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METHOD FOR PRE-PROCESSING OF LEVEL CROSSING IMAGE

Summary. Actuality of problem in the improvement of transport safety at level crossings (LC) is caused by increasing the number of vehicles and reducing discipline of vehicle drivers. One of ways for solution of this problem is associated with using the video surveillance systems for monitoring danger area of level crossing. In such systems due to the limited bandwidth of data channel usually the image compression techniques are used. In this paper the pre-processing method for compression of images is presented. Proposed method accounts unequal subjective informational content of different LC image regions (using fuzzy logic and wavelet transform). Comparison of this method with plain set partitioning in hierarchical trees (SPIHT) technique showed that proposed method allows obtaining better result at image compression in terms of reconstruction quality and compression ratio.

МЕТОД ПРЕДВАРИТЕЛЬНОЙ ОБРАБОТКИ ИЗОБРАЖЕНИЯ ЖЕЛЕЗНОДОРОЖНОГО ПЕРЕЕЗДА

Аннотация. Актуальность проблемы повышения безопасности движения на железнодорожных переездах обусловлена увеличением количества автотранспортных средств и снижением дисциплины водителей. Одно из направлений для решения данной проблемы связано с использованием систем видеонаблюдения для мониторинга опасной зоны переезда. С учетом ограниченной полосы пропускания канала передачи данных в таких системах обычно применяется сжатие изображений. В данной работе представлен метод предварительной обработки для сжатия изображений. Предложенный метод учитывает неодинаковое субъективное информационное заполнение различных участков изображения переезда (используя нечеткую логику и вейвлет преобразование). Сравнение данного метода с простым методом пространственно упорядоченных иерархических деревьев (SPIHT) показало, что предложенный метод позволяет получить лучший результат при сжатии изображения с точки зрения качества восстановления и степени сжатия.

1. INTRODUCTION

Level crossing (LC) is an object of high danger for automobile and railway transport. LC accidents and fatalities represent more than 25% of all railway accidents on European Union (EU) railways in 2010–2012 [1].

It is not always possible or economically inefficient to remove a LC through grade separation in order to improve safety for rail and road users. For probability reduction of LC accidents various means are used, that can be thought as [2]: information providers – road-side (beacons, St. Andrew's cross, video analysis etc.), rail-side (information signs, axle detectors, train circuits etc.) warning and information [1]; passage preventers – road-side (barriers, gates etc.), rail-side protection (automatic train protection, train driver braking).

According to [1] 85 % of significant accidents at LCs for the EU in 2012 occur on passive (unprotected) LCs and on LCs with user-side warnings. Accidents on rail-side protected LCs are extremely rare. LC accidents tend to be caused by human factor and violations of traffic regulations [3].

Modern LC systems perform not only train detection but also road vehicle detection involving, inter alia, video surveillance. Video streams usage at mentioned systems can be: active (obstacle detection with ability to force train to stop), that usually use raw (or lossless compressed) [4] video data; passive (archiving for transport inspection needs, monitoring by LC keeper), that usually use lossy compressed stream because of relatively low bandwidth requirements. Current paper dedicated to video surveillance systems (VSS) that use lossy compressed video stream. The paper presents method for pre-processing of LC image, which takes into account unequal information value in different regions of LC image. Proposed method allows improving of balance between overall image quality and image compression ratio (CR).

2. STATE OF TRANSPORT SAFETY AT THE LEVEL CROSSINGS IN UKRAINE

Level crossings in Ukraine are classified into four categories depending on: the number of rail tracks that cross roads; traffic intensity. LCs are also divided into regulated (road traffic is regulated by LC signalling devices and/or LC keeper) and unregulated. Regulated LCs of I, II, III categories and some IV categories are serviced by the LC keeper (manned LC), remaining LCs are operated without duty worker (unmanned LC). Distribution of LCs at Ukraine's railways (see Tab. 1) shows that number of unmanned LCs about 2 times exceeds number of manned LCs [5].

Table 1

Type of level crossing	Unmanned with signalling and other	Manned with signalling	Manned without signalling
Number of level crossings	2862	1402	61

Tab. 2 presents distribution of accidents at LCs in Ukraine for 2010 and 2011 years [5].

Table 2

Type of level crossing	Unmanned with signalling	Unmanned without signalling	Manned with signalling	Manned without signalling	Beyond crossing
Accidents in 2010 [%]	66	9	17	1	7
Accidents in 2011 [%]	52	10	20	0	18

Tab. 2 shows that the number of accidents at manned LCs is 3-4 times lower compared to unmanned LCs. However, presence of LC keeper does not guarantee the complete transport safety. Thus, according to information of Ukrainian state transport inspection, in only 42% from all registered accidents the LC keeper fulfilled all action to prevent an accident in timely manner. Actuality of the problem of transport safety at LCs is caused by increasing of road vehicles number and reducing discipline of road vehicle drivers. Statistics shows that drivers violate LC regulations and often ignore

the information from road-side warning systems. One of the ways to increase traffic safety at LCs is associated with usage of VSS.

