DETECTING THE TOPOGRAPHIC CHANGES OF SPATIAL FEATURES FROM SATELLITE IMAGES WITH THE EDGE FLOW TECHNIQUES

Yishuo Huang & **Jin-Guei Cheng**
Department of Construction Engineering
Chaoyang University of Technology
Wufeng, Taiwan 413
yishuo@cyut.edu.tw

ABSTRACT

The covered areas of a river play an important role to analyze the causes of debris flows. The damages caused with debris flows costs over thousand million dollars in Taiwan. Usually, after nature disasters passed, like typhoons and earthquakes, the topographic conditions are changed. How to locate those topographic changes is an important research issue in protecting people from natural disaster damages. Remote sensing is an efficient way to study those topographic conditions which occurred before and after those areas visited with natural disasters. This research processes satellite imagery to identify the regional boundaries for the topographic changes of the Chen-Yu-Lan River, Natou County, Taiwan. The regional boundaries are extracted with employing edge flow approach implemented with level set method such that the extracted regions have homogeneous data distribution. With level set algorithms, regions are merged if the regional data distributions are similar. Otherwise, regions are split if the regional data distributions are not close enough. Comparing the extracted regional boundaries at different times is the way to track the spatial changes of the covered areas of the Chen-Yu-Lan River. The research results demonstrate that the proposed algorithm can be used to track the topographic changes, and provides the clue to study the behaviors of debris flows.

INTRODUCTION

Taiwan is the island located at the southeastern Asia. Unfortunately, the Eurasian tectonic plate and the Philippine Sea plate meet at Taiwan. The collisions of two plates often occur, and cause earthquakes. The geologic faults over the island are generated with the collisions, too. In addition to geologic condition, Taiwan is also located at paths while typhoons visit the southeaster China. Usually, typhoons carry heavy rainfall and cause damages on the island. Combining the rainfall and geological conditions generates a perfect environment to give the birth of a debris flow. In 1996, there were 485 debris flows covering over the island. After the 921 Earthquake which occurred in 2000, the numbers of debris flows are increased to over 700. On July 30, 2001, the Toraji Typhoon visited the central Taiwan, and caused the finical lost over thousand million dollars and the deaths over 200. The Chen-Yu-Lan River played an important role for those damage caused with the Toraji typhoon because the river brought lots stones, mud and water to destroy everything while the river passed through. The Chen-Yu-Lan River located at central Taiwan is the main branch of the Choshui River, the longest river in Taiwan. The Chen-Yu-Lan River has wide and flat river bed. In the river bed, the river is divided into several creeks spread over the whole river bed. The average slope of the river bed is around 0.2 to 1 degree. However, the slope will be 3 to 60 degree while the river passes through the mountain areas, like the Central Mountain Range and the Snow Mountain Range. The characteristics of the Chen-Yu-Lan River is that the slopes of the river bed change abruptly such that during the raining season, the river can easily become flood and causes great damage on the surrounding areas. The geographic locations of the Chen-Yu-Lan and other identified debris flows are shown in Figure 1. Remote sensing is an important technique to study the spatial changes of the Chen-Yu-Lan River.

Remote sensing provides a way to study spatial features from satellite imagery. Image classification plays an important role to explore the information contained in satellite imagery. In general, image classification can be based on supervised and unsupervised classification ideas. Several classification methods have been proposed, and lots of them are based on the theories of statistical inference. However, for the specified spatial feature, there are supposed to have an efficient way to isolate the specified feature from its surroundings. In 1988, Kass and Witkin proposed that extracting regional boundaries with the iteration approaches based on minimum energy (Kass, 1988). The proposed method is called the snake Model or deformable Model. Kichenassamy extracted regional boundaries with partial differential equations, PDEs, and evolving curve (Kichenassamy, 1995). The snake model is known as using parameters to represent the curves or surfaces (Cohen, 1991). Osher and Sethian proposed a way to evolve the specified curve with energy tendencies to divide the whole image into several sub-regions such that in each sub-region, the pixel values are homogeneous (Osher, 1988; Sethian, 1990). The algorithm is called as level set method.

