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Dam risk analysis system based on ZigBee+GIS at big data era

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Abstract. At big data era, to improve performance of dam risk analysis algorithm, aimed at risk analysis of Dongzhou reservoir dam of Shandong Province, the dam risk analysis system based on ZigBee+GIS is designed. Firstly, detection algorithm shall be designed, and 4 steps are contained in total: (1) selection of single object; (2) characteristic generation of object selected; (3) object condition classification; (4) ZigBee data information import. Secondly, vector and raster ZigBee data profile matching detection algorithm shall be proposed, a continuous edge with data characteristic width shall be generated as output, and aimed at problem that raster profile shall traverse center of ZigBee search window, search window position correction algorithm is designed, and aimed at flexible window size, gray level space dependency matrix of improved type is designed by converting relevant vector object into raster format. Finally, effectiveness of method proposed in dam risk analysis is verified through simulation experiment.

Key words. ZigBee network, GIS vector raster, Dam risk, Bid dat.

1. Introduction

At present, common system analysis method in domestic and foreign dam risk analysis includes event tree and failure tree method. They can express logical relationship among events of different levels in system better and correlation degree among events, thus making qualitative and quantitative analysis to system. But when system is relatively complex, there are relatively numerous event states, common cause failure exists or when backward inference is required, it will be difficult and even impossible to realize expression and analysis to system through event tree and failure tree method.

Most general ZigBee data processing methods make ground change detection by comparing ZigBee data of the same scene obtained within the same time. However, successful analysis can only be made by using the same sensor at the same season

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and the same time of the same day under cloudless condition. In addition, if ZigBee data acquisition angle is different, dam risk analysis and detection analysis accuracy will be affected. Therefore, it is necessary to consider additional information and expand ZigBee data processing. Integration of ZigBee data and GIS technology has always been research direction concerned in recent years. Application of vector information based on GIS can make object-oriented analysis and additional attribute information processing effectively, thus reducing misdescription caused by relevant factors, such as seasonality, whether and acquisition angle etc. At present, ZigBee data and GIS technology have been utilized in many literatures to detect ground change. For example, information used in literature [6] is sourced from satellite ZigBee data at pre-event and post-event on vector data and extracted from vector object by comparing different texture characteristics. Literature [7] used dam roof GIS data extracted from multidate ZigBee data to make damage evaluation and the author proposed a correction method and made roof regional position extraction by considering ZigBee data roof position displacement caused by different acquisition angle. Literature [8] proposed a comprehensive, taking collapsed dam as research emphasis and making difference detection through grey level and gradient of collapsed and complete dam. Literature [9] assumed that structure of a complete dam is uniform while damaged dam surface is isomerous correspondingly and made dam damage detection based on GIS vector data. In derived rectangular region, continuous uniform region is chosen as roof position and evaluation is made to dam.

Method proposed makes analysis based on dam profile completeness and dam land occupation texture corresponded by ZigBee data, and analyzes vector object change by utilizing texture direction of ZigBee data and homogenization. Then, develop a kind of new method to evaluate dam profile completeness, propose vector and raster data profile matching detection algorithm, and design search window position correction algorithm aimed at problem that raster profile shall traverse center of search window. Method proposed can be used to detect dam damage and newly-built dam and guide dam land source planning.

2. Risk mode of Dongzhou reservoir dam of Shandong Province

Dongzhou reservoir dam of Shandong Province is located at Qingliu River, branch of the Chuhe River that is roughly 18 km away from northwest of Heze City of Shandong Province with 300 km2 catchment area and 0.185 billion total storage, being a large reservoir that is dominated by irrigation and supplemented by comprehensive utilization, such as flood protection, urban water supply and cultivation etc. Normal pool level of reservoir is 40.5 m and design flood level is 42. 35 m this is met every 500 years. The maximum flood level is 43.2 m (this is met every ten thousand years). Project was started in 1958 and completed in 1979 basically.

