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# Diagnostic Device for 3D Surface Analysis

# Diagnostické zařízení pro 3D analýzu povrchu

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*Práce se zabývá návrhem a realizací řídicího systému pro zařízení na skenování povrchu hutnických materiálů. Toto zařízení bude využíváno v hutnických procesech, převážně pak na pozicích výstupní kontroly a diagnostiky. Práce se zabývá analýzou hardwarové části zařízení. V analýze je popsána konstrukce snímacího zařízení, umístění snímacího zařízení a referenčního prvku. Dále je vyhodnoceno využití vzájemné polohy snímacího zařízení a referenčního prvku pro získání obrazu povrchu snímaného objektu a popsán princip pohybu zařízení při snímaní objektu a akční členy, které jsou využívány. Výsledky analýzy jsou použity pro návrh řídicí jednotky včetně programové části systému. Řídicí jednotka zajišťuje správnou funkci akčních členů a referenčního prvku. Její součástí je komunikační protokol, pomocí kterého může být řízena z PLC nebo PC. Součástí práce je návrh programu pro PC na obsluhu zařízení a následné zpracování obrazové informace. Výsledkem programu jsou údaje o snímaném povrchu. V programové části se využívá algoritmů pro rozpoznávání obrazu (Image Processing). Jsou zde popsány použité algoritmy pro detekci hran s využitím konvoluce. Výsledkem takto zpracovaných dat ze snímače jsou souřadnice povrchu snímaného objektu v jedné rovině. Vývoj vyhodnocovacího algoritmu byl realizován v prostředí programu MATLAB. Výsledné algoritmy byly aplikovány v řídicím programu, který je postaven na platformě Net Framework. Řídicí systém byl otestován v laboratořích Vysoké školy báňské – Technické univerzity v Ostravě. První testy byly zaměřeny na detekci povrchových vad krystalizátorů až do hloubky 0,2 mm. Zařízení při testech dosáhlo požadované přesnosti měření. Řešení bylo po ověření dále rozpracováno a prohloubeno.*

*Klíčová slova: řídicí systém; polohování; krokový motor; detekce hran; zpracování obrazu*

*The paper deals with the design and implementation of the control system for a surface scanning device for metallurgical materials. This device will be used in metallurgical process. The device will be used primarily for output control and diagnostics. The work contains the analysis of hardware part of the device. It describes the design of the device, location of the sensor and reference laser, use of the locations of the sensor and reference laser to produce images of the surface of the scanned object, the principle of movement during the scanning of objects and actuators. The results of the analysis are used for design of the control unit, including the software part of the system. The control unit is responsible for correct operation of actuators, and of the reference element. It includes a communication protocol, through which it can be controlled from a PLC or PC. Part of the work deals with design of the PC software for operation of the device and for subsequent processing of the visual information. The results are data describing the scanned surface. The control program uses algorithms for image recognition (image processing). The used algorithms are described in the work. The algorithms are designed for edge detection with the use of convolution. The results of such processed data from the sensor are the coordinates of the scanned object surface in one plane. Development of the algorithm was realized in the MATLAB software environment. The resulting algorithms are applied in the control program, which is built on the platform NET Framework. Device and control parts of device are tested in the laboratories of the VŠB - Technical University of Ostrava. The first tests were focused on detection of the mould's surface defects, when the main condition was the minimum detection resolution of scratches of 0.2 mm. Device successfully passed the tests and achieved the required accuracy. The solution was after confirmation further elaborated and finalized.*

*Key words: system, positioning; stepper motor; edge detection; image*

This work presents a proposal of the control system for 3D digitizing of surface. It describes the principle of scanning the surface of objects using optical sensor and reference laser. Subsequently, it introduces the image detection process realized by the reference laser in order to obtain information about the shape of the surface. Discrete convolution computer algorithms are used for determination of the laser. The control system designed for the device was based on the principle of image processing algorithms. In conclusion, the entire device was implemented and tested. The results of the tests will be evaluated. The device model is shown in Fig. 1.

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# 1. Principle of scanning the surface

A reference laser was used for the optical scan of surface. The laser was equipped with a special lens. The lens changed spot beam into the line. The line of beam lit the surface of the object, which created a clearly visible laser line. The resulting line was an intersection of the object surface and the laser plane.