Evolving curve implemented with level set method can extract the specified spatial features from the given imagery. This paper tries to extract the boundaries of the Chen-Yu-Lan River from SPOT images to monitor the topographic change, especially before and after a natural disaster visited. Usually, an object's boundary is extracted with segmenting the whole image into different sub-region such that pixel values in a sub-region are different with those pixel values located at surrounding sub-regions. From the points of forces, an object's boundary is the position while those forces acting on the object reach equilibrium. Those forces can be classified internal forces and external forces: external forces try to extend the regional boundary outward, and internal forces shrink the regional boundary inward. Those forces act on the regional boundaries like the edges shown in the image. Ma called this phenomena, the edge flows (Ma, 2000). This paper employs the edge flow as forces act on the object. With level set method, the boundaries can be precisely extracted with increasing iteration times. This paper tries to track the boundaries of the Chen-Yu-Lan River with satellite images taken at different times to evaluate its spatial changes.

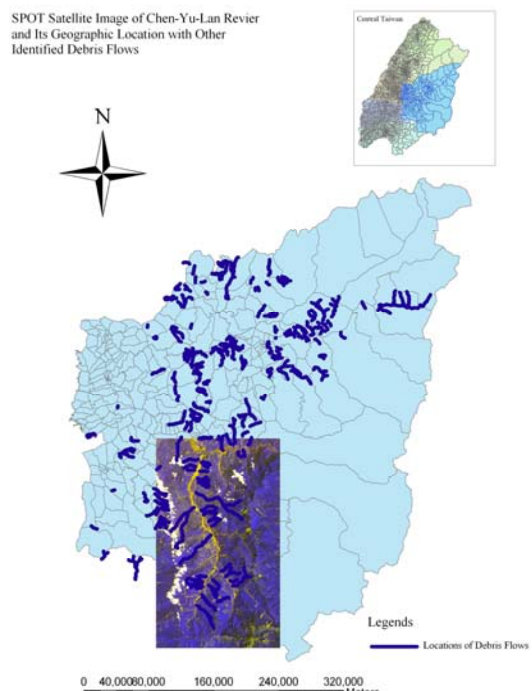


Figure 1. The geographic locations of the Chen-Yu-Lan River and surrounding identified debris flows.

Curve Evolution Implemented with Edge Flows

The snake model is an efficient way to extract an object's boundary. In the Snake model developed by Kass, the image model is composed with different closed sets such that those elements in each closed set are homogeneous. Each closed set is surrounded with a closed curve, and is shown mathematically as follows

$$\Gamma = \bigcup_{i \in I} C_i \text{ --(1)}$$

where C_i is a closed curve with piece-wise continuous property, and is defined as $C = \{c : [a \quad b] \to \Omega, c(a) = c(b), and \quad c \quad is \quad piecewise\}$. The energy, $E(c)$, in the closed curve is supposed to include the internal and external forces acting on the closed curve. The internal forces in the closed curve try to shrink and push the curve inward. On the other hand, the external forces pull the curve outward. The internal forces and external forces gradually reach the equilibrium. At the same time, the closed curve slowly moves. Eventually, the closed curve is stopped while the internal forces are equal to external forces. In the other words, the image energy reaches its minimum. The final shape of the closed curve is located at the object's boundary. The energy is defined as follows

$$E(c)=\left[\int_a^b |c'(q)|dq+\beta\int_a^b |c''(q)|dq\right]+\lambda\int_a^b g^2(|\nabla I(c(q))|)dq \text{ --- (2)}$$

where $c(q)=(c_x(q),c_y(q))$, $c'(q)=(\frac{dc_x}{dq},\frac{dc_y}{dq})$ and $|c'(q)|=\sqrt{\left(\frac{dc_x}{dq}\right)^2+\left(\frac{dc_y}{dq}\right)^2}$. Similarly, *c*" is the second derivative of the closed curve, *c*. With applying the calculus of variation, the equation (2) can be rewritten as Euler-Lagrange equation (Hilbert, 1985; Aubert, 2001).