Hub of Dongzhou reservoir dam of Shandong Province consists of river block dam, 3 sets of culvert (southern culvert, northern culvert and small northern culvert), spillway and extraordinary spillway. Because foundation cleaning at contact surface of dam foundation and dam head is not complete in construction, filling soil material at dam body is mixed and is not compacted firmly, and faying surface is not treated well in construction of many phases, and normal and extraordinary spillway are not completed according to design etc., dam rear leakage, repeated collapse and crack of dam body, culvert breaking and leakage, and brushing and water damage of normal spillway etc. appear shortly after reservoir is filled. Although repeated reinforcement treatments have been made, potential safety hazard of project has not been eliminated completely. Reservoir has always been operated with water level limited under 37. 00 m elevation, being far away from giving play to design benefit and causing huge risk to the downstream. There are many factors and breaking modes affecting the safety of Dongzhou reservoir dam of Shandong Province. Literature [3] analyzed and summarized several following conditions.

Condition 1: burst is caused by dam body leakage with breaking line as follows:

Concentrated leakage of dam body- continuous large leakage - leakage being developed into piping- failure of intervention- burst of dam body;

Concentrated leakage of dam body- continuous small leakage - leakage being developed into piping- failure of intervention- burst of dam body;

Concentrated leakage of dam body- continuous large leakage - leakage being developed into piping- failure of intervention- collapse/dam top settlement and burst;

Concentrated leakage of dam body- continuous small leakage - leakage being developed into piping- failure of intervention- slope instability and overtopping burst.

Condition 2: burst is caused by leakage of dam foundation with breaking line as follows:

Concentrated leakage of dam foundation- continuous large leakage - brushing development of dam foundation- failure of intervention- burst of dam body;

Concentrated leakage of dam foundation- continuous small leakage - brushing development of dam foundation- failure of intervention- burst of dam body;

Concentrated leakage of dam foundation- continuous large leakage - brushing development of side foundation of dam body - failure of intervention- collapse/dam top settlement and burst.

Condition 3: burst is caused by gradual damage of side slope of dam body with breaking line as follows:

Gradual damage of side slope of dam body- piping formation- piping development- failure of intervention- burst of dam body;

Gradual damage of side slope of dam body- continuous damage of side slope of dam body- damage of side slope of dam body being strengthened- failure of intervention- slope instability and overtopping burst.

Condition 4: burst is caused by culvert leakage with breaking line as follows:

Concentrated leakage of culvert -continuous large leakage - leakage being developed- failure of intervention- burst of dam body;

Concentrated leakage of culvert -continuous small leakage - leakage being developed- failure of intervention- burst of dam body;

Concentrated leakage of culvert -continuous large leakage - leakage being developed- failure of intervention- collapse/dam top settlement and burst.

Condition 5: burst is caused by spillway leakage with breaking line as follows:

Concentrated leakage of wing wall of spillway- continuous large leakage - leakage being developed- failure of intervention- burst of dam body;

Concentrated leakage of wing wall of spillway- continuous small leakage - leakage being developed- failure of intervention- burst of dam body;

Concentrated leakage of wing wall of spillway- continuous large leakage - leakage being developed- failure of intervention- collapse/dam top settlement and burst.

3. Algorithm description

3.1. Algorithm framework

Dam risk analysis detection technology proposed mainly includes 4 steps: (1) selection of single object; (2) characteristic generation of object selected; (3) object condition classification; (4) ZigBee data information import. GIS is applied to make change detection analysis to each dam. Algorithm is as shown in Fig.1.

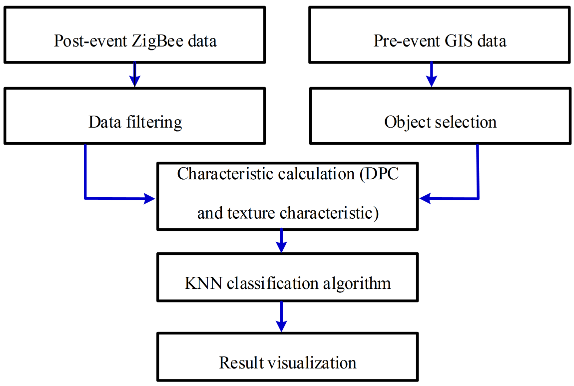


Fig. 1. Framework of algorithm proposed

Automatic object recognition quality is adversely affected by luminance difference of ZigBee data. Illumination form filtering processing can be made to ZigBee data and ZigBee data strength can be rectified through high-pass filtering. Then, normalization and high-frequency component amplification can be made to ZigBee data through homomorphic filtering, such as dam edge or fragment damage.

