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Intelligent Car Control and Recognition Embedded System

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Abstract—**There is presented control system design with autonomous control elements focused on field of automotive industry in this paper. The main objective of this document is description of the control and monitoring system with integrated image processing from the camera. The images obtained from the camera are used for recognizing routing and traffic situation. During system proposal we focused our attention on integration of components for the car localization using GPS and navigation system as well. The implemented embedded system communicates with other car control units using CAN bus and industrial Ethernet. The communication interface between driver and car integrated system is carried out by process visualization on the LCD touch panel.**

I. Introduction

Results for automotive industry development has been the main aim of the presentation in this paper. Our research has focused on process control and monitoring of a process states and values and the specific solution for intelligent car control with autonomous elements has been presented in this contribution. The solution was implemented in a prototype of an electric car, where video-cameras for image processing and objects recognition in a real time were used. Stream data of the recognized objects allow identify route lane, people, other cars, traffic signs and situations. In addition to objects recognition, the accurate position must be obtained from GPS module and then transferred to control system. Information of exact position is useful for the car localization process and system navigation. The position data can be helpful during estimation of a distance between car and surrounding objects where supersonics sensors cannot be used.

The actuators, sensors, control units and video-cameras communicate with each other using industrial interfaces. Implemented industrial interfaces are CAN bus, wire or wireless industrial Ethernet and Bluetooth for extended features. The communication system is able to transfer secured data from one car to another by using open wireless industrial network. Car view information, captured on the camera, is transferred from the car to intelligent highway system. There is also space and possibility to use wireless communication connection for remote diagnostic test. [6]

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Information of the system is displayed on the touch screen panel that is connected into central development board based on 32.bits processor i.MX35. This type of processor is suitable for communication, graphic and multimedia applications. In virtue of using a lot of hardware interfaces and due to complexity of realization, we made a decision to use two types of operating system. Both of them are based on Unix platform. The first one is RTAI Linux which supports a lot of drivers for devices like cameras or modules for wireless connection or Bluetooth. On the other hand there is a lack of preferable memory protection. The kernel runs in the same memory space like drivers and the bug in driver can consequently cause the failure of the whole operating system. The new Linux reboot lasts rather long and it is annoying for a car driver or other passengers in the car. The second solution offers applying the system with great memory protection and memory adaptive partitioning management. The micro-kernel and drivers or other processes run in separate memory space. The failure of one driver or process does not cause operating system crash but only automatic process restart in milliseconds. Subject of concern is the operating system QNX Neutrino RTOS. Disadvantage of QNX Neutrino RTOS is weak support for wireless network drivers.[4]

II. Car System Architecture Design

The system architecture design is composed of embedded modules with special or universal function for the car control process. The central control embedded unit has many functions such as the system for battery management, motion control system, image recognizing system, global position system and others. In this paper we have focused our attention to the system for image processing and recognition of objects. The system embedded design is proposed for mobile devices like robots, car or industrial devices for product testing or measurement. Actual development design is composed of low cost products.

I. Embedded Car System

We propose embedded car system with 8.bits, 16.bits and 32.bits processors according to its functionality. The central unit is based on ARM architecture with build-in 32.bits processor i.MX35. This embedded central unit is reserved for graphic applications, image processing with objects recognition and communication processes. We prefer low power consumption for all our embedded units and that is why we have chosen ARM architecture. [5]

