THE INFLUENCE OF GRADIENT FILTERS AND EDGING ALGORITHMS ON DEFINING ACCURACY OF THE POSITION OF A MEASURED EDGE OF THE CODE ELEMENT IN TESTING THE METRICITY OF LEVELING CODE GRADUATION, BASED ON THE ANALYSIS OF RASTER IMAGE

Sławomir Jastrzębski

Institute of Applied Geodesy
Warsaw University of Technology

1. INTRODUCTION

The accuracy of the method of studying the metricity of leveling code graduation based on the analysis of raster images is, to a large extent, dependent on two main sources of errors, i.e. error in measuring distance to the studied edge and, first of all, error in defining its position.
The distance error is directly caused by the instruments used to measure the distance (an interferometer, line and angle transducers, optic rules) and quite often there is no possibility to limit its influence beyond what the producer offers, whereas the position error of the measured edge is connected with the method of processing the raster file containing the image of the graduation under study.
By relying only on a simple analysis of RGB channels of individual pixels and applying the simplest algorithms to detect the edge, we will merely achieve pixel accuracy of the position of the point, from which the distance (of the edge) should be measured. Additionally, this accuracy depends on scanning resolution (dpi values).

In this paper I would like to present the operational results of gradient filters and algorithms to locate the edge in the processing of a raster image, which enabled to achieve sub-pixel accuracy in determining the position of a measured edge and, to a large extent, made this process independent from scanning resolution.

2. EDGE OF AN IMAGE

The edge of an image can be defined as the area of highly variable intensity of pixel colors.

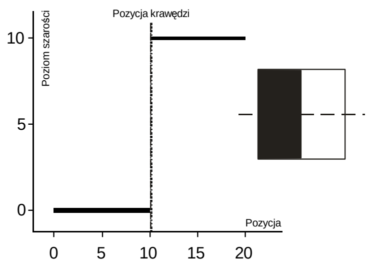

Fig. 1.

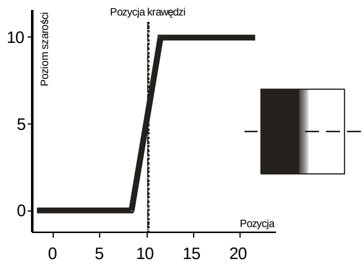

Fig. 2.

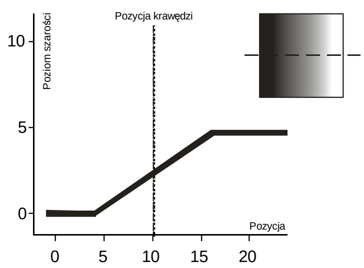

Fig. 3.

An ideal edge (Fig.1.) or a simple color change occurring in one place has been extremely rare in analyzed images. Digitalization and broadly understood image processing makes the change in the grayness level spread over more than two pixels (Fig.2. and Fig.3.). In such cases the real position of an edge is defined as the transit centre between the lowest and highest level of grayness. Obviously, the smaller the difference between the grayness levels and the wider area of changes the more difficult it is to determine its run.

One of the most popular methods of defining the position of an edge is to calculate the image derivative. Calculating both the first and second image derivative is a mathematical operation called the convolution (coincidence) of two functions.
Convolution involves calculating the product of two tables of different size but the same dimensions (Fig.4.). In the context of image processing, an input table is the image. The second one is a much smaller two-dimensional table, called a mask (e.g. a gradient filter).

I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{16}	I_{17}	I_{18}	I_{19}
I_{21}	I_{22}	I_{23}	I_{24}	I_{25}	I_{26}	I_{27}	I_{28}	I_{29}
I_{31}	I_{32}	I_{33}	I_{34}	I_{35}	I_{36}	I_{37}	I_{38}	I_{39}
I_{41}	I_{42}	I_{43}	I_{44}	I_{45}	I_{46}	I_{47}	I_{48}	I_{49}
I_{51}	I_{52}	I_{53}	I_{54}	I_{55}	I_{56}	I_{57}	I_{58}	I_{59}
I_{61}	I_{62}	I_{63}	I_{64}	I_{65}	I_{66}	I_{67}	I_{68}	I_{69}

K_{11}	K_{12}	K_{13}
K_{21}	K_{22}	K_{23}
K_{31}	K_{32}	K_{33}

Fig. 4. Tables of an image and a mask.