Basic principle for profile detection parameter calculation is evaluation to profile completeness, i.e. contact ratio calculation of dam profile in GIS and ZigBee data image profile detection. If dam analyzed is complete, then the maximum profile detection percentage is 100%. Profile detection process can be described briefly as follows: edge detection algorithm is applied to ZigBee data to extract dam edge. Algorithm proposed generates a raster data corresponding to characteristic value of data detected in edge direction. Data characteristics not belonging to any side have "no data" value. In vector data, test point shall be chosen along respective profile. Centering on these points, search region is defined on raster data and data characteristics having proper profile direction shall be counted. Then profile detection value can be calculated on the basis of rate between number of data characteristics detected and number of data characteristics of expected complete dam.

3.2. Detection to profile matching part of vector and raster data

There are numerous edge detection methods, and these methods can be divided into 2 types: (1) the maximum value or the minimum value detection of partial first-order derivative[11, 12] (such as Roberts, Prewitt and Sobel operator); (2) zero crossing point detection of second-order derivative. In our research, Canny edge detector is adopted. Reason for such selection is that the algorithm generates a continuous edge with data characteristic width as output, which provides good foundation for subsequent comparative analysis.

After Canny edge detector is applied, profile orientation angle of each edge data characteristic detected can be calculated as[13]:

$$\alpha = \tan^{-1}\left(\frac{G_y}{G_x}\right) + 90^\circ . \quad (1)$$

Where, G_x and G_y are derivatives in horizontal and vertical direction. Angle value obtained is within section $[0^\circ, 180^\circ]$ that can be divided into 4 sections evenly. Therefore, each data characteristic of ZigBee data is marked as edge data characteristic or non-edge data characteristic, and time interval value of profile orientation corresponded by edge data characteristic.

Vector data explains original city state as polygonal dam, and divides each part of building into small parts further. In center of each section, measure control point and horizontal axis angle α of profile and $\alpha \in [0^\circ, 180^\circ]$. Divide dam profile into relatively small parts, and schematic diagram of procedure is as shown in Fig.2.

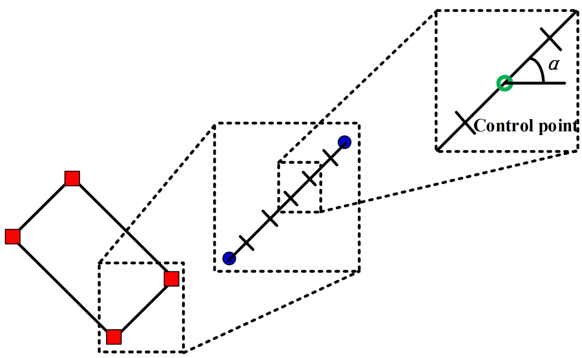


Fig. 2. Dividing dam profile into relatively small parts

Control point can be used as center of search region on raster figure, of which profile part is assumed as detected. Express search region as square data characteristic in $P \times P$ form, of which raster profile shall traverse center of search window. In the case of nonconformance, window position must be adjusted, which will be introduced in subsequent chapter and section. For length of profile within window, following expression can be derived:

$$l_P = \begin{cases} \dfrac{PR}{\cos\beta}, & if\,|\beta| \le 45 \\ \dfrac{PR}{\sin\beta}, & if\,|\beta| > 45 \end{cases} \tag{2}$$

