Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 96 (2014) 227 – 234

Procedia Engineering

www.elsevier.com/locate/procedia

Modelling of Mechanical and Mechatronic Systems MMaMS 2014

Virtual Instrumentation for Visual Inspection in Mechatronic Applications

Dusan Koniar[a]*, Libor Hargas[a], Anna Simonova[a], Miroslav Hrianka[a], Zuzana Loncova[a]

[a]*University of Zilina, Faculty of Electrical Engineering, Department of Mechatronics and Electronics, Univerzitna 1, Zilina, 010 26, Slovakia*

Abstract

Visual inspection becomes very important part of mechatronic and industry applications. The methods which replace human eye and human factor increase speed and reliability of many processes. Virtual instrumentation (LabVIEW from National Instruments e.g.) is very good environment for developing visual inspection tools integrating all basic elements: imaging sensors, I/O hardware and algorithms [1]. Paper focuses on possibilities of designing automated visual inspection link based on LabVIEW for searching and counting of selected parts of products. Algorithms such as Pattern and Geometric Matching, Color Location or Hough Transformation are key elements of all software solutions. Designed visual systems also serves like client communicating with superior system (server) via TCP IP enabling remote control.

Peer-review under responsibility of organizing committee of the Modelling of Mechanical and Mechatronic Systems MMaMS 2014

Keywords: Visual inspection; virtual instrumentation; LabVIEW; mechatronics, TCP IP

Nomenclature

C	Correlation factor
EAN	European Article Number
f(i;j)	Image point
fps	Frames per second
NI	National Instruments

* Corresponding author. tel.: +421-41-513-16-25
E-mail address: dusan.koniar@fel.uniza.sk

Peer-review under responsibility of organizing committee of the Modelling of Mechanical and Mechatronic Systems MMaMS 2014
doi:10.1016/j.proeng.2014.12.148

OCR	Optical Character Recognition
OS	Operating system
PC	Personal Computer
PCB	Printed Circuit Board
QR	Quick Response
R	Normalized cross-correlation factor
VI	Virtual instrumentation / Virtual instrument

1. Introduction

The most simple and most favorite definition of virtual instrumentation (VI) is that VI replaces traditional or specific physical measurement devices by software module with universal I/O interface. Visual inspection is modern branch of image processing implementing machine vision algorithms to industry, mechatronics or robotics. Machine vision eliminates human error in process of product inspection and makes productivity more effective. Development system LabVIEW from National Instruments company and its module Vision Development provides many approaches for machine vision and visual inspection.

The tasks for visual inspection can be divided into following categories [2]:

- *Gauging* – lengths, diameters, angles – if any parameter lies outside tolerance range, task failed,
- *Inspection* – detection of defects, scratches or missing parts,
- *Alignment* – detects position and rotation of product (knowledge of shape features and their relations),
- *Sorting* – searching for objects based on template (counting),
- *Identification* – detection and decoding of QR codes, EAN codes or OCR.

The task “Sorting” is shown in Figure 1. Some applications for this task are described later.

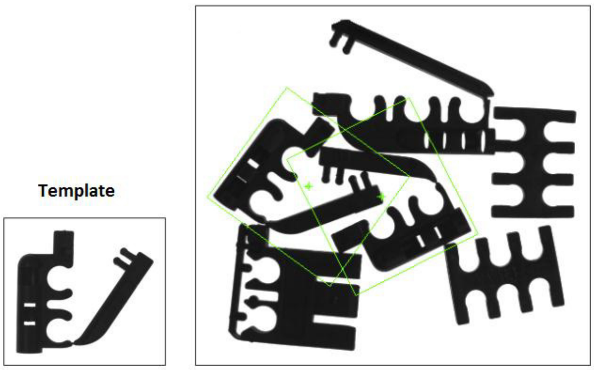


Fig. 1. Application sorting based on Geometrical Matching algorithm

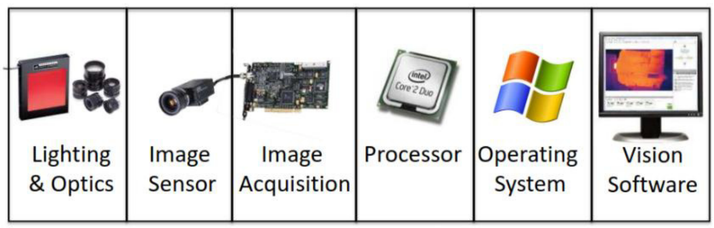


Fig. 2. Concept of visual system for inspection from NI

Key elements for visual inspection system are sorted on imaging hardware and accessories, computer (processor) and visualization [1]. Detailed scheme of NI concept of visual system for inspection is in Figure 2.

