Controlling a Mobile Robot in Indoor Environment with On–Chip Network of Intelligent Sensors

Cristian Andy TANASE[1], Aurel CHIRAP[2]
"Stefan cel Mare" University of Suceava
str.Universitatii nr.13, RO-720229 Suceava
[1]andy_t@eed.usv.ro, [2]aurel@eed.usv.ro

***Abstract*—The aim of the paper is to present the carrying out of an on-chip system (SOC) round about of an on-chip network (NOC) implemented on a FPGA structure. The hardware system is developed in order to control an autonomous mobile device that is able to search and track a mobile target detecting and avoiding all the obstacles in its route.**

The control device consists mainly of two components: 1) Sensorial (Intelligent Sensors) for searching the target and for detection of the obstacles and 2) Informatic System that analyzes and control the information taken over from the sensors, recognizes the target, establishes the route to go on.

The sensorial component is made up of a great number of various sensors, especially selected and mounted, in order to obtain as much information as possible from these about the environment where the robot is moving.

The informatics component is carried out entirely on a reprogrammable device FPGA. The on-chip system (SoC) that is developed is practically a network of functional units that have to receive raw data from the sensors and to transform it in as much useful information as possible. For each sensor is designed an (intelligent) unit of this description. Because of the great number of sensors, these units are interconnected through an internal network (network on–chip NOC).

***Index Terms*—Systems on-chip (SoC), Network on-chip (NoC), Field Programmable Gate Array (FPGA), Intelligent Sensors Systems, Independent mobile devices, Fuzzy control.**

I. INTRODUCTION

This paper describes the design, implementation and the performances of an intelligent sensors system used to control an autonomous mobile robot able to track a mobile target in an environment with obstacles. The intelligent sensors system and the control system are developed as an on-chip system (SoC) implemented on a FPGA structure. The Figure 1 shows the mobile robot for searching and pursuing a target, with the avoidance of the obstacles.

The growing complexity of the multiprocessor on-chip systems (SoC) makes necessary a revision of the on-chip communication techniques. Wireless stations, TV of high definition resolution, mobile telephony and many other devices of great complexity, are only a few applications that are developed because of multiprocessor systems SoC. [1]

In this kind of chips, the restrictions concerning the performances, the energy consumption, the reliability, cost and faults tolerance are extremely severe.

The design and implementation of an on-chip network requires a whole set of dedicated devices that form the infrastructure as well as a set of techniques and connection methods. For example, networks on the chip (NoC) requires switches, routers and communication protocols. [2]

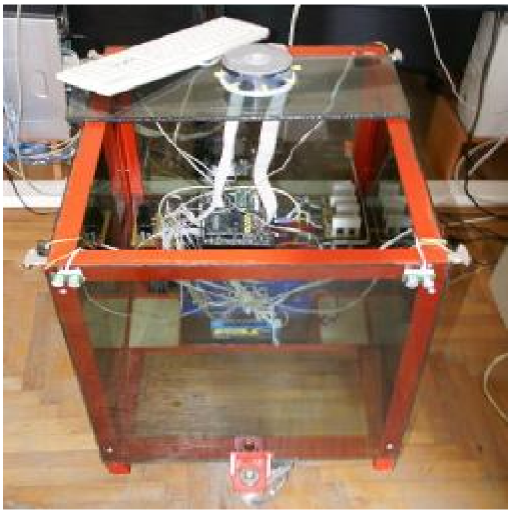


Figure 1. Autonomous robot for searching the target able to avoid the obstacles.

Within the shortest time period, the implementation of the NoC will be as usual as possible. Because of the complexity of SoC, the NoC's will be strictly necessary in the implementation of the communications between different devices on the chip. The basic concept is to communicate inside the chip in the same way, so that the messages are transmitted today on the internet. [2] [4]

In order to become viable, the networks on-chip require the support given by the CAD tools with specialized data base, mapping instruments and FPGA synthesis. The existing networks such as STBus and Æthereal are poorly enough developed. This thing represents an opportunity for the future developments in the field of the NoC chip design. It can be imported for the SoC networking, different simulation methods or existing instruments for various abstracting (simulation) levels. The NoC data bases include switches, routers, links and interfaces, helping the designers with flexible components of connection, the CPUs and the memory systems [3] [5].

II. THE CONTROL SYSTEM FOR A MOBILE ROBOT

II.1. General Description

The hardware system must be developed with the purpose to control a mobile, autonomous robot that must look for and follow a mobile target. On the way to the target, the mobile system must be able to detect and avoid all the obstacles in the route thanks to the great number of sensors. The communication between the functional blocks of the SoC and the functional units assigned to the sensors and implemented on chip, is performed through one on-chip network (NoC).

