., 1988), used to delineate the roundabout outline is now briefly overviewed to provide a basis for further discussion. Further details are provided in Ravanbakhsh et al. (2008) and Ravanbakhsh (2008). Snakes are especially useful for delineating objects that are hard to model with rigid geometric primitives. They are thus well suited to modeling roundabouts since the borders are of diverse shape with various degrees of curvature. Snakes are polygonal curves associated with an objective function that combines an image term (external energy) and measurement of the image force (e.g. the edge strength). There is also a regularization term (internal energy) and a minimization of the tension and curvature of the polygon. The curve is deformed so as to iteratively optimize the objective function. Traditional snakes are sensitive to noise and need precise initialization. Since roundabout borders have various degrees of curvature, a close initialization cannot often be provided. As a result, traditional snakes can easily get stuck in an undesirable local minimum.

To overcome these limitations, the *ziplock snake* model was developed (Neuenschwander et al., 1997). A ziplock snake consists of two parts: an active part and a passive part. The active part is further divided into two segments, indicated as head and tail, respectively (Fig. 8). The active and passive parts of the ziplock snake are separated by moving force boundaries. Unlike the procedure for a traditional snake, the external force derived from the image is turned on only for the active parts. Thus, the movement of passive vertices is not affected by any image forces. Starting from two short pieces, the active part is iteratively optimized to image features, and the force boundaries are progressively moved towards the centre of the snake. Each time that the force boundaries are moved, the passive part is re-interpolated using the position and direction of the end vertices of the two active segments. Optimization is stopped when force boundaries meet each other.

Ziplock snakes need far less initialization effort and are less affected by the shrinking effect from the internal energy term. Furthermore, their computation is more robust because the active part, whose energy is minimized, is always quite close to the contour being extracted. This modified snake model can detect image features even when the initialisation is far away from the solution. However, it can still become confused in the presence of disturbances. In high resolution aerial images, such

disturbances may destabilize the ziplock's active vertices. As a result convergence may not occur or the snake may get trapped near the initial position. As a means of overcoming this problem, an external force with a large capture range can be applied.

The *Gradient Vector Flow* (GVF) field (Xu & Prince, 1997), which is an example for such an external force, is used in the proposed approach. The GVF field was aimed at addressing two issues: a poor convergence to concave regions, and problems associated with the initialisation. It is computed as a spatial diffusion of the gradient of an edge map derived from the image. This computation causes diffuse forces to exist far from the object, and crisp force vectors to be near the edges. The GVF field points toward the object boundary when very near to the boundary, but varies smoothly over homogeneous image regions, extending to the image border. The main advantage of the GVF field is that it can capture a snake from a long range. Thus, the problem of far initialization can be alleviated.

The Evolution of a ziplock snake is illustrated in Fig. 8. The snake is fixed at the head and tail, and it consists of two parts, the active and the passive vertices. These parts are separated by moving force boundaries. The active parts of the snake consist of the head and tail segments.

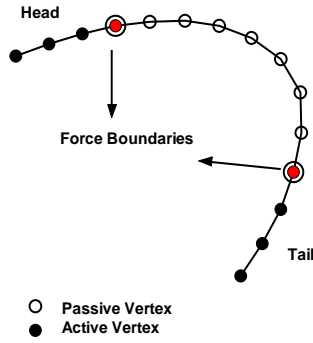


Figure 8. Evolution of a ziplock snake.

The GVF is defined to be the vector field $G(x, y) = (u(x, y), v(x, y))$ that minimizes the energy functional:

$$E = \iint \mu (u_x^2 + u_y^2 + v_x^2 + v_y^2) + |\nabla f|^2 |G - \nabla f|^2 dx dy \quad (8)$$

where ∇f is the vector field computed from $f(x, y)$ having vectors pointing toward the edges. $f(x, y)$ is derived from the image and it has the property that it is larger near the image edges.

The regularization parameter μ should be set according to the amount of noise present in the image; more noise requires a higher value of μ . Through use of calculus of variations (Courant & Hilbert, 1953), the GVF can be found by solving the following Euler equations:

$$\begin{aligned} \mu \nabla^2 u - (u - f_x)(f_x^2 + f_y^2) &= 0 \\ \mu \nabla^2 v - (v - f_y)(f_x^2 + f_y^2) &= 0 \end{aligned} \quad (9)$$

where ∇^2 is the Laplacian operator and f_x and f_y are partial derivatives of f with respect to x and y .