In the paper we present a laboratory prototype of visual inspection system for basic tasks such as identification, sorting and gauging. Visual system is based on LabVIEW and communicates via Internet using TCP/IP protocol with remote control server. In the next part we will describe basic algorithms for machine vision and influence of imaging hardware on task results accuracy and bring some experiences with system.

2. Machine vision hardware and algorithms

Suitable camera is very important factor for visual system. Color camera must be used in the applications of color inspection, high-speed camera must be used in the cases of object inspection in motion. Monochromatic camera is sufficient solution in the tasks such as shape detection or geometrical object matching. In our laboratory prototype we connected to the measurement PC with LabVIEW two cameras (Figure 3).

Fig. 3. Standard webcamera Canyon Vimicro (left) and inspection camera AVT Marlin (right)

First (color) camera Canyon Vimicro CRN-WCAM413G1 is a CMOS camera with resolution 640x480 pixels, USB 2.0 connection and maximal frame rate of 30 fps. It is typically used as portable camera for web applications. The second camera was inspection monochromatic camera Allied Vision AVT Marlin F-046B. Marlin communicates with PC via FireWire IEEE 1394 standard, its resolution is 780x582 pixels (CCD chip) and maximal frame rate reaches 60 fps.

Pattern matching quickly locates regions of an image that match a known reference pattern, also referred to as a model or template. A template is an idealized representation of a feature in the image. When using pattern matching, you create a template that represents the object for which you are searching. Your machine vision application then searches for instances of the template in each acquired image, calculating a score for each match (Figure 4). This score relates how closely the template resembles the located matches. Pattern matching finds template matches regardless of lighting variation, blur, noise, and geometric transformations such as shifting, rotation, or scaling of the template.

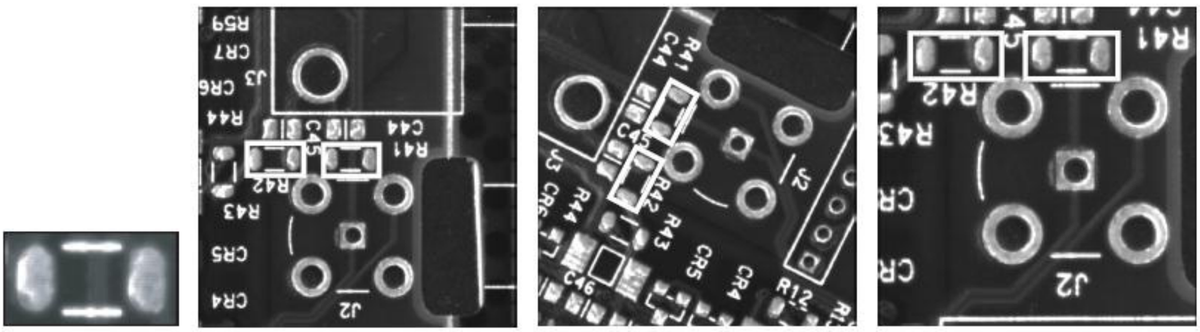
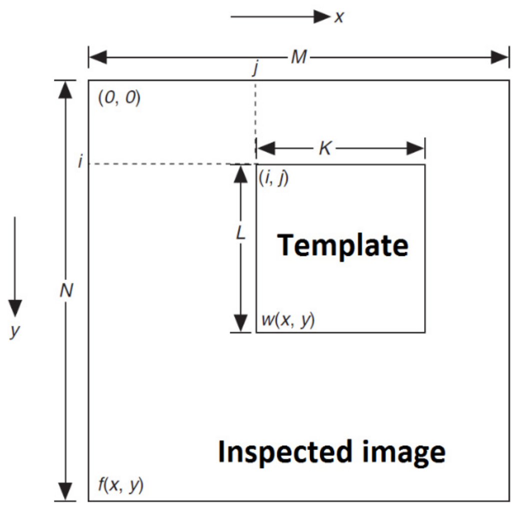


Fig. 4. PCB image in process of Pattern Matching: template (left) and ability of algorithm to find rotated or scaled feature

A pattern matching algorithm needs to locate the reference pattern in an image even if the pattern in the image is rotated or scaled. Pattern matching techniques include normalized cross-correlation, pyramidal matching, scale- and rotation-invariant matching, and image understanding [2].