3. GRADIENT FILTERS AND EDGE DETECTION ALGORITHMS

Gradient filters (Fig.5.) belong to a group of upper-pass filters, which means that they can be used to bring out image components responsible for quick brightness changes.

-3	-3	-3
-3	0	-3
5	5	5

Kirsch

1	1	1
0	0	0
-1	-1	-1

Prewitt

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

Sobel

-1	0	-1
0	4	0
-1	0	-1

Laplasjan

Fig. 5. Masks of gradient filters.

As a result of the convolution of two functions (i.e. an input file (Fig.6.) and the mask of an appropriate gradient filter), we obtain a raster file which contains for every single pixel the information about the gradient value, i.e. the change in color intensity in relation to its environment (Fig.7.).

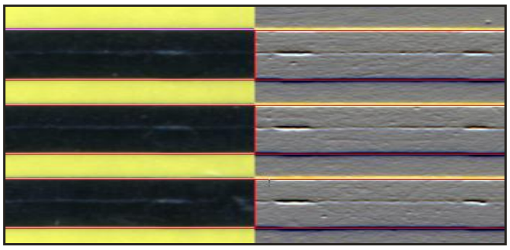

Fig. 6. Fig. 7.

These values, due to the offset applied in calculations, can be of the 0-255 range. The numbers close to 0 or 255 denote the gradient maximum and suggest the occurrence of an edge, whereas the values in the 127 range indicate the lack of color change in the evaluated raster file.
In the raster file obtained by means of convolution, gradient values in rows undergo averaging, which leads to a single column obtained (Fig.8.). Next the column is studied to determine the minimal and maximal gradient values as well as the threshold which confines the range of search for maximal values and enables clear identification of the edge.

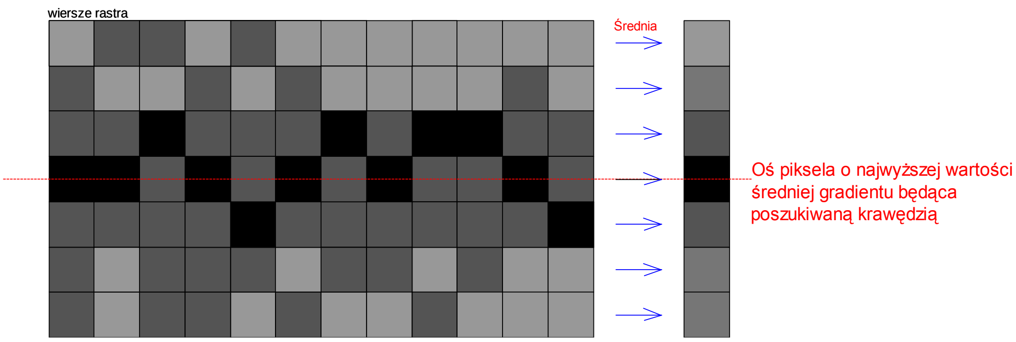

Fig. 8. Schematic diagram of a fragment of the raster file after applying edge filtering. The figure shows the area of where the edge occurs.

The accuracy of defining the edge by this method is, at best, half of the linear value represented by a single pixel (e.g. for the 800 dpi resolution it is 15 μm) and is directly dependent on the scanning resolution. Due to this reason, I have modified the above algorithm, which has enabled to obtain a sub-pixel accuracy of the edge in question.

The modification involves establishing "the window" (Fig.9.) of a definite number of lines around the edge detected with the first of the described algorithms.