Where, l_P is length of profile within search region; P is data characteristic size of search region; R is resolution ratio of ZigBee data; β is profile angle of vertical axis and $\beta \in [-90°, 90°]$ is met and $\beta = \alpha - 90°$. Formula (2) can be rewritten as:

$$l_P = \frac{PR}{\max\left(\sin|\beta|, \cos\beta\right)} \tag{3}$$

The number of fragment at side of each dam can be defined as through l_P value:

$$N = int\left(\frac{L}{l_P}\right) = int\left(\frac{\max\left(\sin|\beta|, \cos\beta\right)L}{PR}\right). \tag{4}$$

Where $int\,(x)$ represents lower limit of x, and L is length of side of dam profile (distance between 2 crests). Therefore, fragment length can be represented as:

$$int\,(x)\,l_s = \frac{L}{N} = \frac{L}{int\left(\frac{\max(\sin|\beta|,\cos\beta)L}{PR}\right)}. \tag{5}$$

It is obvious that $l_s \ge l_P$, which represents that a small part of polygon is deleted in search process and reflects that it is impossible for any profile surface to realize seamless coverage when search window is not overlaid and fixed. If side length is lower than l_P value calculated, then the number of section along the side is equal to 0 ($N = 0$), which means that the side will not be considered to be integrated to DPC calculation. Fig.3 gives search region along dam profile.

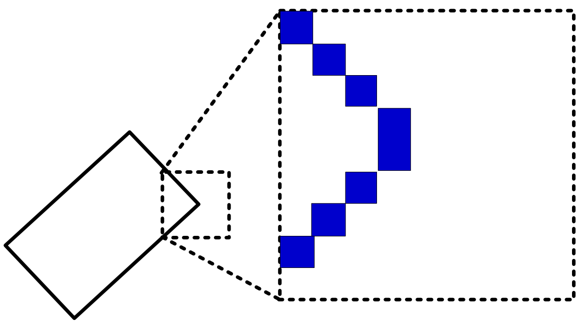


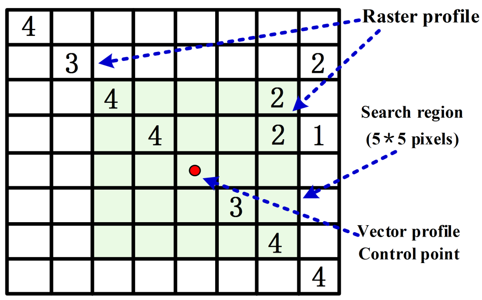
Fig. 3. Search region at upper part of raster profile

3.3. DPC value calculation and search window position correction

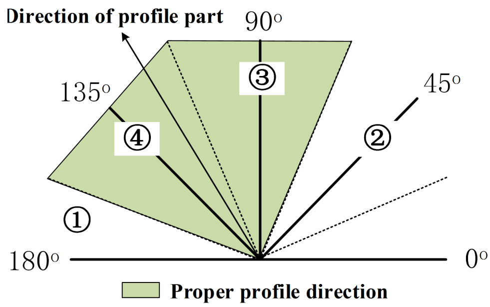
If profile of search region provided includes Pdata characteristics as a minimum, then profile of the part is assumed to be complete. To reduce effect of surplus data characteristics on final result, the maximum number of data characteristics of each search region is confined to be P. Considering the whole profile, DPC is defined as:

$$DPC = \frac{\sum_i^{N_P} \min(P, N_i)}{N_P P} \times 100\% . \tag{6}$$

Where, N_i is data characteristic number found in the ith search region, P is data characteristic size of search region, and N_P is the number of search region. Search region can cover data characteristics not belonging to profile of dam analyzed. To reduce effect of such data characteristics, we only calculate data characteristics approaching to direction of control point considered in profile direction. In addition, change of calculated value of raster profile is not obvious within time interval in 2 directions, which is as shown in Fig.4a.



(a) Calculated value of raster profile



(b) Definition to direction of profile data characteristics

Fig. 4. DPC value and direction calculation

Considering the change, if a data characteristic approaches to direction of control point analyzed from 2 interval directions in the nearest way, then the data characteristic shall be received, which is as shown in Fig.4b. The method provides strong profile data characteristic selection way.