Normalized cross-correlation (Figure 5) is the most common method for finding a template in an image. Normalized cross-correlation is a good technique for finding patterns in an image when the patterns in the image are not scaled or rotated. Typically, cross-correlation can detect patterns of the same size up to a rotation of 5° to 10°. Extending correlation to detect patterns that are invariant to scale changes and rotation is difficult.

Correlation is the process of moving the template or subimage w around the image area and computing the value C in that area. This involves multiplying each pixel in the template by the image pixel that it overlaps and then summing the results over all the pixels of the template. The maximum value of C indicates the position where w best matches f. Correlation values are not accurate at the borders of the image.



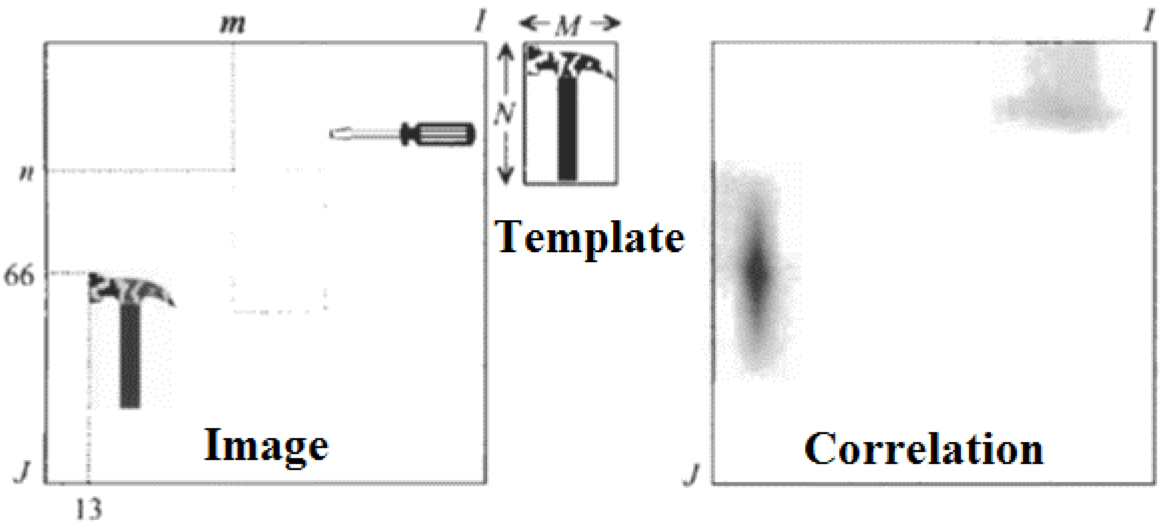


Fig. 5. Algorithm for image cross and normalized cross-correlation and simple example below

Image cross-correlation is defined as:

$$C(i,j)=\sum_{x=0}^{L-1}\sum_{y=0}^{K-1} w(x,y)\, f(x+i, y+j) \tag{1}$$

and normalized correlation as:

$$R(i,j)=\frac{\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}\left(w(x,y)-\overline{w}\right)\left(f(x+i,y+j)-\overline{f}(i,j)\right)}{\left[\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}\left(w(x,y)-\overline{w}\right)^2\right]^{\frac{1}{2}}\left[\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}\left(f(x+i,y+j)-\overline{f}(i,j)\right)^2\right]^{\frac{1}{2}}} \tag{2}$$

where *w(x,y)* is pixel of template, *f(i,j)* is pixel of inspected image, $\overline{w}$ and $\overline{f}$ are intensity averages of template respectively image.

Basic correlation is very sensitive to amplitude changes in the image, such as intensity, and in the template. You can overcome sensitivity by computing the normalized correlation coefficient R, which lies in the range –1 to 1 and is independent of scale changes in the intensity values of f and w.

For scale-invariant matching, you must repeat the process of scaling or resizing the template and then perform the correlation operation. This adds a significant amount of computation to your matching process. Normalizing for rotation is even more difficult. If a clue regarding rotation can be extracted from the image, you can simply rotate the template and perform the correlation.