Malladi proposed to employ level set approach to identify the regional boundary (Malladi, 1995). Level set is an approach to consider a closed curve which is moving toward the object's boundary with increasing time while the forces acting on the curve are the same. In general, the initial curve is called the zero level set, and time parameter is set to zero, *t*=0. While the time parameter is cumulated, the curve is moving along its normal direction with the speed function, *F(k)*. For simplicity, the b shown in the equation (2) is set to zero such that Euler-Lagrange equation is shown as follows (Caselles, 1995).

$$\frac{\partial u}{\partial t}=g(I)|\nabla u|div(\frac{\nabla u}{|\nabla u|})+\nabla g\cdot\nabla u=g|\nabla u|\kappa+\nabla g\cdot\nabla u \text{ -- (3)}$$

where *I* is the original image, ∇ is defined as the gradient operator, $g(I)=\frac{1}{1+|\nabla I|^2}$, *u* is the image containing the curve, $div(\frac{\nabla u}{|\nabla u|})=\frac{u_{xx}u_y^2+u_{yy}u_x^2-2u_xu_yu_{xy}}{(u_x^2+u_y^2)^{3/2}}$=k and · is the inner product. Employing finite difference approach and initial condition, the equation (3) can be rewritten as

$$u_{i,j}^{n+1}=u_{i,j}^n+\Delta t\nabla^+u_{i,j}^n \quad \text{and} \quad u((),x)=u_0(x) \text{ -- (4)}$$

where Δt is the time interval, $\nabla^+u_{i,j}^n=\begin{bmatrix}\max(\delta_x^-u_{i,j}^n,0)^2+\min(\delta_x^+u_{i,j}^n,0)^2+\\ \max(\delta_y^-u_{i,j}^n,0)^2+\min(\delta_y^+u_{i,j}^n,0)^2\end{bmatrix}^{1/2}$, $\delta_x^+u_{i,j}^n=\frac{u_{i+1,j}^n-u_{i,j}^n}{\Delta x}$, $\delta_x^-u_{i,j}^n=\frac{u_{i,j}^n-u_{i-1,j}^n}{\Delta x}$, and $\delta_y^+u_{i,j}^n$ and $\delta_y^-u_{i,j}^n$ are similar to $\delta_x^+u_{i,j}^n$ and $\delta_x^-u_{i,j}^n$ except the direction. Edge flows can be recognized as the external force.

Edge flows employ anisotropic diffusion to generate the vector information of the given image. Anisotropic diffusion was used to detect texture boundaries (Rubner, 1996). The energy of vector information is defined as follows

$$F(s,\theta)=[E(s,\theta),P(s,\theta),P(s,\theta+\pi)] \text{ -- (5)}$$

where $E(s,\theta)$ is the edge energy at position s along θ direction, $P(s,\theta)$ is the probability at position s along θ direction and $P(s,\theta+\pi)$ is the probability at position s along $\theta+\pi$ (Ma, 2000). Gaussian function is introduced to calculate edge energy. Gaussian function in two-dimensional form is given as follows

$$G_\sigma(x,y)=(\frac{1}{\sqrt{2\pi\sigma}})\exp(-\frac{x^2+y^2}{2\sigma^2}) \text{ --- (6)}$$

The first order derivative of equation (6) with respect x direction is $\frac{\partial G_\sigma(x,y)}{\partial x}=-\frac{x}{\sigma^2}G_\sigma(x,y)$. The energy function, $E(s,\theta)$, at the specified scale σ is defined as follows

$$E(s,\theta) = \left|\frac{\partial}{\partial n} I_\sigma(x,y)\right| = \left|\frac{\partial}{\partial n}\left[I(x,y) * G_\sigma(x,y)\right]\right| \quad \text{------(7)}$$

where * is the convolution operator between the given image, *I*, and 2D Gaussian function. The probability, $P(s,\theta)$, is given as follows

$$p(s,\theta) = \frac{Error(s,\theta)}{Error(s,\theta) + Error(s,\theta+\pi)} \quad \text{------(8)}$$

where $Error(s,\theta) = \left|I_\sigma(x + d\cos\theta, y + d\sin\theta) - I_\sigma(x,y)\right|$ and *d* is the shift in x direction.