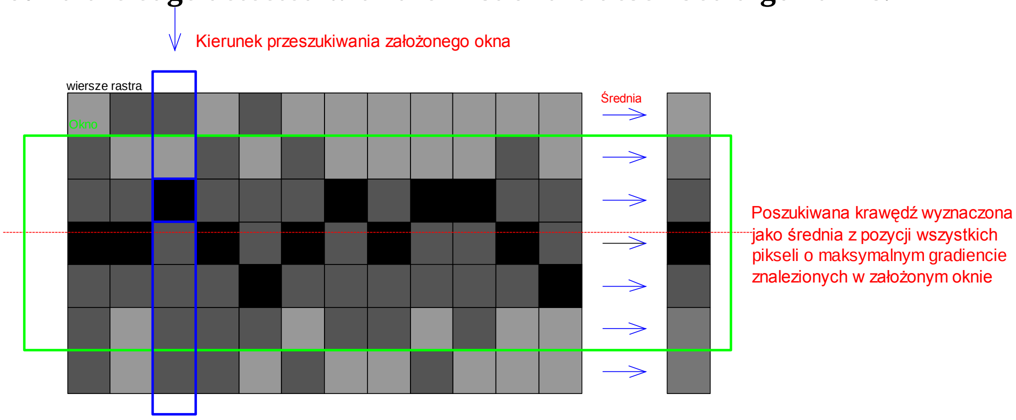

Fig. 9. Modification of the edge detection algorithm.

In this window all the columns are searched subsequently in order to determine the position of pixels of the highest gradient. Next the axis coordinates of all discovered pixels are averaged, which results in defining the position of the studied edge.
The above algorithm modification increases the defining accuracy of the investigated edge position and, to a large extent, frees the process from the scanning resolution.
As it appears from my analyses, the position error for the resolution provided by the scanner FENIX VISION 9508dpi) and the raster width of 700 pixels is about ±0.7 µm.

4. MEASUREMENTS OF THE FASTER FILE CONTAINING AN IMAGE OF CODE GRADUATION BY APPLYING GRADIENT DETECTORS AND EDGE DETECTION ALGORITHMS

In order to practically verify the influence of gradient detectors and edge detection algorithms on the measurement accuracy of a raster file containing an image of the leveling staff graduation I carried out a series of measuring experiments, the main purpose of which was to define the edge filter yielding the highest accuracy and vectorization repetitiveness.
The method of comparing calculation algorithms and gradient filter operation was based on statistical analysis of width differences between individual black code elements of the measured graduation (between the measured and nominal value). The synthetic values of the measurements are presented in the table below.

FENIX VISION AB scanner 508dpi

Filter	**Ave. std. dev. for 4 meas.**	**Std. dev.**	**Ave. min. diff. for 4 meas. (mm)**	**Std. dev.**	**Ave. min. diff. for 4 meas. (mm)**	**Std. dev.**
Prewitt |20|20 (Precise)	0,0069	0,0009	0,0003	0,0002	0,0265	0,0036
Sobel |15|15 (Precise)	**0,0065**	**0,0004**	**0,0002**	**0,0001**	**0,0250**	**0,0036**
Kirsch |15|15	0,0206	0,0007	0,0004	0,0001	0,0491	0,0048
Prewitt |20|20	0,0227	0,0015	0,0004	0,0001	0,0531	0,0023
Sobel |15|15	0,0229	0,0017	0,0004	0,0000	0,0523	0,0045

As it stems from the results presented above, due to the application of gradient filters and the modified edge detection algorithm described earlier (termed in the table as “precise”), it was possible to triple the accuracy of raster image processing and measurement as compared to the edge algorithm based on a simple analysis of RGB channels of individual raster pixels.
The conducted experiments also showed that testing the metricity of code graduation by analyzing their raster images by means of gradient filters, modified edge detection algorithm, with all necessary amendments included (i.e. temperature and scanner scale amendment), yield the results and accuracy comparable to metricity studies carried out with an analogue interferometric comparator (Fig.10.).