Let $V(s) = (x(s), y(s))$ be a parametric active contour in which s is the curve length and x and y are the image coordinates of the 2D-curve. The internal snake energy is then defined as

$$E_{\text{int}}(V(s)) = \frac{1}{2} \left[\alpha(s) |V_s(s)|^2 + \beta(s) |V_{ss}(s)|^2 \right] \quad (10)$$

where V_s and V_{ss} are the first and second derivatives of V with respect to s . The functions $\alpha(s)$ and $\beta(s)$ control the elasticity and the rigidity of the contour, respectively. The global energy

$$E = E_{\text{int}}(V(s)) + E_{\text{img}}(V(s)) \quad (11)$$

needs to be minimized, with $\alpha(s) = \alpha$ and $\beta(s) = \beta$ being constants. Minimization of the energy function of Eq. 11 gives rise to the following Euler equations:

$$-\alpha V_{ss}(s) + \beta V_{ssss}(s) + \frac{\partial E_{\text{img}}(V(s))}{\partial V(s)} = 0 \quad (12)$$

where $V(s)$ stands for either $x(s)$ or $y(s)$, and V_{ss} and V_{ssss} denote the second and fourth derivatives of V , respectively. After approximation of the derivatives with finite differences, and conversion to vector notation with $V_i = (x_i, y_i)$, the Euler equations take the form

$$\begin{aligned} \alpha_i (V_i - V_{i-1}) - \alpha_{i+1} (V_{i+1} - V_i) + \beta_{i-1} [V_{i-2} - 2V_{i-1} + V_i] \\ - 2\beta_i [V_{i-1} - 2V_i + V_{i+1}] + \beta_{i+1} [V_i - 2V_{i+1} + V_{i+2}] + G(u, v) = 0 \end{aligned} \quad (13)$$

where $G(u, v)$ is the GVF vector field. Eq. 13 can be written in matrix form as

$$KV + G(u, v) = 0 \quad (14)$$

where K is a pentadiagonal matrix.

Finally, the motion of the GVF ziplock snake can be written in the form (Kass et al., 1988)

$$V^{[t]} = (K + \gamma I)^{-1} * (\gamma V^{[t-1]} - \kappa G(u, v)|_{V^{[t-1]}}) \quad (15)$$

where γ stands for the viscosity factor (step size) determining the rate of convergence and t is the iteration index. κ alters the strength of the external force.

It is noteworthy that the proposed model still might fail to detect the correct boundaries in the following cases:

- High variation of curvature at the roundabout border resulting in an initialization that is too poor in some parts, with the consequence that the snakes becomes and remain straight.
- The roundabout central area lacks sufficient contrast with the surroundings, causing the curve to converge to nearby features.

Through the use of shape description parameters such as curvature computed from the snake vertices, another force can be added to the GVF force field. This is the so-called *balloon force*, which lets the contour have a more dynamic behaviour (Cohen, 1991), thereby addressing the two described problems. This new force, which makes the contour act like a balloon, applies an inflating effect to the contour to localize the concave part of the roundabout outline:

$$F = k_1 \vec{n}(s) \quad (16)$$

where $\vec{n}(s)$ is the normal unitary vector of the curve at point $V(s)$ and k_1 is the amplitude of the force. The combination of the GVF force field and the balloon force modifies Eq. 15 to the form

$$V^{[l]} = (K + \gamma I)^{-1} * (\gamma V^{[l-1]} - \kappa G(u, v)_{v|_{v^{[l-1]}}} - k_1 \vec{n}(s)) \quad (17)$$

The balloon force is activated when the snake's passive and active parts are approximately straight, i.e. their overall curvature, which is defined as the sum of the absolute curvatures along the curve, is below a threshold. It is applied only on the passive part of the curve. This is regarded as lying outside the roundabout's border, whereas the snake at the active parts is assumed to be on the right track. The direction in which the balloon force is applied is towards the roundabout central area. However, in order to be able to delineate the roundabout outline, the balloon force has to be applied in two different directions, central island inwards and outwards (Fig. 9a).

The answer to the question of when and in which direction the balloon force needs to be applied differs for different samples. As a result, several parameters need to be tuned on an ad hoc basis to address this question, which is not a desirable requirement. To resolve this, the external force field of the snake approach described so far is modified based on the shape of the central island. As the shape of the roundabout outline corresponds to the shape of the enlarged central island, the island is enlarged to an extent depending on the width of the circulating roadway (Fig. 9b). Subsequently the snake external force field is modified based on the enlarged central island. The external force field in the enlarged central island is replaced with the GVF of an intensity-step image (Fig. 9c) whose main characteristic is that its external force points directly from the centre outwards so that snakes situated in this area are drawn toward the outline of the roundabout.