Fig. 1    Model of the device
Obr. 1    Model zařízení

When viewed perpendicularly to the plane of the laser it had a curved shape of the scanned surface. It was not technically possible to look straight perpendicularly to the plane of the laser; therefore the optical sensor monitored the resulting light line under a very small angle. Relative position of the laser and sensor is illustrated in Fig. 2. The image captured from the sensor is shown in Fig. 3.
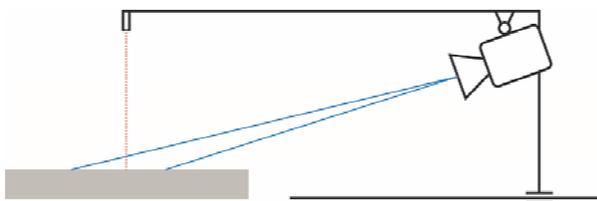


Fig. 2    Diagram of scanning of the object surface
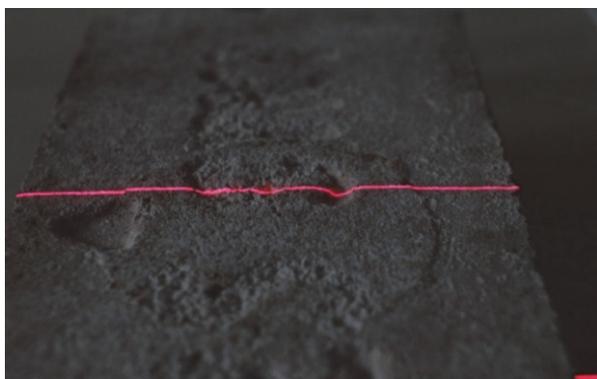Obr. 2    Schéma snímání povrchu objektu



Fig. 3    View from the sensor
Obr. 3    Pohled ze snímače

For acquiring information about the entire surface of the subject, we had to repeat this process in the new position. The scanning process consisted of two operations. The first operation was a visual record. The second operation was a shift of the entire structure (Fig.4). These two operations were repeated in the cycle. This shift used the fact that linear displacement sensing accuracy was inversely proportional to the displacement.
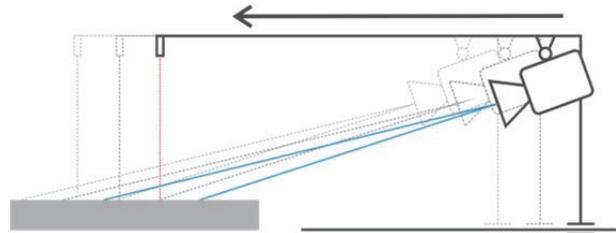


Fig. 4    Diagram of motion sensors and lasers along the scanned object
Obr. 4    Schéma pohybu snímače a laseru podél snímaného objektu

# 2. Image processing

We then focused on obtaining information about the object surface in one plane. One level of the subject represented a visual record. Procedures for obtaining information from the object image are referred to as image processing. Image information can also be described as a function of two variables

$$f(x, y), \tag{1}$$

where $x$ and $y$ are coordinates of the pixel and the function value corresponds to the values of brightness or spectral components. Therefore, it is called luminance function or a function of intensity. Laser in the picture is analogous to the physical edges of the recorded object. The edge is within the image properties given pixel and its surroundings. It is determined by how abruptly changed the value of visual function. Mathematical tool for analysing changes in the function of two variables are partial derivatives. Change of the function indicates the size of the gradient (2) and the direction of the gradient (3). The direction of the gradient $\varphi$ is always perpendicular to the edge

$$|\nabla f(x, y)| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \tag{2}$$

$$\varphi = \text{arctg}\left(\frac{\frac{\delta f}{\delta x}}{\frac{\delta f}{\delta y}}\right) \tag{3}$$

For calculation of the gradient a discrete 2D convolution is used (4), where $a$ is the input signal and $b$ is the kernel or convolution mask. The expression vector can be broken down to the summing of the expression (5), which is suitable for use in the algorithms.

$$\overline{c} = \overline{a} * \overline{b} \tag{4}$$

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$$c_{m,n} = \sum_{i=-k}^{k} \sum_{j=-k}^{k} a_{m-i,n-j}\, b_{i,j} \qquad (5)$$

