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Method of image analysis in the process of assessment of ice occurrences

Kasper Jędrzychowski[1], Artur Kujawski[2]

Maritime University of Szczecin
[1] Navigation Department, Regional Water Management Administration in Szczecin
[2] Transport Engineering and Economy Department
70-500 Szczecin, ul. Wały Chrobrego 1–2
e-mail: [1] kasper.jedrzychowski@szczecin.rzgw.gov.pl, [2] a.kujawski@am.szczecin.pl

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Abstract
The authors present the method of assessing the percentage of coverage of surface of the river by ice occurrences. This article concentrates on image analysis methods applied to assess the percentage of coverage of a waterway by ice occurrences. A decision, whether to stop navigation depends on an accurate calculation of amounts of ice floe and overall atmospheric conditions. For this purpose closed-circuit video camera images converted with the use of a set of edge detecting filters and subjected to quantitative analysis have been used. The correct assessment of ice occurrences may positively influence the navigation itself, as well as help in planning the use of inland waterways in transportation process.

Introduction

In order to secure the safety of ship movement and to provide navigation markings, the waterway management administration, in conformity with national [1] and international [2, 3, 4] regulations creates the procedure [5], which determines that with the first ice occurrences a waterway must be closed for navigation. The experience of the administration staff proves that from the first appearance of slush ice 2 to 4 days are needed to collect onshore and floating markings (Fig. 1). With ice occurrences covering about 30% of the river surface ship movement becomes dangerous to hull plating and threatens with damage to propeller. With slush ices covering about 10% of water surface water jet vessels are excluded from operation, because slush ice clogs their water tunnels.

Due to the above mentioned issues, the most important task while taking decisions, during the winter season is the monitoring of development of ice occurrences. The monitoring is performed by local branches of Regional Water Management Administration (RWMA), which on an up-to-date basis supply information to Coordination-Information Centres of RWMA (CIC) [6].

In the space of the last 17 years the length of the navigation season on the Odra River fluctuated between 222 and 365 days, and in the average amounted 317 days a year (Table 1). Introduction of stages of the winter season on a waterway will help in a better understanding the specifics of that season and the possibility to use closed-circuit video cameras:

1. Preparation to the winter season – control of resources;
2. First ice occurrences (closing of waterway) – after appearance of first ice occurrences (slush ice) branch office staff starts collecting onshore and floating markings. Depending on the intensity of occurrences and weather forecasts, a waterway is either being closed immediately or the first transition stage with limited markings is being introduced;
3. Observation of ice occurrences – after closing a waterway branch office staff observes and analyses the development of ice occurrences;