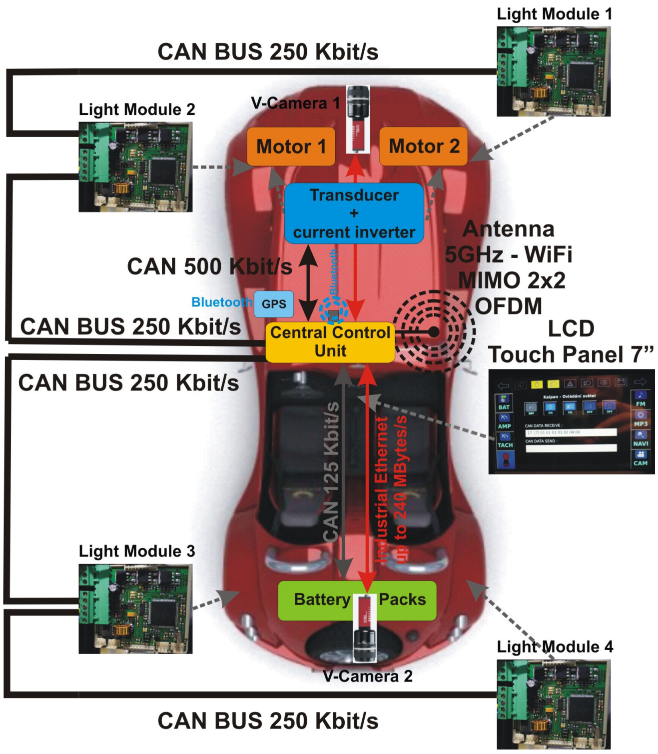

Fig. 1 Embedded car system architecture

Figure 1 presents some of the basic embedded modules implemented in the car control and monitoring system.

II. Software Implementation for Vision Car System

The vision system capability is to react to various types of traffic situations. Together with processing image data there has to be artificial intelligence implemented with ability to predict a critical traffic situation. Our development has been divided into 3 phases. The first one is testing our objects recognition algorithms design in Matlab with cheap webcam on platform x86. Standard USB interface was used for webcam connection. The next development phase was a test on mobile devices like PDA. The last phase was a transfer of the recognition system in embedded device that is part of car system. A new communication interface was used. We decided to choose a new camera with GigaEthernet interface on industrial Ethernet protocol. There is high data stream of data for a new 4 Megapixel camera with resolution up to 2336 x 1752l therefore we need very fast communication interface.

III. Real Time Operating System Implementation

Central control unit carries many functions which present a lot of processes running at the same time. Therefore we decided to use the real time operating system. There are 2 types of operating system mentioned in this paper – RTAI Linux and QNX Neutrino RTOS. [1]

RTAI Linux was modified for our purpose and for our hardware architecture. For this operating system, communication drivers have been adjusted for wire and wireless connection, based on industrial protocols - FlexCAN, EtherCAT and Bluetooth.

QNX Neutrino RTOS was rather easier to implement due to BSP supplied by QNX Company, but there was a problem with wireless communication driver. We still continue working on it with QNX community cooperation. Following figures 2 and 3 show the difference between Embedded Linux and QNX.

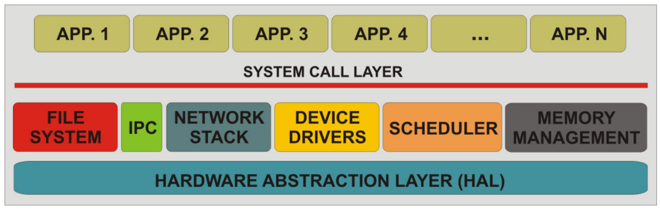

Fig. 2 Architecture of embedded Linux operating system

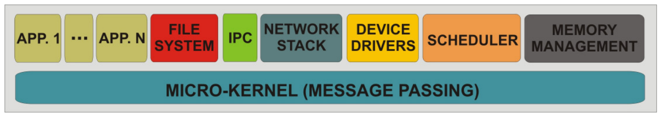

Fig. 3 Architecture of QNX Neutrino RTOS

IV. QT cross-platform graphic framework

The software Qt is the cross-platform application and UI framework used for embedded applications. Graphics interface was chosen with regards to both operating systems. Our selection was influenced by our experiences with graphical QT system from Nokia. QT embedded graphical interface is applicable for Linux and QNX as well. Figure 4 shows the example of car graphic user interface.