3. PASSIVE VIDEO SURVEILLANCE SYSTEMS AT LEVEL CROSSINGS

In passive video surveillance system (PVSS) at LC the results of intelligent video processing (obstacle detection) don't force train to stop (rail-side warning only). Endpoints of video stream in such system may be LC keeper, train driver or video archive.

Installation of VSS allows reducing of costs and human resources needed. For example at Inkerman I–Sevastopol span (Ukraine) the LC keeper simultaneously monitors two level crossings on 1536 km and 1537 km through passive video surveillance system [6]. Example of enhanced PVSS presents in [7]. Improvement is in added option for LC keeper – video can be sent directly to the approaching train driver.

According to tab. 2 absence of LC keeper in close proximity to LC area leads to increasing of accidents as a result of low discipline of road vehicle drivers. Therefore as a psychological barrier additional warning plates (about video surveillance) are used.

Alternative way to increase safety at LC equipped VSS without involving of LC keepers is redirection of video stream to train driver, which performs direct train control. For instance “SN-PEREEZD” system [8] provides wireless transmission of video images of LC to the train cabin at distance of 500-2500 meters. That allows train driver to make an assessment of LC image and take adequate prompt actions for train stop in case of emergency situation at LC danger area.

Similar systems are described also in [3] and [9]. Mentioned systems [3, 8, 9 and 13] also provide obstacle detection at LC danger area with sending of corresponding warning signals (audio, visual) to train driver. And some of them [3] initiate automatic braking, which makes them an active VSS.

4. BRIEF OVERVIEW OF IMAGE COMPRESSION METHODS

Raw or lossless compressed [4] video requires high bandwidth of data channel and therefore rarely used for video transmission. There are intraframe-only (frames are processed independently, like an image compression) video compression methods (M-JPEG, DV, ProRes etc.). Modern lossy video compression methods (MPEG1, MPEG2, H.264 etc.) account inter frame correlation (interframe compression). Intraframe compared to interframe compression requires lower computational resources, but also has lower compression ratio. Further explanation in paper is given for intraframe processing case.

Human is a final receiver of video stream in PVSS. Therefore taking into account properties of the human visual system (HVS), images can be more efficiently compressed (good review presents in [10]). Development of computational HVS-models still has many issues that remain to be solved. It is necessary to make assumptions on viewing conditions, which can restrict application of HVS-models to very specific situations, because some viewing parameters may not be known in advance [10].

Basic standards for the compression of photorealistic images are JPEG (based on discrete cosine transform – DCT) and JPEG2000 (based on discrete wavelet transform – DWT). Their perceptual optimization features are not activated by default, and user allowed supplying the required HVS-model. This option is used in proposed method for pre-processing of LC image.

5. METHOD FOR PRE-PROCESSING OF LEVEL CROSSING IMAGE

For investigation the LC located at the Nizhnedneprovsk Uzel station (Dnepropetrovsk, Ukraine) was chosen. Set of LC images (8 bpp, grayscale, aspect ratio 2:1) have been obtained using fixed video surveillance device. Examples of open LC images are shown in Fig. 1.

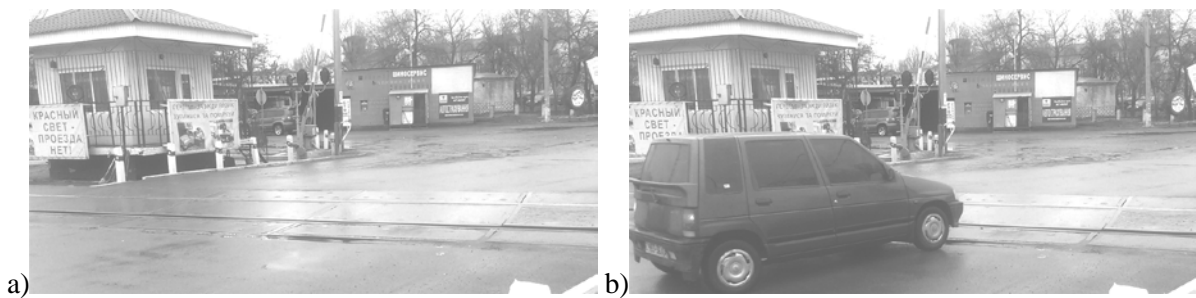


Fig. 1. Examples of level crossing image: without obstacle (a), with vehicle (b)