Geometrical matching locates regions in a grayscale image that match a model, or template, of a reference pattern. Geometric matching is specialized to locate templates that are characterized by distinct geometric or shape information.

Edge detection is a key element in Geometrical Matching. Algorithm learns a template as a vector of edges and mutual relations between them.

Hough Transformation is very efficient way to find linear or circular objects in image. Mathematical apparatus of this transformation is very simple, but this algorithm is very time consuming. The basic theory and approaches can be found in [3] – [9].

3. Physical model of visual system

Before the laboratory visual system construction we compared accuracy of matching algorithms for both cameras. The task was formulated to search the discrete components (ports, capacitors…) on the computer mother board PCBs. We knew the proper numbers of discrete devices and we calculated the ratio of successfully found features (Table 1).

We did the test for raw image from camera and then for processed image (image was filtered by Gaussian spatial filter 5x5 and in the case of Canyon converted to grayscale image).

As we can see from Table 1, Geometrical Matching is more suitable for matching of such simple objects as discrete electronic devices like Pattern Matching. Preprocessing increased accuracy more than 20% in average. Standard web camera Canyon Vimicro is not suitable for inspection tasks due to lower matches against the AVT camera. AVT camera became the primary camera system for our solution (Figure 6). Camera is equipped with controlled LED illumination module (continuous illumination or stroboscopic mode) and system can be placed into the dark chamber (black box).

Processor part of visual system was represented by personal computer with OS Windows 7 and L.abVIEW 2011. LabVIEW uses a wide palette of functions for networking and communication, so each computer with linked camera was set to client with public IP address doing the selected inspection tasks and central computer – server – is able to read the results via Ethernet / Internet using TCP IP. This modality emulates the communication of industry inspection system with superior system or dispatching system (Figure 7).

Table 1. Pattern and Geometrical Matching accuracy test

		Raw image				Preprocessing			
		AVT Marlin F-046B		Canyon Vimicro		AVT Marlin F-046B		Canyon Vimicro	
PCB #	Objects to find	Pattern M. [% found]	Geom. M. [% found]	Pattern M. [% found]	Geom. M. [% found]	Pattern M. [% found]	Geom. M. [% found]	Pattern M. [% found]	Geom. M. [% found]
1	9	67	89	33	44	89	100	56	67
2	11	73	91	36	27	82	73	64	73
3	5	60	80	40	40	100	80	60	80
4	12	67	75	58	50	75	83	50	67
5	9	100	100	78	100	100	100	100	100
6	7	71	86	14	57	86	100	71	86
7	8	100	100	63	75	75	88	50	63
8	10	80	90	60	70	70	100	70	50

Fig. 6. Inspection camera AVT Marlin F-046B and measurement stand

In the experimental part we simulated 3 selected inspection tasks with our laboratory system: identification (automatic QR code detector and decoder), inspection (counting and checking the packages with power transistors) and gauging (distance measurement). For each task, the application front panel is shown.