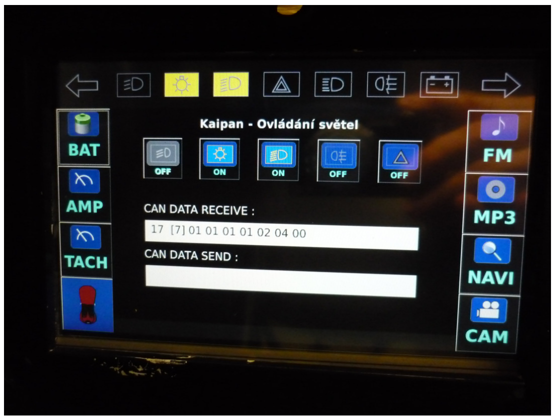

Fig. 4 LCD touch panel with QT embedded car system

III. Recognition Driver System

The recognition driver system was developed for traffic signs and traffic lanes detection. The system processes real-time image captured by a camera. Implemented algorithms are based on the idea of standardized form and appearance of traffic signs.

Nowadays there are two production technologies of image scanners available, namely scanners based on CMOS and CCD technologies. Better quality cameras use scanners based primarily on CCD technology. The advantage of this technology is a high luminous sensitivity ensuring better image quality with low brightness. In comparison, the CMOS technology is much cheaper, because it is based on standard technology, which is used in mass production of memory chips. By virtue of this technology, the scanning element can be placed on one chip together with other electronic circuit elements. Moreover, the advantage of CMOS technology is lower energy consumption in comparison with CCD technology. Generally, there is a reasonable argument that when the scanner is heated up, the undesirable noise increases and reduces the quality of final record.

For the presented application determined for image recognition, the VGA camera has satisfactory resolution. Better resolution would extend the process time, as each point of image matrix prolongs recognition process. In this case, a web camera with VGA resolution based on CMOS technology is used for image recording. These cameras communicate with in-built systems with the help of multi-purpose standard interface. The advantage of these cameras is a low price and very good availability, while undesirable disturbance, which can be fixed by developed software, is a disadvantage. Methods for reducing the undesirable noise disturbance are based on using filters, such as linear and median filters, which are very simple, reliable and quickly implemented.

The developed system retrieves images in real time directly from a webcam and they are evaluated immediately. Webcams Logitech with resolution 352 * 288 pixels were used for the test. Image quality reflects necessary quality of traffic signs identification. Low image resolution of traffic signs causes that recognition success will decrease to 90%. It is about 5% less than if the original high resolution image is evaluated. Application speed is convenient, as it is able to process more than 10 frames per second with presented camera resolution.

An application is created for Linux, Windows CE, Windows Mobile QNX. Testing was performed on a development kit i.MX35. Use of 32-bit multimedia applications processor based on iMX357 ARM11 ™ core is run on 532MHz frequency and size of RAM is 128 megabytes.

Implemented algorithms are suitable for wide range of applications in existing PDA devices and mobile phones. These devices are limited by low frequency computing power and memory space compared to being commonly used in desktop computers. The application was tested in devices E-TEN Glofiish X650. This device contains a Samsung S3C2442 processor 500 of MH, 128 MB Flash ROM, 64 MB RAM and a VGA TFT display 2.8-inch. The device has also a camera 2Mpix. Installed Operating System is Windows Mobile 6 Professional. Testing has shown that reduced performance of the device has largely affected algorithms time consumption. Acceleration of algorithms is likely by more efficient use of resource devices and optimizing memory management. The developed application shows examples of detection system for traffic signs in Fig.5.

Fig. 5 Application for devices with operating system Windows CE and Windows Mobile

Execution time for implemented algorithms depends on several parameters. The first parameter is size of the input image, size and number of objects that are inside image. Number of inside objects is input criteria which affects the number of cycles that must be done during patterns comparison. The execution time, which consumes the algorithm, depends on the performance of computer on which it has been executed. Processing time code implemented in C on a desktop PC in test events, did not exceed the period of 1 second.

The verification of the developed software was accomplished approximately on 50 traffic signs. The majority of test results are correct, i. e. in majority of cases traffic signs were detected correctly, but rarely there was not detected any traffic sign. This error was caused by damage to traffic signs, the excessive pollution or poor light conditions. Traffic signs were successfully recognized with patterns in range from 90 to 95%.

During the recognition process, the distance of traffic signs from the camera plays a big role. Due to a small number of pixels of traffic sign that is located too far, it cannot be guaranteed that the system will find the required consensus. Threshold for identifying traffic signs is approximately equal to 50 meters, if the camera zoom value is set to 1:1.