The control device mainly consists of two components:

Sensorial (intelligent sensors) for searching the target and for detecting the obstacles

The informatics system for identification and localization of the target, establishing the route to go on, the analysis and the control of the information taken over from the sensors.

The mobile target may be an IR source searched by means of an IR radar responder consisting of 8 sensors placed equidistant on the circumference of a circle. In the moment of the determination of the direction of the target, the compass reads this direction and follows it permanently. When an obstacle appears, the algorithm of detection and avoidance of the obstacles is activated and after that the route to the target is calculated again.

The informatics system is carried out entirely on a programmable device FPGA. The on-chip system (SoC) that is performed is actually an internal network (NoC) of functional units that have the task to receive the raw data from the sensors and to transfer them in useful information as much as possible. To every sensor is assigned an intelligent unit.

II.2. Network of Intelligent Sensors

The sensorial component is made up of a great number of sensors of different kinds, especially selected and mounted in order to obtain a quantity as great as possible of information from these. They are IR sensors to locate an IR target. The ultrasonic sensors detect the great obstacles placed at distances over 1m. The optical sensors avoid the collision with small obstacles and keep a certain distance from the walls. There are more sensors with the Hall effect for maintaining the direction. All the sensors are included in an intelligent sensors system.

The intelligent sensors system will respect the following main specifications:

must be adaptive to the environment, optimizing the detection performance of the sensors, the energy consumption, and the activity of communication

acquires and records the information; extracts the information, defined as a measure of the way of harmonizing with the predefined or learned models of information.

offers some possibilities of self-training such as: the possibility to determine “normal” or “abnormal” functioning of the internal processes, to evaluate the quality as well as their re-booting.

it is reprogrammable through the communication ports and permits the access in order to receive data and to program variables at all the levels.

is not only recognize patterns but also have the possibility to predict their evolution and can generate believable conclusions from these predictions; [8], [9], and [10].

For every sensor is assigned a functional unit that is really an automat that links with the dedicated sensor and reads the data generated from it. These automats have some features specific for the systems with intelligent sensors. They are matchable to the medium, that means they optimize the activity of detection and communication according to the needs of the medium. Another feature is that the data are registered and the result is only a useful information. The digital automats are implemented self-diagnostic functions such as for normal or abnormal work and make it to be informed about by the other sensor of the system.

Practically, the intelligent sensors system consists of sensors and the functional units dedicated and implemented in FPGA. They are connected with each other through an internal NoC. This network shows some features, such as: a dedicated protocol, a system of switches and network interfaces, devices for detection and correction of the errors, protocols of routing the messages depending on their priorities. There is more, implemented on the chip, a main module for design the trajectory to the target, according to the information received through the network from the sensors.

II.3 The NoC Architecture

The implemented NoC architecture consists of a ring network of switches. Every switch is connected to a resource block in which is implemented the functional unit dedicated to the sensor. These functional units are different from architectural and functional point of view. For this reason there are necessary bocks of interfacing with the network. One of the resources blocks is destined for a main decision module according to the information acquired from the sensors.

This module is built round about a classical CPU. In another resource block is implementing a memory unit. Every resource has one address in the frame of the network and is connected to the switches through the network interface. In the Figure 2 it is presented the diagram of the network of intelligent sensors implemented on-chip.

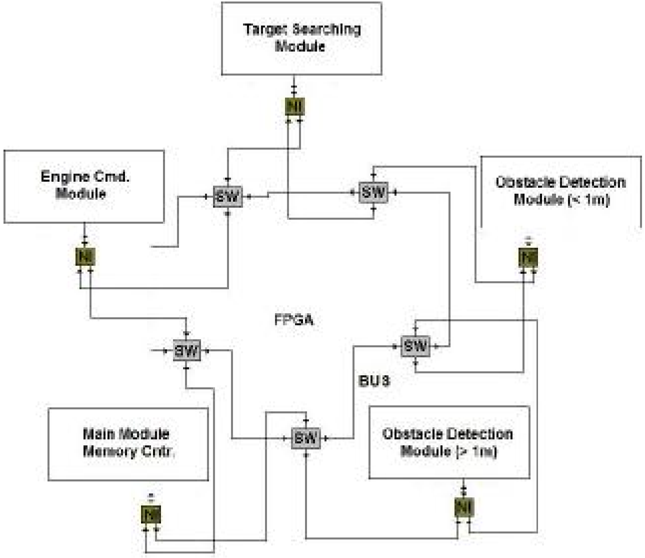


Figure 2. The internal network of intelligent sensors.