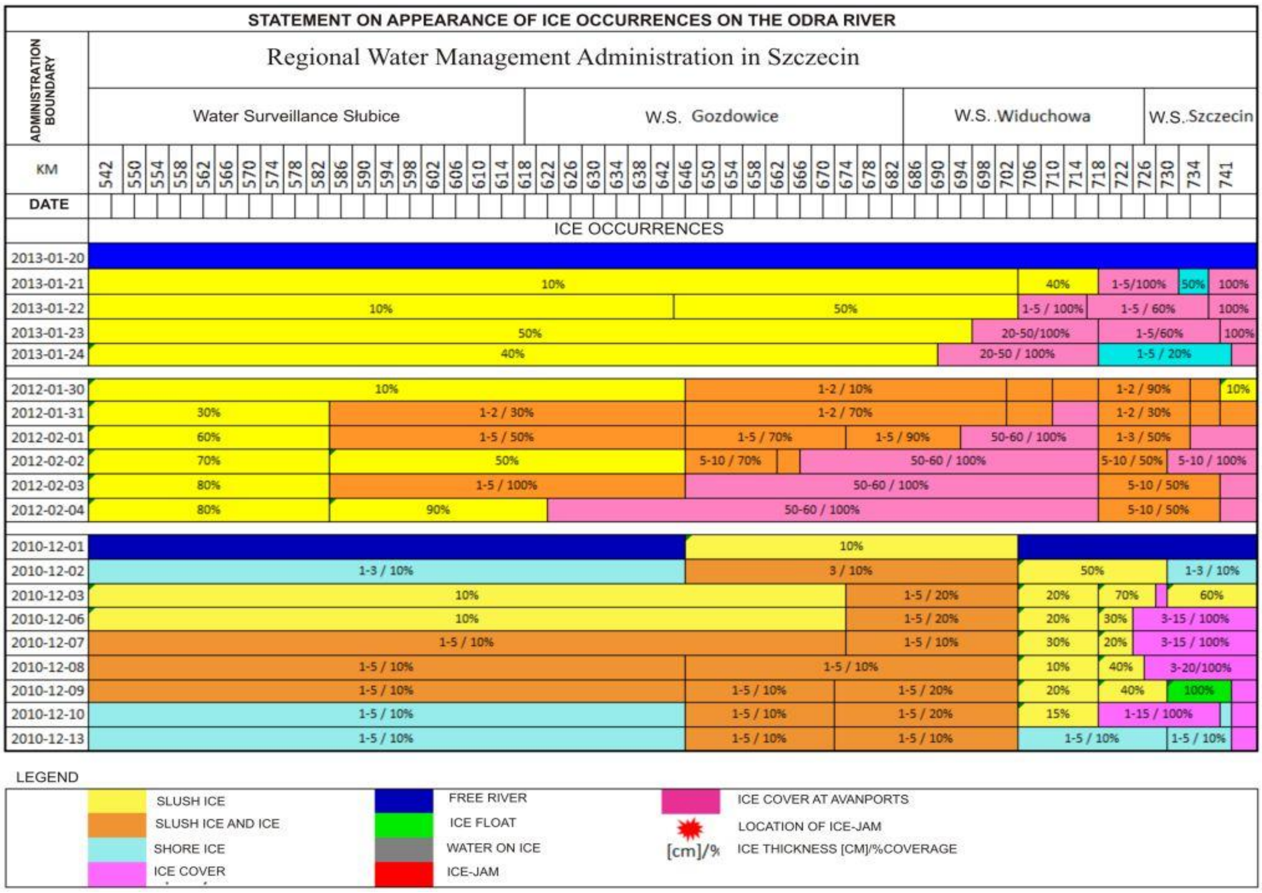


Fig. 1. Specification of development of ice occurrences in the years 2010–2013 [own study on the basis of information from RWMA Szczecin]

Table 1. The length of navigation season on the Odra River from km 542.4 to km 704.1 (in days) [own study on the basis of information from RWMA Szczecin]

Year	Section I	Section II	Section III	Section IV
	km 542.4–586.0	km 586.0–617.6	km 617.6–667.0	km 667.0–704.1
1996	263	263	263	263
1997	267	264	264	264
1998	343	343	343	343
1999	365	365	365	365
2000	357	357	357	357
2001	365	365	365	365
2002	325	325	325	325
2003	315	315	315	315
2004	330	327	327	327
2005	355	355	355	355
2006	270	270	270	270
2007	365	365	365	365
2008	359	359	359	359
2009	294	294	294	294
2010	222	217	217	217
2011	303	303	303	303
2012	309	309	309	309
Average	318	317	317	317

4. Control of solid ice sheet – all days long branch Office staff control the development of solid ice sheet and indicate its rim;
5. Thaw (beginning of ice breaking action) – the beginning of the ice breaking action is determined by two factors: in-plus air temperature and weather forecasts, confirming persistence of in-plus temperatures over a longer period of time;
6. Running ice breaking action – during the ice breaking action branch office staff control the solid ice sheet and continuously report any changes in its structure to the action's management. That is aimed at avoiding danger both to people working on icebreakers and to hydro technical structures and bridges;
7. Receding of ice – completion of ice breaking action;
8. End of winter season (preparation of waterway to navigation – placing markings, trawling and sounding – determination of transit depth).

In order to eliminate mistakes, caused by human factor and to increase precision of measurement of percentage of ice occurrences on the water surface it is possible to utilise the closed-circuit video cameras image analysis [7].

Fig. 2. Colour scale change to blue channel – representation in greyscale [own study]

The image conversion algorithm model

Thanks to the proposed method it will be possible to assess the percentage amount of ice float on river surface through collection of video material or static photographs and submitting them to graphic processing, and then calculating the number of singled out objects. The model of such an algorithm must consist of appropriate filters in order to eliminate superfluous elements which will not be statistically analysed.

The phases of the model are as follows:

1. Video image aggregation;
2. Conversion of colour scale;
3. Edge detection with Canny filtering:
   – Gaussian mask;
   – thresholding;
   – Sobel mask;
4. Opening and closing operations;
5. Filling in the objects;
6. Calculating objects surface;
7. Image masking;
8. Statistical calculations;
9. Verification of results.