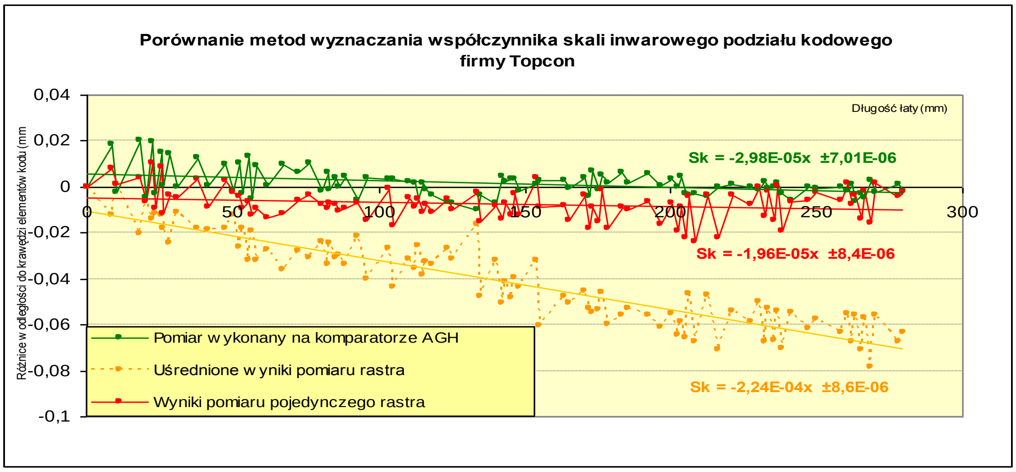

Fig. 10. Comparing the methods of defining the scale coefficient of a code invar graduation made by Topcon. Green color – interferometric measurement, red color – measurement made by raster image analysis.

5. CONCLUSIONS

The results of the research showed that due to the application of gradient filters and appropriate modification of the edge detection algorithm it was possible to obtain sub-pixel accuracy in defining the position of measured edges of a raster file and, to a large extent, to free the process from the scanning resolution.

Additionally, the comparison of defining methods concerning the scale coefficient of invar graduation by the Topcon company showed that metricity testing of code graduation by means of raster image analysis involving advanced edge detection algorithms can completely automate the process of comparing standard staves and engineering code graduation as well as ensure high accuracy required in this type of research.

REFERENCES

Bobrowski D., Warsaw 1980r., „Probabilistyka w zastosowaniach technicznych".

Canny J.F., Massachusetts Institute of Technology, 1983r., „Finding Edges and Lines in Images", Technical report No. 720.

Jastrzębski S., Grant Dziekański 2001r., „Badanie przydatności niestandardowych rozwiązań instrumentalnych w monitorowaniu przemieszczeń pionowych konstrukcji inżynierskich".

Jastrzębski S., Grant Dziekański 2003r., „Badanie możliwości zastosowania niestandardowych metod testowania inżynierskich łat kodowych wykorzystywanych w monitorowaniu przemieszczeń pionowych konstrukcji inżynierskich".

Jastrzębski S., Reports on Geodesy, Warsaw 2005r., Poland, „A metod of testing the metricity of code graduation, based on the analysis of raster images".

Pitas L, Kluwer, Academic Publishers, 1990r., „Nonlinear Digital Filters".

Tadeusiewicz R.,Korohoda P., Wydawnictwo Fundacji Postępu Telekomunikacji, Kraków 1997r., "Komputerowa analiza i przetwarzanie obrazów".

Walker A., Wolfart E., Perkins S., Fisher R., ISBN: 0-471-96234-0, 1996r., "Hypermedia Image Processing Reference (HIPR)".

Vodopivec F., Kogoj D., Reports on Geodesy, Nice 2002r. France, „The comparator for levelling rods on the base of optical encoder system".

Ziou D., Tabbone S., technical report, No. 195, Universit de Sherbrooke, 1997r., „Edge detection techniques - an overview”.