In actual ZigBee data, dam edge detected does not traverse search region center generally, which may cause loss of profile data characteristic. To correct the condition, position of window where data characteristic number found is lower than$P$ shall be corrected. Firstly, we calculate dam profile centroid (X, Y) detection data characteristic:

$$X = \frac{\sum^{x_i}}{N} Y = \frac{\sum^{y_i}}{N} . \tag{7}$$

Where, N is the number of profile data characteristics found, and x_i, y_i are coordinates of profile data characteristics detected, which is data characteristic when center of search region moves to the location the nearest to centroid. Therefore, it can be ensured that profile edge detected traverses center of search region.

4. Instance analysis

4.1. Instance introduction

This paper takes risk analysis of Dongzhou reservoir dam of Shandong Province as example to verify application effect of method proposed in dam risk analysis. Dongzhou reservoir is a set of key middle-sized reservoir that is dominated by flood protection and supplemented by comprehensive utilization, such as irrigation, cultivation and power generation etc. Flood control standard of reservoir is design of flood that is met every 100 years, design flood level is 230.57 m with check of flood that is met every 1000 years, and maximum flood level is 231.27 m and total storage is 92 million m3. The reservoir was constructed in 1959 and constructed in 1972 again, and water storage was integrated in 1977. Landslide appeared at upstream dam slope of dam in 1981, the dam was listed as defective and dangerous reservoir by Water Conservancy of Shandong Province and was authenticated as dangerous reservoir type-III dam by Safety Authentication Center of Nanjing Water Science Institute in 2000. Structure stability analysis of reservoir shows that upstream dam shell sand is at loose condition with low relative density. Stability calculation result shows that under static flood water level of different standards and sudden water level falling, the minimum skid resistance stability safety factor of upstream dam slope is lower than code value and is lower than 1.0, which shows that upstream dam slope is at unsteady state and dam slope landslide risk that may cause burst of dam exists.

According to landslide condition in 1981, the landslide appeared at 1+05-1+140 dam section, landslide length is 87 m and area is 2 200 m‘ roughly. After argument and analysis of expert, the landslide is considered to belong to landslide of superficial layer and partial landslide. Considering that upstream dam slope landslide risk exists at the reservoir under flood level of flood season, deep-strata landslide may appear at upstream dam slope. Once landslide appears, dam body may drive slide of foundation, top crack of landslide mass presents circular arc, and alternate distance may appear at upper and lower side of crack, and slide mass will be relatively great, thus causing great and rapid landslide; if great and rapid landslide is developed further, obvious relative displacement or malposition will appear at dam body part, and separation from original dam body and slump may be caused, thus causing unstability of dam body and burst of dam.

Based on the above analysis, potential possible failure mode of Dongzhou reservoir dam is that upstream dam slope landslide at flood season causes dam burst, and through speculation, possible dam burst line under the mode is: upstream dam slope landslide- occurrence of great and rapid landslide- further development of landslide- dam burst. Take each process in dam burst line as each line event of event and do not consider manual rescue intervention to construct dam burst event of dam under 230.57m design flood level load at flood season, which is as shown in Fig.5.