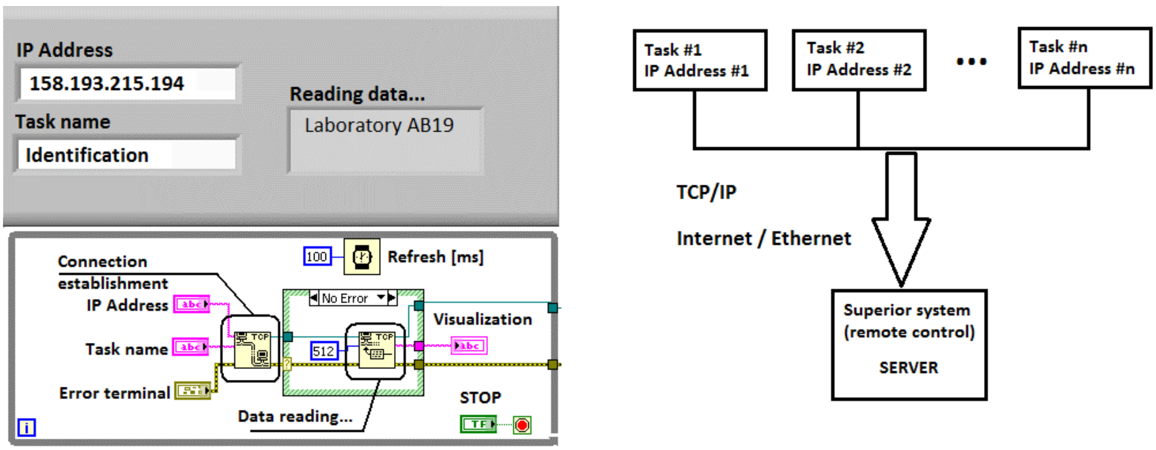
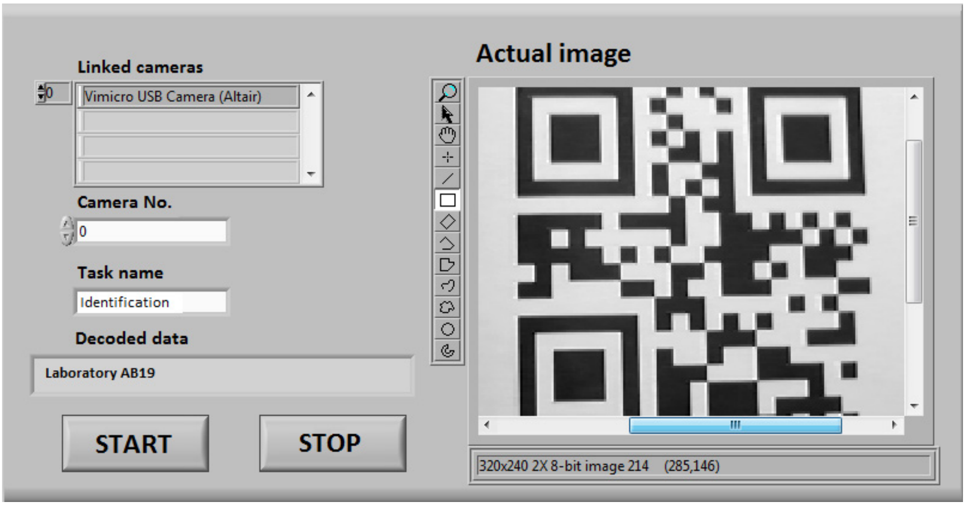


Fig. 7. Server (superior system) communication with inspection system on defined IP address and LabVIEW code

Identification is a common task in many industry or scientific branches. EAN, QR and OCR decoders improves the product signing, creating the product databases or converts the images to written text. LabVIEW contain wide



palette of code decoders, algorithms automatically search for code in image, read them and pass the text information to another processing step. The front panel of QR reader is in Figure 8.

Fig. 8. Identification task – LabVIEW front panel

Geometrical matching is the main tool in inspection task for counting the power transistors in package (Figure 9).

Gauging is very often for automated or contactless measurements of distances and angles on products (Figure 10). The principle of measurements is based on searching for the strongest edge in horizontal or vertical direction. The method is very sensitive for illumination homogeneity. The key LabVIEW tool for gauging is Clamp [5].

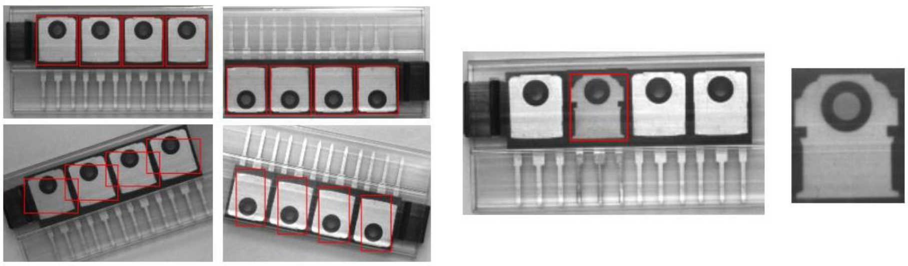


Fig. 9. Inspection task: Rotation invariant matching (left), power transistor package checking and template (right)

It is often very useful to calibrate gauging system from pixels to real world units (mm). During this process we considered no camera distortion. Length etalon was acquired as an image and then we determined how many pixels are needed for 1 cm of length. Calibration constant was set to 0.233: 100 pixels represents 23.3 mm.

4. Conclusion

Paper focuses on possibilities to integrate virtual instrumentation development system LabVIEW with visual inspection systems. We created laboratory prototype solving basic tasks. The system communicates with superior system (server) via TCP IP protocol and emulates communication of visual systems with control unit in industrial application.