$a$ – 2d matrix of input signal (pixels)

$b$ – matrix of convolution kernel

$c$ – value of transformed pixels

It is obvious that each new pixel in the filtered image, depending on the co-evolutionary mask, affects the nearby pixel. A properly chosen mask can be approximated as the first derivative or gradient. For finding laser we used in the painting features the gradient direction, thus it was always perpendicular to the edge. Structurally the device always had the laser in horizontal position. It follows the gradient properties and from the assumption that the reference laser is horizontal, that it is preferable to count only in the vertical direction. This will filter out all edges that are not horizontal. The following kernel was used for application:

$$b = \frac{1}{1} * \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \qquad (6)$$

$b$ – matrix of convolution kernel

Final image contained only the laser line, which projected on the scanned object (Fig. 5).
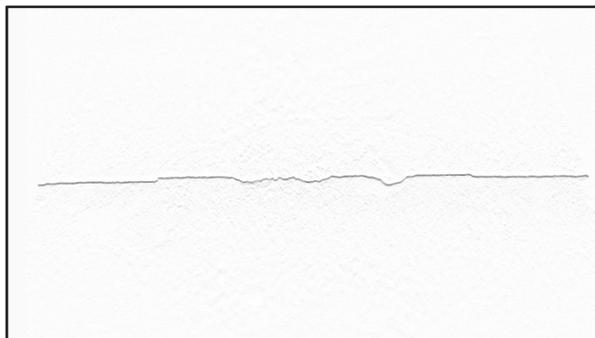


Fig. 5     Image information after application of convolution
Obr. 5     Obrazová informace po aplikaci konvoluce

## 3. Control system

The proposed control system is composed of several parts, which can be grouped into two blocks. The first block of the control system software is part of the personal computer as the "First block". The second block is the driver for control of a stepper motor and reference laser, as well as the "Second block" (Fig. 6). The control unit has been tailored for the device. It is equipped with a processor STM32F4 from STM. This processor is used as the main part of the subordinate logical block. It ensures communication with the master block. The system uses for communication with the RS232 a protocol, which is using the transmitter

transferred to the USB bus. The processor is equipped with a real-time operating system RTOS. The actual control algorithms are written in C++.
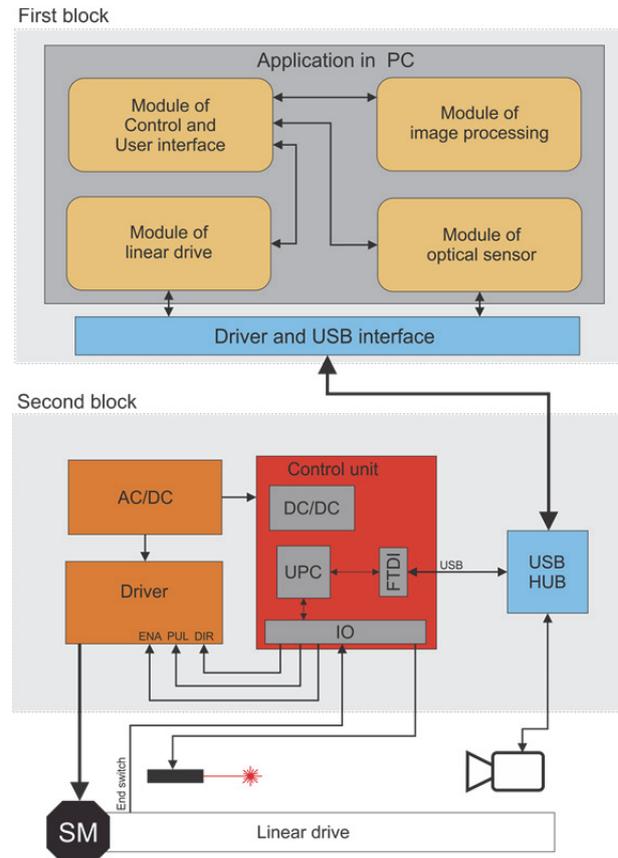


Fig. 6     Diagram of the control system
Obr. 6     Schéma řídicího systému

As it was already mentioned, the superior block is a software application in the PC. The application is designed and developed within the framework for the Microsoft .Net Framework 4.5 and it is written in C# .Net. The application is divided into separate functional modules. Individual modules solve always an isolated problem. These individual modules connect the main module of the program, which also serves as the user interface.