TRACKING THE SPATIAL CHANGES OF CHEN-YU-LAN RIVER

The research employs level set and edge flow method to extract the boundaries of the Chen-Yu-Lan River at different times. Comparing the boundaries collected at different times is the way to identify the spatial changes of the Chen-Yu-Lan. In this paper, two satellite images were taken on May 11th and July 12th, 2004. In other words, an image was taken before the Typhoon Mindulle, the typhoon visited Taiwan on July 2nd, 2004. The typhoon caused the deaths of twenty-five people and finical lost over four million dollars; the other image was taken after the typhoon had visited. Those images are illustrated in Figure 2 and Figure 3. The aerial photos of the Chen-Yu-Lan River were taken on the middle of July, 2004. Those photos arranged their geographic coordinates are shown in Figure 4.

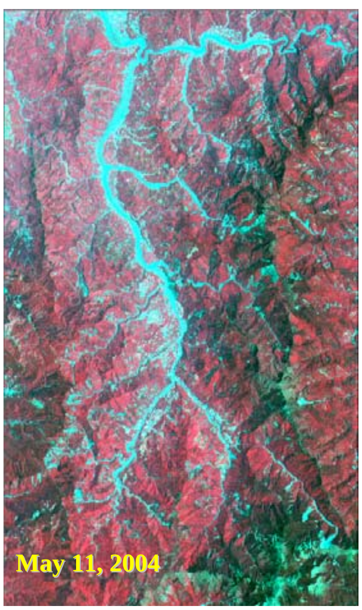


Figure 2. The image was taken on May 11th, 2004.

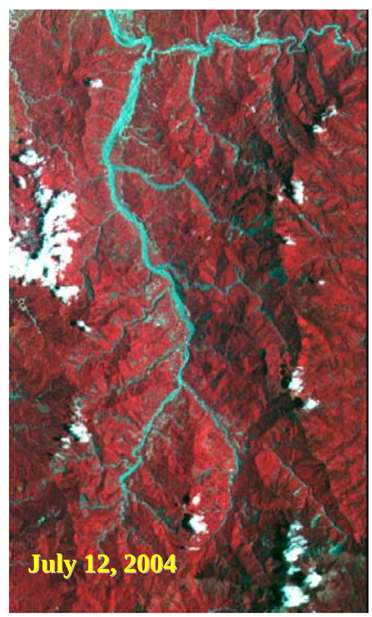


Figure 3. The image was taken on July 12th, 2004.

Figure 4. The aerial photos of the Chen-Yu-Lan River were taken after the typhoon had visited in 2004.

Edge flows is the vector information contained in the given image. This paper employs edge flows as forces acting on the initial curve to extract the boundaries of the specified spatial features. The green band information of the given SPOT image is shown in gray levels and is employed to extract edge flows. Figure 5 shows the grand band information in gray levels. The characteristics of the image in the horizontal direction is extracted and shown in the Figure 6(a). Similarly, the Figure 6(b) illustrates the characteristics of image in the vertical direction. The information of edge flows is in the Figure 7.

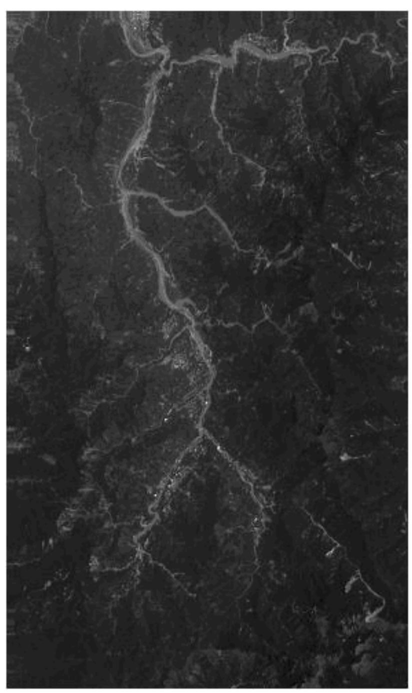


Figure 5. The green band information in gray levels is shown.