IV. Algorithms for Traffic Signs Recognition

The algorithms are based on ideas of standardized appearance and shape of traffic signs. Parameters are defined by traffic signs in the Czech Republic, which are stated in the regulation no.30/2001, Ministry of Transport The algorithms consist of two main parts. The first part implements correction and segmentation of the input image. The second part implements object searching, analysis and user information system.

V. Image segmentation and conversion

The basic aim of image segmentation is to search continuous parts in whole figure from a camera. From these analysed parts the objects are created, which are explored by parameters and the similarity of the patterns. The method chosen for continuous parts searching is based on conversion of the input colour image into the binary structure, taking into account the colour matrix with limited number of colours. Converted traffic signs image is composed of 5 basic colours, where 4 colours (red, blue, black and yellow) determine the motive of the label and white colour is chosen as the background of the label. The analysis of algorithms also solves the segmentation problem of traffic signs, which are composed just of red and blue colours, so it is converted to only one object, which has to be divided to separated objects. There are not green colour analyses, because traffic signs do not contain this color. For converting the image to a binary algorithm defined by next presented function is used. The example of image segmentation is presented in Fig.6.

$$f(p_{(x,y)}) = \begin{cases} 0 & for \quad R_{(x,y)}, G_{(x,y)}, B_{(x,y)} >= h \\ 1 & for \quad R_{(x,y)}, G_{(x,y)}, B_{(x,y)} < h \end{cases} \quad (1)$$

where: p is pixel
h is colour limit
R,G,B are colour components

1	0	0	0	1	1	1	1	1
1	1	0	0	0	0	0	1	1
1	1	0	0	0	0	0	0	0
1	1	0	1	1	1	0	0	0
1	1	0	1	0	1	0	0	0
1	1	0	1	0	1	0	1	1
1	0	0	1	0	1	0	1	1

2	0	0	0	4	4	4	4	4
2	2	0	0	0	0	0	4	4
2	2	0	0	0	0	0	0	0
2	2	0	3	3	3	0	0	0
2	2	0	3	0	3	0	0	0
2	2	0	3	0	3	0	5	5
2	0	0	3	0	3	0	5	5

Fig. 6 Continuous parts searching (left) and Individual part segmentation with different number of each segment (right)

VI. Image rotation and angle correction

The camera images, which are obtained from real camera output, can be rotated to incorrect angles. Rotation is related to one point by an angle α. The simplest cases are: $\alpha=90^\circ$, $\alpha=180^\circ$, $\alpha=-90^\circ$. In these cases it is practical and easy to change the representation of x and y axis. In reality, the angle α does not take exactly predictable values, thus we need to use trigonometric functions conversion to new pixel location. Special situation occurs when the traffic signs not only need to correct their orientation, but also to determine the angle of which are deflected from the vertical position. Traffic signs are not always installed completely vertically. This fact leads to lower conformity of recognition. The solution image has to be rotated to known angle. This angle can be calculated by algorithms based on symmetry of traffic signs as shown in Fig.7.

The figure shows the geometric layout of the problem where the presented trigonometric functions is used for determination the angle α. The presented algorithm for

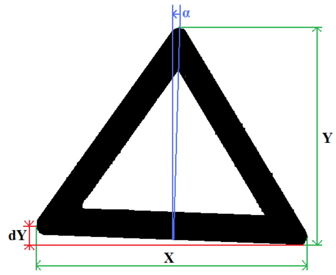

Fig. 7 Geometric expression of rotation traffic signs

rotation calculation cannot serve for traffic signs of circular shape. Angle α is calculated by next equation. [3]

$$tg\,\alpha = \frac{dY}{X} \quad (2)$$

The algorithm for rotation chooses reference point, which is located in the lower left corner of the editing image. The calculation of new coordinates is based on the next presented equations, where x‘,y‘ are new coordinates and x, y are current coordinates.

$$x' = \cos\left(\alpha + tg^{-1}\frac{y}{x}\right)\cdot\sqrt{x^2+y^2} \quad (3)$$

$$y' = \sin\left(\alpha + tg^{-1}\frac{y}{x}\right)\cdot\sqrt{x^2+y^2} \quad (4)$$

The rotation method gets images of traffic signs in a vertical position. New calculated pixel coordinates appear in the original matrix, but not always. Therefore there is necessary to consider boundary data fields so as not to exceed their limits.