The switches have five bases emission-reception: four of them are used for connection with the adjacent switches in the frame of the network and one is for the connection to the resource block. The inputs are buffered while the outputs are multiplexed for the selection of the direction of communication. A logic block that takes the decision of routing is also present.

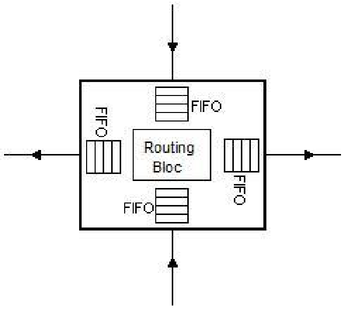


Figure 3. Switch

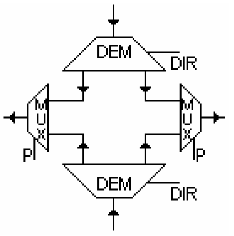


Figure 4. Routing block

The routing of the packets is made by the switches on the basis of their proprieties, when an input stack is filled, this is announced to the switch from the respective direction. In Figure 3 it is shown schematically a switch while in Figure 4 is presented the schema of a block of routers.

The message packets includes the following information: address, priority, packet, flag of error, date, CRC (figure 5). The length of a packet is 64 bits.

Every module is processing the data independently of the other modules achieving a model of parallel calculus.

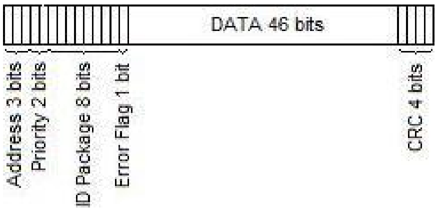


Figure 5. Structure of a message packet

The modules are permanently informed about the existent situation in the network. They can take decisions separately, depending on the current situation.

II.4 The Strategy of Navigation

In a first stage it is using a reactive strategy of navigation, which implies the detection of a space without collisions and the pursuit of the target. These are totally based on the sensorial information. The detection of a space without collisions is built with a STFIS (Self Tunable Fuzzy Interference System) that controls the speed and the linear velocity of the mobile robot. The variables ω and υ are computed permanently by the implicated modules of intelligent sensors while the network is permanently informed with their values.

The structure of a STFIS consists of triangular function members with the goal to extract and to show easily the final results. So, the output values y(ω or υ) are given by the formula:

$$y = \frac{\sum_{i=1}^{n} w_i \times a_i}{\sum_{i=1}^{n} a_i}$$

where a_i are the true values for every component while w_i are the afferent loads for these.

The architecture of the control system is shown in Figure 6.

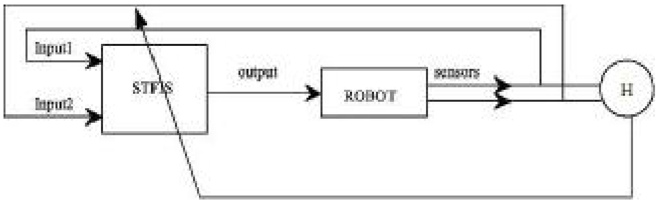
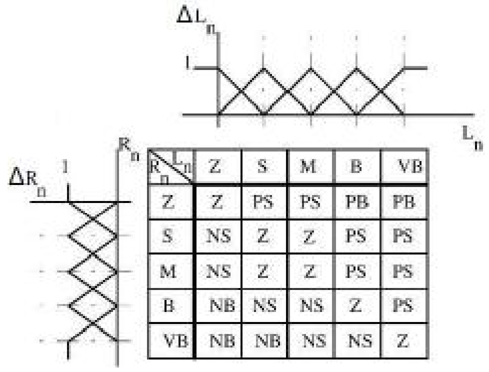


Figure 6. The simplified architecture of the control system.

The modules are implementing together a navigation system that is built through two elementary behaviors: a fuzzy controller with its own adjustment for detecting the middle of the free space and a component for detection and pursuit the target. The variables ω and υ – angular speed and linear velocity can have values within -1 and 1.