The intensity-step image is generated from a signed distance function. To generate this function, the border of the enlarged central island is taken as the reference (Fig. 9b). Successive concentric layers at a specific distance interval from the reference to the centre point are then defined. Conversely, proportional to the distance of each layer to the reference, an intensity value is calculated and assigned to the respective layer, i.e. layers closer to the reference curve are brighter and vice versa.

The obtained intensity-step image has a gradual increase of intensity values from the centre point towards the reference curve. Consequently, its GVF field points directly outward. The modified force field pulls the snakes toward the outline even if the initialization is far away from true borders. Furthermore, with this modified force field, problems created by the presence of various kinds of disturbances such as trees and vehicles within and outside the central island are overcome. An example illustrating the improved result using the proposed modified force field is shown in Fig. 10. The complete reconstruction of a

roundabout using the proposed modified snake model is shown in Fig. 11, along with intermediate results.

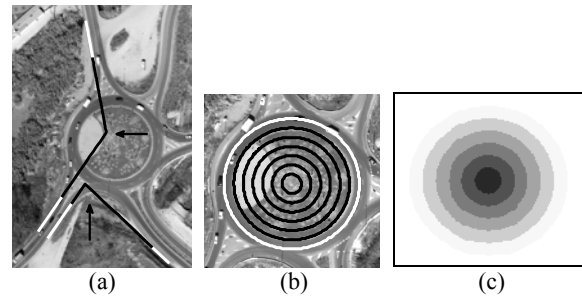


Figure 9. (a) Two directions in which the balloon force is applied; (b) reference for the signed distance function (white curve) computation and concentric regions (black curves); (c) intensity-step image from the signed distance function.

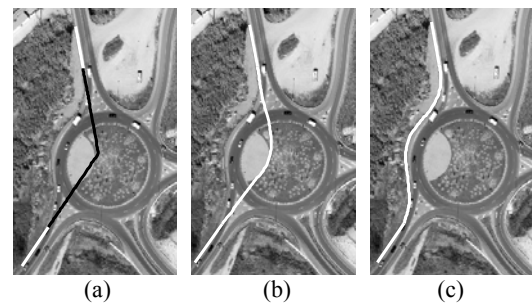


Figure 10. The effect of the modified external force field: (a) intersection lines (black) from initial snakes, (b) results from unmodified GVF, and (c) improved results with modified GVF.

4. RESULTS AND EVALUATION

The proposed approach was tested using 0.1m GSD panchromatic aerial orthoimagery covering rural and suburban areas. The Authoritative Topographic Cartographic Information System of Germany (ATKIS), which nominally corresponds to a mapping scale of 1:25,000, was used as the source of external vector data. Roads are modelled as linear objects in ATKIS. Tests were conducted on 10 roundabouts. Sample results that highlight the capabilities of the proposed approach are shown in Fig. 12, where it can be seen that the method can deal with a variety of disturbances inside and outside the central island. Also, most of the roundabout borders were captured correctly. However, in areas where the curvature of the outline was too high, as is the case in the top-left example (lower border) and top-right image (right border), roundabout borders were extracted with some deviation.

In order to evaluate the performance of the approach, the extracted roundabout areas were compared to the manually plotted roundabouts used as reference data. The comparison was carried out by matching the extracted road borders resulting from the connection of the roundabout to its associated road arms to the reference data using the so-called *buffer method* (Heipke et al. 1998). Although the buffer width can be defined using the required accuracy of ATKIS, which for a road object is defined as 3m, it was decided to set the buffer width within the range of 0.5 m to 3 m, i.e. 5 pixels to 30 pixels, in concert with the image resolution of 0.1 m. This allowed assessment of the relevance of the approach for practical applications that demand varying degrees of accuracy.

An extracted road border is assumed to be correct if the maximum distance between the extracted road border and its corresponding reference does not exceed the buffer width.

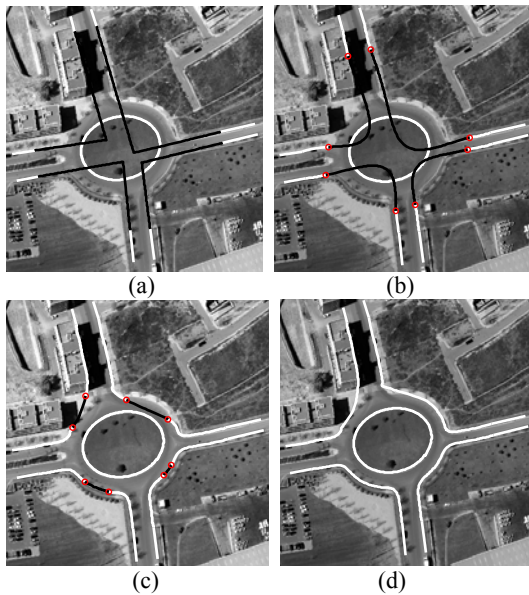


Figure 11. Capture of roundabout outline: (a) initial snakes in black and road arms in white, (b) and (c) evolving curves, and (d) reconstructed roundabout.