The input material may consist of an image from the closed-circuit video camera, situated directly on a bridge or any image taken with any video camera with resolution of minimum VGA (640×480 px), as well as a sequence of photographs from a digital photo camera. The aggregated image needs to be converted from RGB colour scale to greyscale. It can be achieved either by changing the 256 individual channels to greyscale or (as in this case) by separating the red and green colour components and leaving only the blue channel which after converting its blue component into the black one will result in greyscale channel (Fig. 2). Thanks to this procedure the image analysis covering mainly blue areas (water and sky) will allow to obtain more precise results during the next stage, i.e. during the edge detection.

On the basis of the studies [8] it has been concluded that more effective, as compared to other edge detection algorithms, there is Canny algorithm which relies on the combination of Gaussian, Sobel and Prewitt operators. The Gaussian operator is used in smoothing of images. It uses convolution filters of a specific mask size. The widely described method [9] contains efficient detection criteria which determine the algorithm's ability to detect the possibly greatest number of edges and thus minimize the risk of omitting any of them (Fig. 4). The correct localization criterion determines that the error in location of any detected edge in relation to the actual one is as minimal as possible. In turn, the minimal answer error criterion leads to the elimination of detector's errors arising from image distortions (noise) which lead to "detection" of false edges [8].

Sx

-1	0	+1
-2	0	+2
-1	0	+1

Sy

+1	+2	+1
0	0	0
-1	-2	-1

Fig. 3. Sobel direction operators used in Canny filtering [own study]

Thus converted image will, at the further stage, undergo morphologic algorithms such as erosion and dilatation. They may be used in the construction of complex conversions. The erosion and the following it dilatation are called the opening and putting the same conversions together in an inverse order is called the closing [10]. The names of the two conversions contain their characteristics, i.e. closing open objects and excising insignificant objects, which occupy space below the chosen legibility threshold (Fig. 5). While observing the following assumptions, both conversions relay on the structure of the element being converted:

Opening:

$$X \circ B = (X \ominus B) \oplus B$$

set X is cut off against B if $X \circ B = X$.

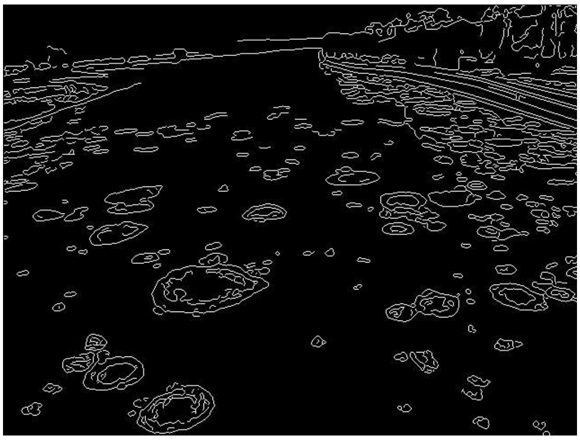


Fig. 4. Canny's method of edge detection with the use of experimentally chosen threshold of 0.15 through 0.25 [own study]

Closing:

$$X \cdot B = (X \oplus B) \ominus B$$

set X is filled in against B if $X \cdot B = X$.

In order to calculate the percentage of ice covered water surface the image is being binarised and stored in the memory as a matrix of zeroes and nonzeroes, where zeroes refer to pixels of black colour, and the nonzeroes refer to pixels of white colour. Thanks to such a simplification, it is possible to statistically calculate the proportion of white pixels representing ice float against black pixels representing the rest of the image which in this case is water. Of course, for correct calculations it is necessary to eliminate land areas which are not being calculated. For this purpose a polygonal mask