The prototype is also used in educational process for Computers in Industry Automation and Virtual Instrumentation courses at our university. The system helps to understand machine vision algorithms and visual inspection tasks. System is modular and easy to reconfigure to do the many variants of visual inspection and machine vision tasks. Similar system with ultra-high-speed camera and light microscope is in presence successfully used for kinematic analysis of living cells in clinical environment.

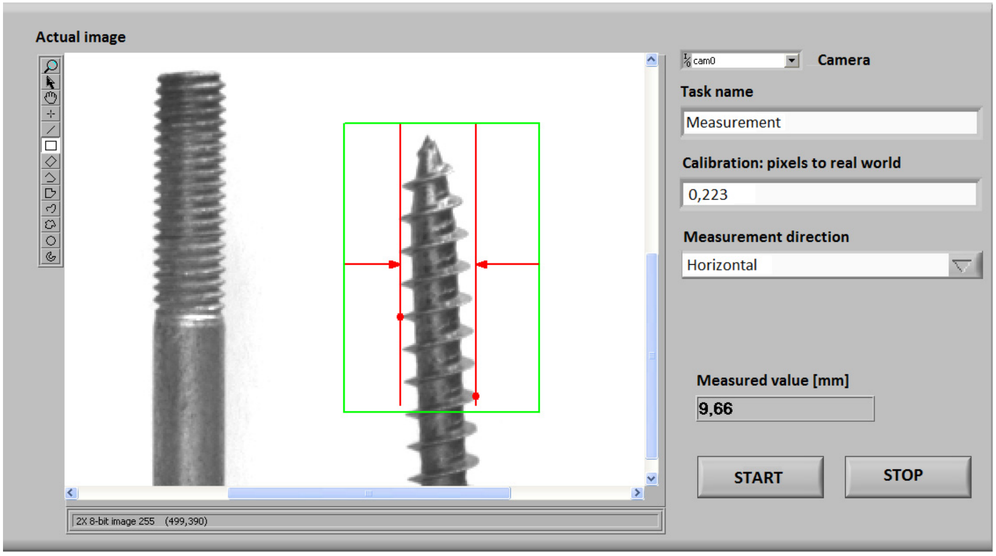


Fig. 10. Distance measurement with Clamp function

Acknowledgements

Results of this work were supported by grant KEGA No. 003STU-4/2014: Pokročilé metódy spracovania obrazu z vizuálnych systémov a ich implementácia do vzdelávacieho procesu (Advantage image processing methods for visual systems and their implementation to educational process).

References

[1] ŠTEFAN R.: NI Vision, electronic document, www.ni.com/vision
[2] NI Vision Concepts Manual. National Instruments, July 2007.
[3] THEODORIDIS, S., KOUTROUMBAS, K.: Pattern Recognition. Second Edition, Elsevier: Academic Press, 2003, ISBN 0-12-685875-6.
[4] THEODORIDIS, S., KOUTROUMBAS, K.: Pattern Recognition. Fourth Edition, Elsevier: Academic Press, 2009, ISBN 978-1-59749-272-0.
[5] KLINGER, T.: Image Processing with LabVIEW™ and IMAQ™ Vision, Prentice Hall PTR, 2003, ISBN 0-13-047415-0.
[6] KEHTARNAVAZ, N.: Digital Signal Processing System Design, LabVIEW-Based Hybrid Programming, Elsevier, 2008, ISBN 978-0-12-374490-6.
[7] SHOU-DER WEI, SHANG-HONG LAI: Fast Template Matching Based on Normalized Cross Correlation With Adaptive Multilevel Winner Update, IEEE Transaction on Image Processing, Vol. 17, No. 11, November 2008, pp. 2227 – 2235
[8] SUROVEC R., KELEMEN M., VACKOVÁ M., VIRGALA I.: A conceptual design of the self-reconfigurable mobile robot Wheeking 1, ATP Journal plus 1, 2011, ISSN 1336-5010, s. 57-60.
[9] BABINEC A., DUCHOŇ F., DEKAN M., PÁSZTÓ P., KELEMEN M.: VFH\astTDT (VFH\ast with Time Dependent Tree): A new laser rangefinder based obstacle avoidance method designed for environment with non-static obstacles, ROBOTICS AND AUTONOMOUS SYSTEMS Volume: 62, Issue: 8, Pages: 1098-1115