VII. Image pattern analysis

After image segmentation and image rotation, there is possibility to analyze patterns with the actual edited image from camera. Traffic signs patterns are stored in a binary matrix. Each of the patterns is size-standardized at 100 x 100 pixels. The resolution is chosen on the basis of compromise between size of the matrix patterns and quality of the patterns.

Fig. 8 Example of binary matrix with patterns of traffic signs

Each object has location in the original matrix and is given its size. In order to apply the correlation function, size unification securing of objects and patterns is needed. Function re-calculates the object's size on defined dimension. The resize algorithm can be used after object continues parts recognition. The captured image can contain more traffic labels with other recognized noise, which is not desirable. Therefore, the method for object segmentation is supplemented with object centres identification. In case the centre is outside the other object area, it is solved separately. This recognition method eliminates problems with noise parts of objects, which disturb object comparison with patterns by correlation. This is processed by analyzing the geometric centre of coordinates and objects. The example of described method object separation is shown in Fig.9.

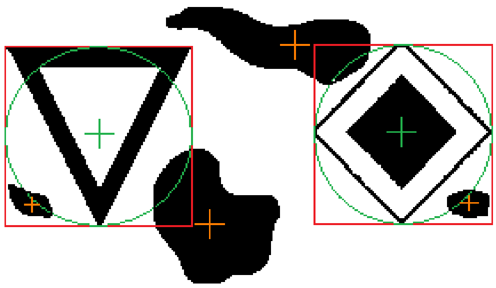

Fig. 9 Example of recognition basic points of image objects

Obtained object is then compared with correlation function used to all patterns. In this process the biggest matching of the object with patterns in percentage is expressed. The correct result is evaluated from the chosen pattern, which is the most identical to traffic sign in actual image. Practical tests have found that matching in more than 87% is sufficient to search traffic signs.

Learning the patterns number and rate of compliance is an adequate criterion for the correct formulation of the result recognition. Each number corresponds with specific patterns traffic signs.

Correlation function is used to determine the relationship between two signals (in this case signal represents the analysed image), the similarity of their histories, depending on their mutual displacement. Correlation can be expressed for linear and discrete signals. These signals cannot just be one-dimensional (vector) signal, but can be expressed by multidimensional signals. Correlation function of two signals is called a peer or cross-correlation functions. The result of correlation is a new signal, which has been displaced amplitude proportions have similar signals. This fact can be expressed as correlation coefficient *R*, which takes values between zero and one and reflects the similarity of two signals. For discreet binary two-dimensional signals can be expressed by the correlation coefficient *R* values range from zero to one.

$$R=\frac{\sum_{x=1}^{x}\sum_{y=1}^{y} f(x,y)\cdot g(x,y)}{x\cdot y} \tag{5}$$

Function f(x,y) represented examined image and g(x,y) represented image pattern. Multiplying the correlation coefficient value by 100 represents the unity signal in percentage. Correlation is often used for the detection of known signals. [2]

VIII. Number recognition and analysis from image

Optical character recognition OCR is a method that enables the digitization of texts from retrieved images. The developed program converts the image either automatically or must learn to recognize characters. The converted text is almost always dependent on the quality of the draft should undergo thorough proofreading, because OCR program does not recognize all the letters correctly.

For the detection of traffic signs that inform about the maximum speed limit a simplified version of OCR algorithms are applied. OCR algorithm is applied to each traffic sign that is probably found with the help of the correlation function in comparison to the patterns. Segments of the traffic signs are systematically compared with known patterns of numbers. [3]

Fig. 10 Patterns for implemented OCR algorithm

Neural networks are useful for solving problems in image and signal recognition or diagnosis. The neural network is generally designed for a structure of spread parallel processing information, which consists of certain (usually very high) number of simple computing elements. Each element is named as the neuron. Neuron receives a finite number of inputs and their input information and passes its output to a finite number of outputs information. Formalized algorithm model of neuron is shown in Fig. 11.