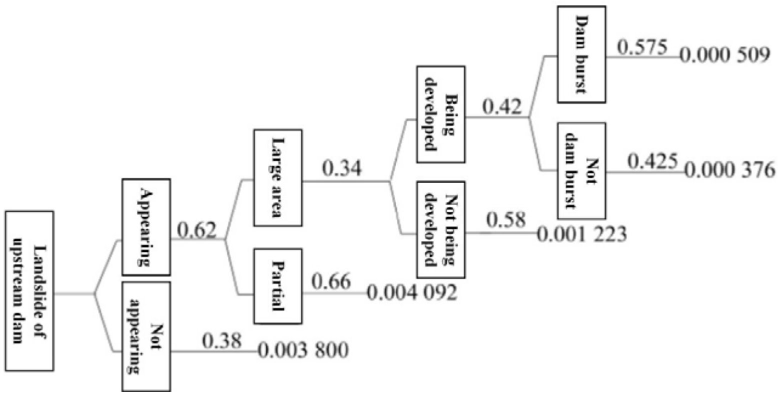


Fig. 5. Structure chart of dam burst event tree

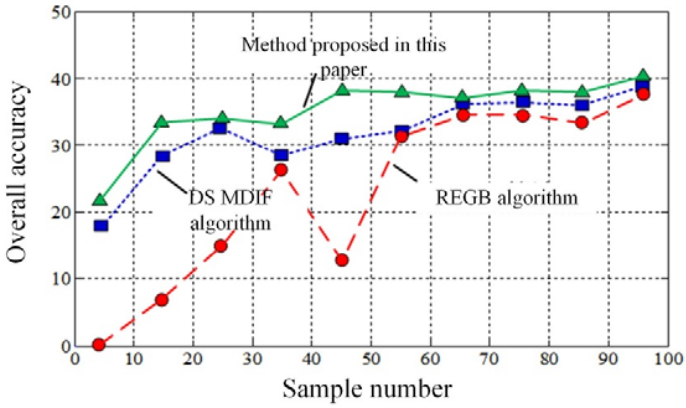
4.2. Comparison of dam risk analysis accuracy

Comparison result of algorithm proposed, DSMDIF algorithm and REGB algorithm in terms of overall accuracy (OA) index is as shown in Fig.6.

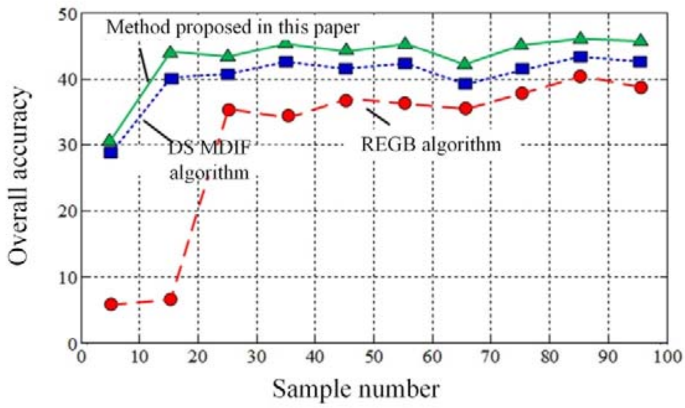
According to index comparison result as shown in Fig.6, in overall accuracy (OA) index, index value of algorithm proposed in this paper is greater than that of 2 comparison algorithms chosen, i.e. DSMDIF algorithm and REGB algorithm, which embodies relatively high detection accuracy of algorithm proposed in this paper.

5. Conclusion

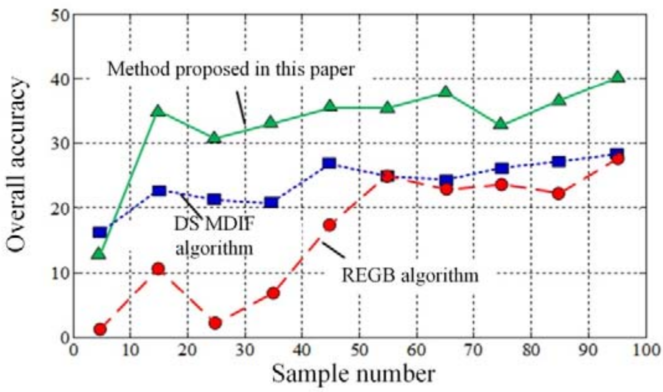
This paper proposes a kind of profile window correction detection algorithm based on GIS vector raster data to improve performance of dam risk analysis detection algorithm. Design algorithm firstly, aimed at problem that raster profile shall traverse center of search window, design search window position correction algorithm and design gray level space dependency matrix of improved type by converting relevant vector object into raster format to realize algorithm performance improvement. Research direction in the future: (1) non-supervision design to algorithm; (2) further expansion of experimental subject and verification of algorithm performance; (3) the development of application system.



(a) ZigBee data 1



(b) ZigBee data 2



(c) ZigBee data 3

Fig. 6. Comparison of computational result of overall accuracy

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