Рис. 1. Примеры изображения железнодорожного переезда: без посторонних объектов (a), при наличии автомобиля (b)

Fig. 1 shows, that different image regions contain unequal information about state of LC danger zone. For instance upper left and lower right corners are subjectively less important than central regions. Due to absence of crisp criteria for separation of LC image into regions by their information value (weight) the fuzzy inference system (FIS) [11] has been used. Proposed method for pre-processing of LC image contains two stages:

1. creation of FIS that accounts subjective heterogeneity of analyzed image (is performed before exploitation of PVSS for every fixed video camera in VSS on LC);
2. applying created FIS as a perceptual mask for weighting of DWT levels of image (is performed during exploitation of PVSS for images sequence).

Resulted weighted wavelet coefficients can be used directly for compression purposes.

FIS creation involves expert evaluation of image structure from particular LC camera. Weight of different regions depends on their location, so experts were invited to evaluate pixel coordinates in fuzzy terms. Results have been approximated with gauss membership functions (MF). In this example term corresponding to horizontal position (Col) has four MFs (Left, CLeft, CRight, Right), and vertical position (Row) – three MFs (Down, Middle, Up). Pixel coordinates are FIS inputs. FIS output (coefficient weight) is expressed as insignificant (Low), medium (Normal) and significant (High) from lowest to highest weight, respectively approximated with triangle MF. Assumed division, terms and MFs may vary to depend from current fixed camera position.

Next step – creation of fuzzy rules in “if-then” form:

if (Col is Left) and (Row is Up) then (Weight is Low);

if (Col is Left) and (Row is Middle) then (Weight is Normal);

and so on. Total number of rules in this case is 12. Created FIS has two inputs (coordinates of image element) and single output (weight of image element in range of [0,1]), which is shown at Fig. 2.

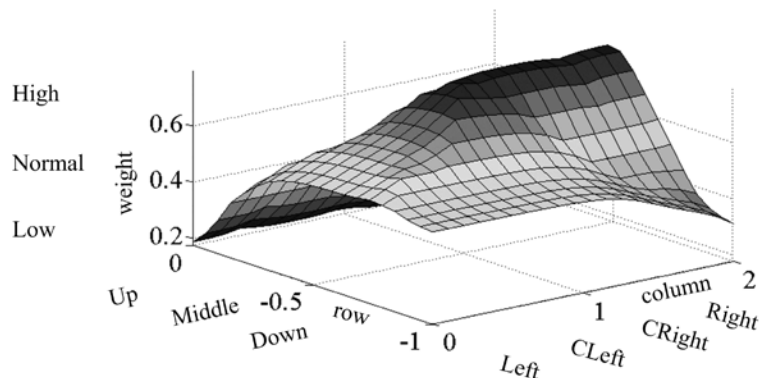


Fig. 2. Output of fuzzy inference system

Рис. 2. Выход системы нечеткого вывода

In Fig. 2 the modified Cartesian coordinates are used for “row-column” plane. Upper left element of image (see Fig. 1) corresponds to the coordinate origin (0,0), lower right – to the point (2,-1). Size of rectangular “row-column” plane is caused by aspect ratio of analyzed image.

Surface in Fig. 2 shows the weight of image elements. Relatively “high” surface regions approximately correspond to road direction at images shown in Fig. 1, and relatively “low” – to upper part and lower right corner of image.

At second stage of proposed method created FIS is used for weighting the high-frequency subbands (details) of DWT of LC image. DWT (comparing with DCT in JPEG) was chosen accounting a fact that, in general, blocking artifacts (JPEG) appear less natural and more annoying than ringing artifacts (DWT codec) [10].

6. SIMULATION AND RESULTS

Test set contains 16 greyscale images of LC (see examples at Fig. 1 and Fig. 3 (a)). Original image (Fig. 3 (a)) has been pre-processed by proposed method and then has been processed with SPIHT method. Resulted image (Fig. 3 (g)) was compared to image processed by plain SPIHT (Fig. 3 (d)). SPIHT was chosen since it is one of the popular wavelet compression techniques [12].



Fig. 3. Compared images: (a)–(c) – original, (d)–(f) – plain SPIHT compressed, (g)–(i) – proposed pre-processing with SPIHT

Рис. 3. Сравнимые изображения: (a)–(c) – оригинальное, (d)–(f) – сжатое простым SPIHT, (g)–(i) – предлагаемая предобработка со SPIHT

Images were compressed to approximately equal size of file, which allowed comparing their quality. Fig. 3 (d)–(i) presents results at relatively high compression rates, approximately 40:1 under next conditions. At second stage of proposed method original image was decomposed with DWT on

2 levels. All high-frequency subband coefficient matrices at first decomposition level, that is horizontal, vertical and diagonal details, were weighted with FIS (Fig. 2). At second decomposition level weighting was applied to diagonal details only. Biorthogonal (“bior4.4” according to Matlab notation) wavelets were used for DWT.