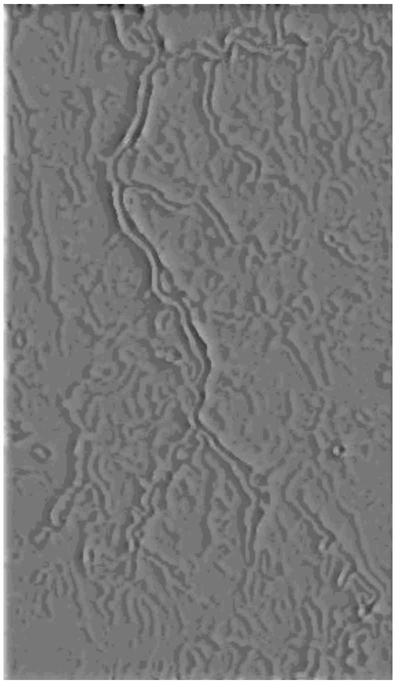


Figure 6(a). Information in horizontal direction.

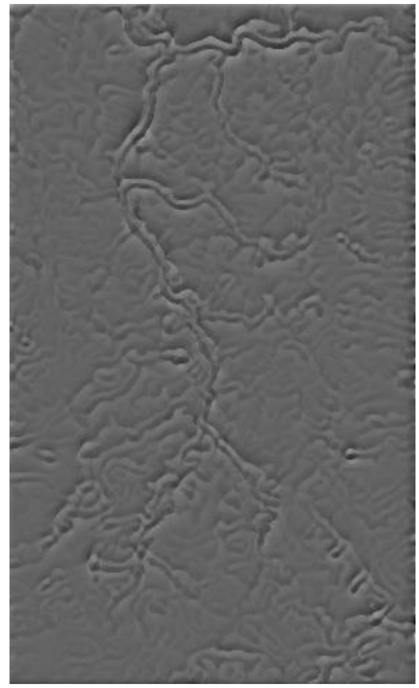


Figure 6(b). Information in vertical direction.

Figure 6. The characteristic of the image is shown.

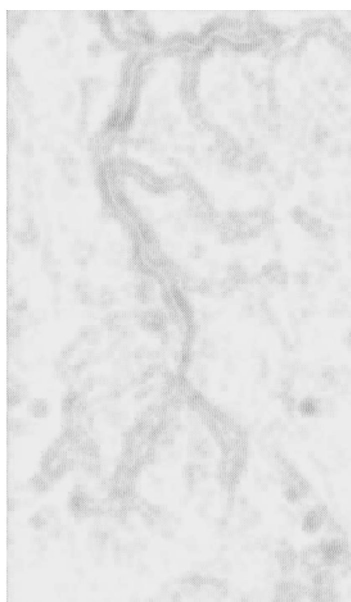
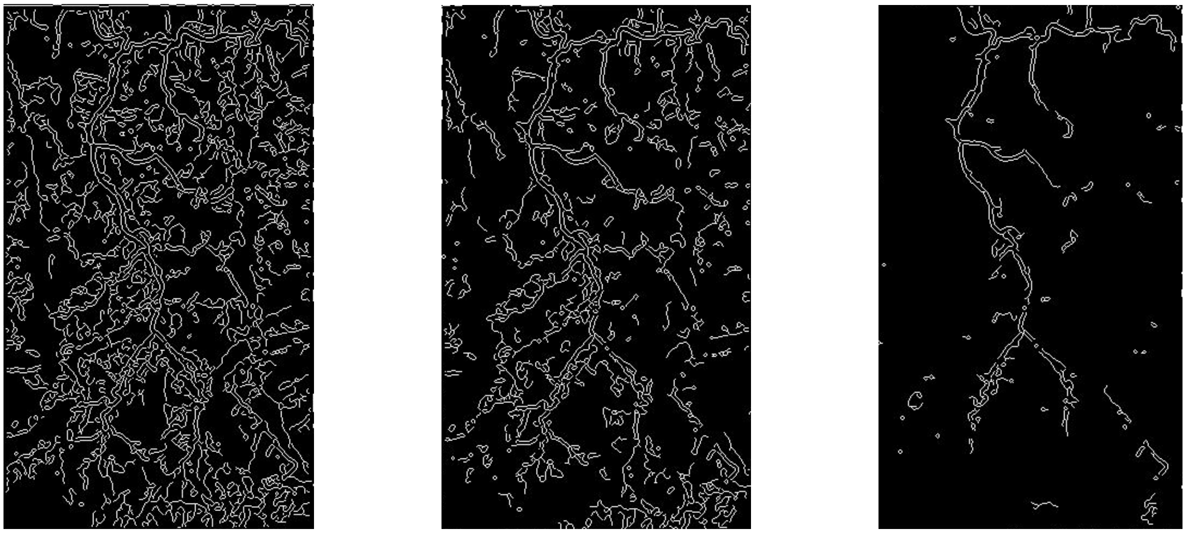