## Conclusions

The function of the whole device had to be tested after completion of the control system, assembly of the support structure and interconnection of all the elements. Gradually each piece of the equipment was tested. Linear displacement alone without a parent block was tested as first, especially the homing function and the function of the shift to the desired position. After verifying the functionality and editing software of the control unit the equipment was connected to a parent block. The functions of imaging and laser control were then tested. It created a basic configuration for the sensor and the image processing

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module. After testing and configuration of individual parts of the system, the scanning process as such was tested. A shaped object shown in Fig. 7 was chosen for the test. Scanning was triggered after setting the ideal sensor parameter. Start and end points were set to be one centimetre in front of the object and one centimetre behind the object.



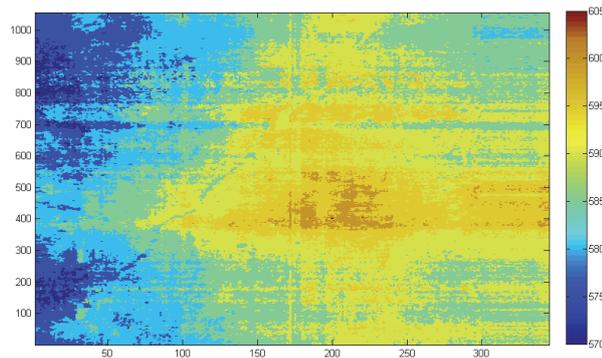Fig. 7     Testing object
Obr. 7    Testovací objekt



Fig. 8     Diagram of the testing object
Obr. 8    Graf testovacího objektu

Fig. 8 shows a graph drawn from the data. It is obvious that the graph corresponds to the measured object. Small measurement errors can be observed at the beginning of the object. They were caused by laser reflections from the front edge of the object, and at the end of the object where the error was caused by covering the reference laser. Given the desired function when the device scans unevenness of the upper surface of the object, these two errors are negligible. The entire length of the upper surface of the model then corresponds to the scanned object.

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# Ocelářská prognóza MBI: Ceny oceli by měly v prvním čtvrtletí zůstat

*MBI STAHL AKTUELL*        *20.01.2017*

Na ocelářském trhu se všechny zraky soustřeďují na Čínu a USA. 28. ledna začínají v Číně oslavy Nového roku a hospodářský život usne. Vychází se proto z předpokladu, že kvůli tomu ceny oceli a železné rudy poklesnou. Peking by mohl ještě před začátkem svátků oznámit nová opatření k likvidaci přebytečných kapacit v ocelářském a železnorudném sektoru, což by se mohlo pozitivně projevit na cenách oceli a železné rudy. V USA by mohly ceny profitovat z toho důvodu, že nový prezident bude detailně informovat o svých ambiciózních plánech pro infrastrukturu. Současně je ale třeba se obávat možnosti, že nový prezident uvalí tučná trestná cla na dovoz zboží, ve kterém je využívána intenzivně ocel, jako je tomu například v automobilech. V nejhorším případě by mohla vypuknout obchodní válka s Čínou, ale i jinými zeměmi. To by se negativně projevilo na cenách surovin a zejména kovů. Od poslední MBI prognózy z 6. ledna se ceny oceli zvýšily v průměru o 1 až 2 %. Ve stejném období se ale zvýšila cena železné rudy (Fe 62 procent, CFR, Tanjin) o více než 7 % na 81,7 USD za tunu. Jinak to ale vypadalo u koksovatelného uhlí (prémiová kvalita, export Austrálie): zde ceny spadly o 14 % na 178 USD za tunu. MBI Research vychází z toho, že ceny pro dlouhou ocel a hrubé plechy v zůstávajících týdnech prvního čtvrtletí zůstanou stabilní. Ceny za ploché výrobky by mohly ve stejném časovém období zhruba o 2 % poklesnout, i když poptávka po oceli ze strany zpracovatelského průmyslu stoupá.