Fig. 3 shows an advantage of proposed method. Plain SPIHT technique preserves information that outside of region of interest – ROI (text at Fig. 3 (e)) and simultaneously wastes valuable information – front of car and door texture is more blurred at Fig. 3 (f) comparing to Fig. 3 (i). This can be explained by fact that plain SPIHT doesn’t know anything about required ROI, which is accounted by proposed pre-processing method.

Application of proposed method with relatively low compression rates (for example, 4:1) leads to insignificant blurring of image’s upper region (sky, trees), according to Fig. 2. Therefore usage of proposed method has the best advantage at low bitrates.

Most commonly used image quality metrics are mean squared error (MSE) and peak signal-to-noise ratio (PSNR) [12]:

$$MSE = \frac{1}{N \cdot M} \sum_{i=1}^N \sum_{j=1}^M [I_1(i, j) - I_2(i, j)]^2, \quad (1)$$

$$PSNR = 20 \log_{10} \left(\frac{\alpha}{\sqrt{MSE}} \right), \text{ dB} \quad (2)$$

where I_1 and I_2 – images of equal size $N \times M$ and same range of pixel values; α – max possible value in image matrix.

Evaluation results of image quality (for three images presented in paper namely Fig. 1 (a), (b) and Fig. 3 (a)) are shown in Tab. 3 – Tab. 5, where MSE is (1), PSNR is (2) and compression ratio (CR) expressed in percentage (file size of compressed image equals only CR [%] of the initial storage size). Program was realized with Matlab, so wavelet names noted respectively.

Table 3

Results with “bior4.4” wavelet

Image	Plain SPIHT			Proposed method		
	MSE	PSNR [dB]	CR [%]	MSE	PSNR [dB]	CR [%]
Fig. 1 (a)	25.42	34.08	8.45	18.11	35.55	5.74
Fig. 1 (b)	23.83	34.36	7.98	16.87	35.86	5.35
Fig. 3 (a)	25.84	34.01	8.75	18.38	35.49	5.95

Table 4

Results with “sym4” wavelet

Image	Plain SPIHT			Proposed method		
	MSE	PSNR [dB]	CR [%]	MSE	PSNR [dB]	CR [%]
Fig. 1 (a)	24.37	34.26	8.78	20.73	34.96	6.78
Fig. 1 (b)	23.03	34.51	8.35	20.49	35.02	6.40
Fig. 3 (a)	24.48	34.24	9.13	20.95	34.92	7.06

Table 5

Results with “db4” wavelet

Image	Plain SPIHT			Proposed method		
	MSE	PSNR [dB]	CR [%]	MSE	PSNR [dB]	CR [%]
Fig. 1 (a)	25.18	34.12	8.87	20.98	34.91	6.85
Fig. 1 (b)	23.39	34.44	8.44	19.75	35.18	6.48
Fig. 3 (a)	25.13	34.13	9.23	21.55	34.80	7.14

Tab. 3 – Tab. 5 shows total advantage of proposed method over plain SPIHT technique. Proposed method has lower MSE values and greater PSNR values corresponding to plain SPIHT. Moreover, obtained compression ratio is better for proposed method.

According to [10] some studies indicating that pixel-based error measures (MSE, PSNR) are not accurate for quality evaluations across different scenes or distortion types. Therefore it is necessary to involve observer into image quality evaluation process.

7. FUTURE WORKS

Resulted image after pre-processing of proposed method depends from variety of factors: FIS inner structure (rules) and parameters (kind of MFs); wavelet kind and amount of decomposition levels; wavelet-based lossy compression method that have been complemented by proposed pre-processing. Given this, further research is needed in this direction.

8. CONCLUSIONS

Brief analytical review shown topicality of problem of improving transport safety at the level crossings. Modern LC systems tend to involve intelligent safety systems and video surveillance systems.

In case when LC danger area monitored by fixed video surveillance device, the improvement of LC image compression can be achieved by account unequal informational content of different LC image regions. Due to absence of crisp criteria for separation of LC image by regions according to their information value, fuzzy inference system was involved. FIS was applied as a perceptual mask for weighting of high-frequency subbands of image's wavelet decomposition. Proposed pre-processing method allows observer to participate in choosing of image ROI.

Simulation results, their subjective and objective estimations allow to assert, that usage of proposed method for pre-processing of LC image under other equal conditions provides compression rate, which is comparable with existing modern wavelet-based compression techniques (SPIHT), and simultaneously retains better quality of reconstructed image.

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