Figure 7. The edge flows of the given image are generated with the algorithm introduced in the paper.

With the generated edge flows, level set approach is employed to implement the curve evolution. With increasing the time parameter, the zero level set is moving toward the boundaries. Instead of increasing the time parameter, the number of iterations is increased. The series of results with the different numbers of iterations are shown in the Figure 8.



Results after 25 iterations Results after 50 iterations Results after 60 iterations

Figure 8. The extracted spatial boundaries with the proposed approaches are shown.

TRACKING THE CHANGE OF THE SPECIFIED SPATIAL FEATURES

The proposed approach can effectively extract the specified spatial features. Tracking the changes of the spatial boundaries can be used to evaluate how natural disasters damaged the topography after the disasters have visited. With employing edge flows and level set approach, the spatial boundaries are extracted from the given images, and the results are shown in Figure 9. With overlaying the extracted boundaries together, the spatial changes between two images are extracted and shown in Figure 10. From Figure 10, the upper areas of the Chen-Yu-Lan River show the difference between two images. The difference shows that river bed is decreased after the typhoon had visited. Possibly, the debris flow brought lots of rocks, stones and sand stacked on the river bed. In implementing level set method, how many numbers of the iteration are needed to extract the spatial boundaries is still an interested issue. Chan proposed a method to calculate the mean values inside and outside the specified regions provides a threshold to stop iteration (Chan, 2001). In future, the proposed threshold will be employed to evaluate its effects on the algorithm used in this paper.

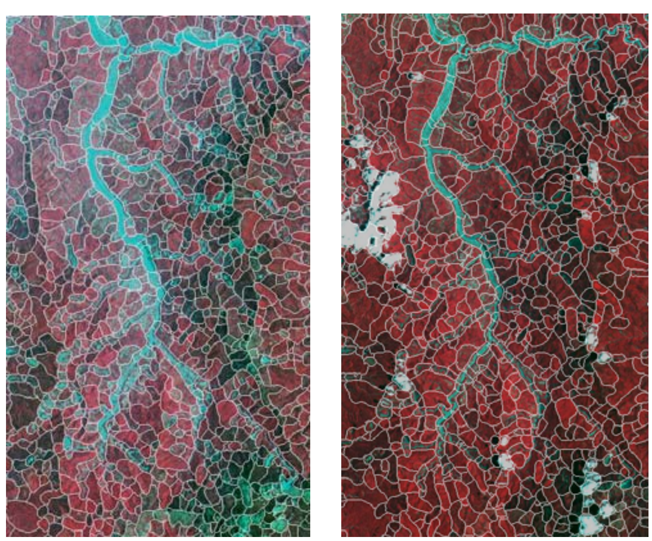


Figure 9. The extracted boundaries with proposed approach are shown.