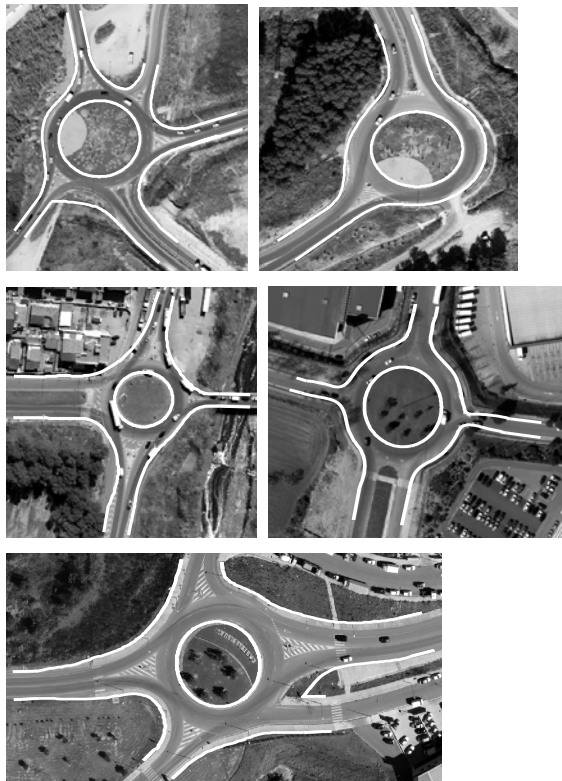


Figure 12. Sample roundabout extraction results for scenes with varying degrees of complexity including disturbances.

A smaller value of the buffer width can be chosen for an application that requires more accurate extraction results. A reference road border is assumed to be matched if the maximum deviation from the extracted object is within the buffer width.

Based on these assumptions, three quality measures were adopted, the first being completeness, which is the ratio of the number of matched reference road borders to the number of reference objects. The second is correctness, which is the ratio of the number of correctly extracted road borders to the number of extracted objects, while the third is geometric accuracy, which is expressed by the average distance between the correctly extracted road border and the corresponding reference border, expressed as a Root Mean Square (RMS) value falling within the range of $[0, \text{buffer width}]$.

Road border extraction results computed with different buffer width values are shown in Table 1. The completeness of the road border extraction increased as the buffer width value increased from 0.5m to 3m, implying that the results are more complete for higher buffer width values. The geometric accuracy increase is inversely proportional to buffer width so that results obtained with a value of 0.5m are more accurate than those obtained with a larger buffer width. For the buffer width value 0.5 m, the completeness is rather low. The reason is that a slight deviation of the extraction results from the true boundaries exceeding the buffer width frequently occurs due to disturbances and sometimes also due to road markings.

Buffer width (m)	0.5	1	2	3
Number of road borders	41	41	41	41
Completeness	53%	62%	74%	85%
Geometric accuracy (m)	0.30	0.38	0.50	0.58

Table 1. Evaluation results for road borders.

As seen in Table 2, a favourable evaluation result was achieved in the extraction of central islands, which proved the robustness of the proposed method. Central islands of roundabouts were extracted with high values for completeness and correctness for the buffer width of 0.5m, implying the effectiveness of the proposed hybrid evolution strategy. For the buffer width value 1m, all of central islands were extracted correctly.

Buffer width (m)	0.5	1
Number of central islands	10	10
Completeness	90%	100%
Correctness	90%	100%
Geometric accuracy (m)	0.26	0.35

Table 2. Evaluation results for central islands.

5. CONCLUDING REMARKS

A new snake-based approach to automatic extraction of road roundabouts has been described and analysed. Under the approach, the snake's external force field is modified based on the shape of the central island to delineate the roundabout border. The modified snake force field can overcome various disturbances inside and outside the central island. It was shown that the use of prior-knowledge derived from an existing topographic database can considerably enhance the extraction performance. Furthermore, a level set approach with a hybrid evolution strategy was proposed to extract central islands. This produced good results in all 10 test cases, as central islands were extracted correctly for an assigned buffer width of 1m. Nevertheless, partial occlusion of the central island border by large trees and shadowing cannot be overcome at this stage (Fig. 13). There are several possibilities to further enhance the results obtained so far and to be able to deal with more complex scenes. The incorporation of high-level prior knowledge about

the shape of central islands within the level set framework can potentially provide a solution to these problems.



Figure 13. Example of a central island that cannot be extracted due to heavy occlusions caused by trees and shadows.

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