- ω = -1 turning around strongly left
- ω = 1 turning around strongly right
- υ = -1 great speed forward
- υ = 1 great speed backwards
- ω = υ = 0 robot stopped

These numerical values are translated in symbolic values in order to check the logic sense of these rules. We assign them a linguistic interpretation by form: PB (positive big) for values greater than 0,7, PS (positive small) for values between 0,2 and 0,7, Z (approximately zero) for values between -0,2 and 0,2, NS (negative small) for values between -0,7 and -0,2 and NB (negative big) for values lower than -0,7. Finally, it is obtained the linguistic table for the angular speed from the Table 1. [7]



R_n \ L_n	Z	S	M	B	VB
Z	Z	PS	PS	PB	PB
S	NS	Z	Z	PS	PS
M	NS	Z	Z	PS	PS
B	NB	NS	NS	Z	PS
VB	NB	NB	NS	NS	Z

Table 1. The linguistic table for the angular speed ω.

where:

$$R_n = \frac{R}{R+L},\ \mathrm{L_n} = \frac{\mathrm{L}}{\mathrm{R+L}},\ \mathrm{F_n} = \frac{\mathrm{F}}{MAXRANGE},$$

with:

F = min(UL2, UL3),
R = min(OP1,OP2,OP5,OP6,OP7,OP14,UL2),
L = min(OP4,OP3,OP10,OP11,OP12,OP13,UL3).
If υ < 0 then:
F = min(UL8, UL9),
R = min(OP4,OP3,OP10,OP11,OP12,OP13,UL3),
L = min(OP1,OP2,OP5,OP6,OP7,OP14,UL2).

A similar structure is used for generating the control rules for the linear velocity υ depending on the angular speed ω and the front distance F. The adjustment coefficient (see Figure 6) is obtained with the formula:

H = mod(υ - F)

The application is performed on a FPGA Xilinx - Vintex II system with SRAM (XC2V1000-4FG456C). The developing system round about this FPGA is Altium Nano Board NB-1.

III. CONCLUSIONS

In the design of the achieved control system for a mobile robot the idea of on-chip network it was put into connection with intelligent systems. So there can be performed systems much more complex than the actual ones, based on the same principle. These systems may control mobile autonomous devices. They can process a very big amount of information acquired from a great number of sensors. At the same time, the systems SoC-NoC with intelligent sensors can be used in all the fields where the machines need more information from the environment.

It can also use self-reconfigurable devices that can change on-line the architecture for calculation and for inter-sensorial communication in order to gain an increased efficiency of the power of computation and of the silicon area density.

Due to the complexity of the SoC, the networks on the chip will be strictly necessary in the implementation of the communications between different devices on the chip. The basic concept is to communicate inside the chip in the same manner like the messages are sent today on the internet.

In the same way, the independent systems equipped with mechanic intelligence and a solid sensorial system will be obliged to rethink the system of communications between the functional blocks. The NoC architectures can be a solution for these problems.

ACKNOWLEDGMENTS

This research and backgrounds for this article writing was fiunded by 131-CEEX/2006 (INTEROB) research grant.

REFERENCES

[1] Rajesh Gupta, *On-chip networks*, IEEE Design&Test of Computers, September-October 2005

[2] Andre Ivanov, Giovanni De Micheli, *The Network-on-Chip Paradigm in Practice and Research*, IEEE Design&Test of Computers, September-October 2005

[3] Partha Pratim Pande, Cristian Grecu, Andre Ivanov, *Design, Synthesis, and Test of Networks on Chips*, IEEE Design&Test of Computers, September-October 2005

[4] Se-Joong Lee, Kangmin Lee, Hoi-Jun Yoo, *Analysis and Implementation of Practical, Cost-Effective Networks on Chips*, IEEE Design&Test of Computers, September-October 2005

[5] Kangmin Lee, Se-Joong Lee, Donghyun Kim, Kwanho Kim, Gawon Kim, Joungho Kim, Hoi-Jun Yoo, *Networks-on-chip and Networks-in-Package for High-Performance SoC Platforms*, Dept. of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea

[6] Andy Cristian TĂNASE, Adrian GRAUR, et al. Coriolan Andrei LEONTE, Dorin PALANCIUC, George HOLCA, *Autonomous System for Searching and Elimination of Fire Sources*, Advances in Electrical and Computer Engineering, Suceava, Romania, No 1/2005, volume 5 (12), pp. 96-100

[7] H. Maaref, C. Barret, *Sensor-based navigation of a mobile robot in an indoor environment, Robotics and Autonomous Systems* 38, 2002.

[8] Luis Montesano, Javier Minguez, *Lesson Learned in Integration for Sensor-Based Robot Navigation Systems*, Advanced Robotic Systems 2006.

[9] Iwahashi, N. *A Method for the Coupling of Belief Systems through Human-Robot Language Interaction*, Proc. 12th IEEE Workshop Robot and Human Interactive Communication, pp.385-390. (2003)

[10] George MAHALU, Adrian GRAUR. *Bus Communication in Robotic Leading System*, Advances in Electrical and Computer Engineering, Suceava, Romania, , No 1/2005, volume 5 (12), pp. 17-24