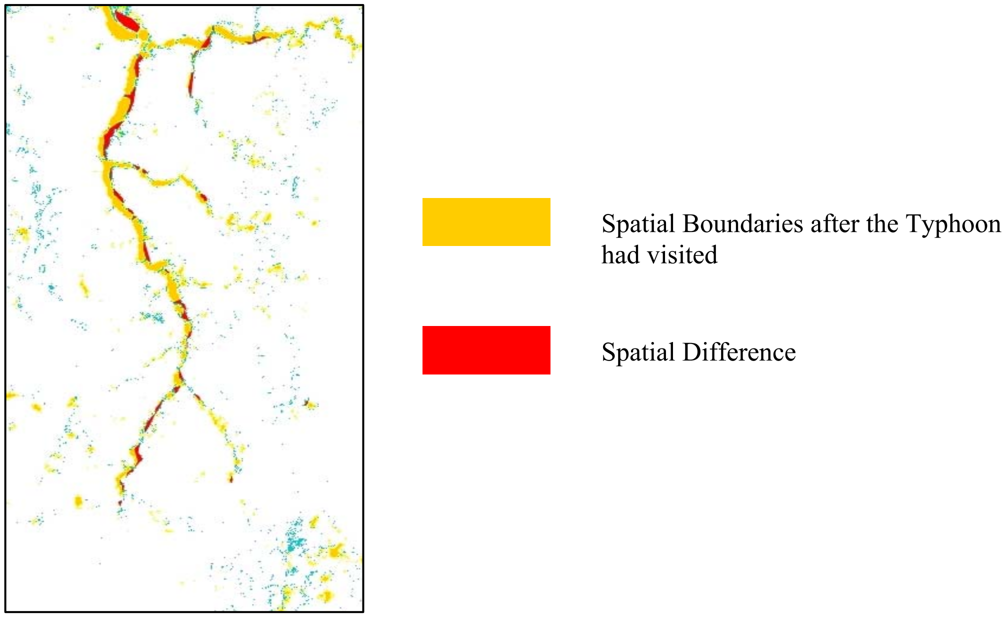


Figure 10. The spatial difference of two extracted boundaries is given.

ACKNOWLEDGEMENTS

The authors like to show their appreciations to Dr. Sumengen for his matlab toolbox to implement level set methods (Sumengen, 2005).

REFERENCES

Ma., W.Y. and Manjunath, B. S., 2000. EdgeFlow: A Technique for Boundary Detection and Image Segmentation, *IEEE Trans. on Image Processing*, Vol. 9, No. 8, pp. 1375-1388.

Rubner, Y. and Tomasi, O., 1996. Coalescing texture descriptors, Proceedings of ARPA Image Understanding Workshop, pp. 927-935.

Courant, R. and Hilbert, D., 1989. *Methods of Mathematical Physics*, Wiley.

Aubert, G. and Kornprobst, P., 2001. *Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations*, Springer.

Osher, S. and Fedkiw, R., 2002. *Level Set Methods and Dynamic Implicit Surfaces*, Springer.

M. Kass, A. Witkin, and D. Terzopoulos, "Snake: Active Contour Model," *International Journal of Computer Vision*, Vol. 1, pp. 321-331, 1988.

S. Kichenassamy *et al*., 1995. "Gradient flows and geometric active contour models," in *Proc. 5th International Conference on Computer Vision*, Boston, MA., USA.

L. D. Cohen, 1991. "On the active contour models and balloons," *Computer Vision, Graphics, and Image Processing*, Vol. 53, No. 2, pp. 211-218.

S. Osher and J. A. Sethian, 1989. "Fronts propagating with curvature dependent speed: Algorithms based on Hamilton-Jacobi formulation," *Journal of Computational Physics*, Vol. 79, pp.12-49.

J.A. Sethian, 1985. "Curvature and the evolution of fronts," Communication in *Mathematical Physics*, Vol. 101, pp. 487-499.

R. Malladi, J. A. Sethian and B. Vermuri, 1995. "Shape Modeling with Front Propagation: A Level Set Approach," *IEEE Trans. on PAMI*, Vol. 17, No.2, pp.158-175.

Chan, T. F. and Vese, L. A., 2001, "Active Contours without Edges," *IEEE Trans. on Image Processing*, Vol.10, No.2, pp. 266-277.

Sumengen, B., 2005, A Matlab Toolbox for implementing Level Set Methods, barissumengen.com/level_set_methods/index.html.