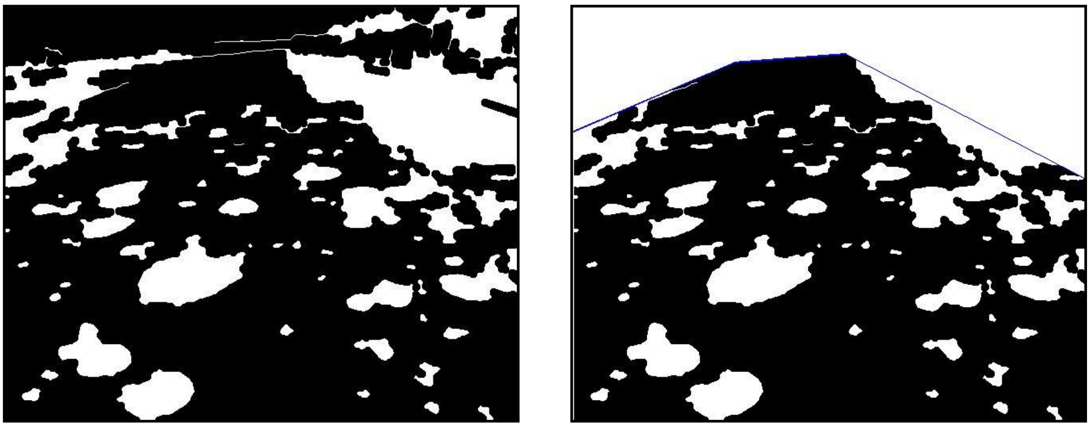
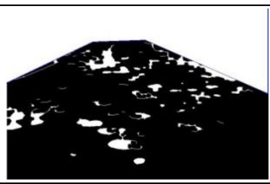
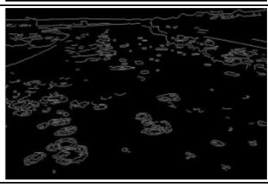
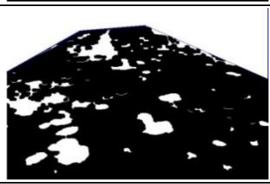
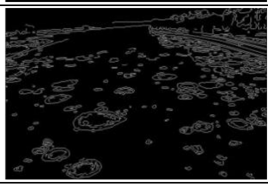
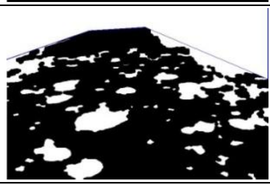
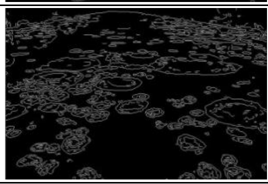
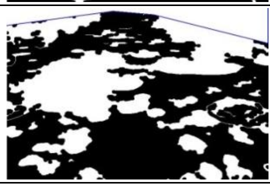


Fig. 5. Opening and closing operations and masking land areas [own study]

Table 2. Specification of results of the percentage degree of ice floats cover [own study]

No.	Original picture	Detected edges	Final picture	Calculation area [px]	Icing degree [%]
1				208 211	11.1
2				225 488	19.8
3				222 182	34.2
4				176 290	67.4

with specific coordinates has been used. The masking of unwanted areas and calculation of field area of each mask (a different mask will be used for consecutive trials) will enable to exclude that area from calculations. The value of pixels of the considered area (I) consists of the sum of black (b) and white (w) pixels belonging to the mask (Im):

$$I = \sum_{w=0}^{i} \sum_{b=0}^{j} f(b,w)$$

Then values of all black and of all white pixels are calculated:

$$\text{sum}_b = \sum \sum bf(b,w); \ \text{sum}_w = \sum \sum wf(b,w)$$

The table 2 contains the list of results for 4 different images chosen out of a few tens, which constitute a representative trial for two different groups of images. The first two are the sequence of video frames and the following two are photographs. The resolution of each of the images is 640×480 px at 24 bit RBG colour depth.

This list illustrates how the input material influences on individual calculation results.

The most representative trial out of the presented ones is the example No. 3. Firstly, the quality of static photographs has an advantage over video sequences. The image is more detailed, even at the same resolution and colour depth parameters, which allows more precise projection of edge detection filtering. Secondly, the thing that influences the quality of results is the projection of the area of interest. If the image aggregation equipment is incorrectly calibrated, for example too small vision angle, the results will be distorted because the algorithm calculates percentage share out of the image visible through a photo lens.

Conclusions

The length of the navigation season is the key element in the profitability of functioning of inland waterway transport. During the autumn period, there are escalated rainfalls which increase water levels in rivers and thus increase shipowners' transportation possibilities. The possibility to extend the navigation season into the winter period and to close navigation routes as late as possible is particularly important to shipowners, as well as to water administration.

The use of closed-circuit video cameras and situating them on structures traversing a waterway (for ex. rail or road bridges) will enable ongoing control of ice occurrences, as well as observation of ice breaking actions which in turn will allow the possibly greatest extension of the navigation season.

The basic benefit that arises from the image analysis method as described in this article consist in the more precise, as compared to the estimation based on a direct observation, estimation of river surface covered with ice occurrences. The method enables carrying out, such an analysis both from a single photograph and from a video sequence. The quality of obtained results depends greatly on the input material. In order to eliminate errors of the quantitative method, an image should be obtained with the use of a lens of a possibly widest field of vision, so both river banks are visible possibly at the closest to the image aggregation point. With these assumptions and with the use of the proposed image edging filters it is possible to obtain results that are more precise than assessments made "at face value" by man, i.e. without any measuring instruments. That will allow the Ice Breaking Action Centre and Coordination-Information Centre of RWMA a more precise calculation of ice occurrences development and taking decisions based on concrete data.

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