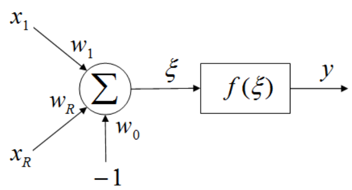

Fig. 11 Formalized algorithm model

Activity of this neuron can be expressed by:

$$y=f(\xi), \tag{6}$$

where y is input of neuron and ξ is so-called potential, which may be expressed by equation

$$\xi=\sum_{j=1}^{R} w_j x_j - w_0 \tag{7}$$

In this relationship x_j symbol indicates the value of j-th entry of the neuron, w_j denotes the value of j-th entry, and w_0 denotes the threshold of neurons and the function $f(\xi)$ shows generally nonlinear signal transfer function of neurons.

Neurons are arranged in networks, this arrangement is known as network topology. Neural network does not contain any information about finding the object.

At the moment, neural methods and algorithms for OCR analyses are prepared, but implemented and successfully tested OCR recognition by correlation function is available. The problem of correlation function, compared to other method, is insufficient speed of algorithm execution, which increases with number of patterns.

V. Algorithms for Traffic Lanes Recognition

For the detection of lanes on a road, Hough transform is implemented. At the moment the implementation is solved in MATLAB environment and it is prepared for implementation to embedded system. This transformation is analytical method used to find a parametric description of the objects in the picture. This method is used for the detection of simple objects in the picture, which are example lines, circles and ellipses. The main advantage of this method for lane detection is robust against irregularities and infringements looking curve, which is particularly suitable for the detection of dashed centre line. To find a mathematical model of the object in a picture we used Hough transform as an input pixel input image. For example, detection of lines in the image edited by the Hough transform was used in the equation:

$$x \cdot \cos\theta + y \cdot \sin\theta = r \quad (8)$$

Where:
r – Length of normal from the origin of coordinates to the line.
θ - Angle between the normal and the x.

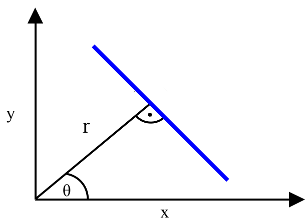

Fig. 12 Parametric description of detected traffic lane

Hough transform is applied here, by an adjustment of the input image. The adjustment consists of the image transfer to binary image, and finding local maxima using edge detector. One of the most important edge detection is Canny edge detector, which is implemented by algorithm for edge detection in two-dimensional discrete image.

VI. Conclusion

The main goal of this paper is to show development of car system for object recognition. The basic car system architecture and algorithms for traffic signs and lanes recognition are presented here. Neural networks were used in order to solve problems in image and signal recognition or diagnosis. The problem of image processing and object recognition was discussed in this contribution. We presented development stages of recognition system.

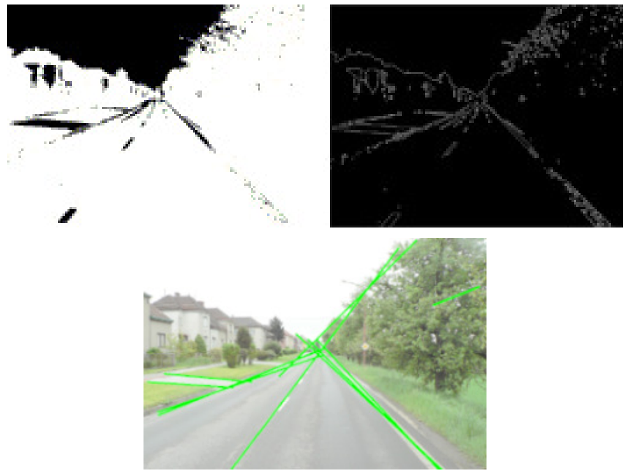

Fig. 13 Examples of road lanes recognition system implementation

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