Ambient Intelligence in Distributed Modular Systems

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Abstract: Analyzing adaptive possibilities of agents in multi-agents system, we have discovered new aspects of ambient intelligence in distributed modular systems using intelligent building blocks (I-BLOCKS) [1]. This paper describes early scientific researches related to technical design, applicable experiments and evaluation of adaptive processing and information interaction among I-BLOCKS allowing users to easily develop ambient intelligence applications. The processing technology presented in this paper is embedded inside each DUPLO1 brick by microprocessor as well as selected sensors and actuators in addition. Behaviors of an I-BLOCKS modular structure are defined by the internal processing functionality of each I-Block in such structure and communication capacities between I-BLOCKS. Users of the I-BLOCKS system can do "programming by building" and thereby create specific functionalities of a modular structure of intelligent artefacts without the need to learn and use traditional programming language. From investigating different effects of modern artificial intelligence, I-BLOCKS we have developed might possibly contain potential possibilities for developing applications in ambient intelligence (AmI) environments. To illustrate these possibilities, the paper presents a range of different experimental scenarios in which I-BLOCKS have been used to set-up reconfigurable modular systems. The paper also reports briefly about earlier experiments of I-BLOCKS in different research fields, allowing users to construct AmI applications by a just defined concept of modular artefacts [3].

Ambient intelligence, intelligent building blocks, tangible programming, cooperative autonomous vehicles, behavior-based robotics, disappearing and invisible computer, learning by playing

1. INTRODUCTION

Ambient Intelligence (AmI) today refers to a new paradigm in information technology in which people are empowered though a digital environment that is aware of their presence and context, and is sensitive, adaptive to their needs, habits, gestures and emotions. According to the vision of AmI provided by the Information Society Technologies Advisory Group (ISTAG) to the European Commission, all the environment surroundings around us will collectively develop into a pervasive network of intelligent devices that cooperatively operates to gather, process and transfer information. Therefore, in the vision of the future AmI is the extended direction of today's concept of ubiquitous computing, i.e. the integration of electronic processing power to everyday objects. However, AmI is much more potentially extended than this, as the AmI should distribute and adapt to user's needs and behaviors.

Until now, many different directions existing are approached to a general solution for ambient intelligence applications. In this paper we describe technologically innovative implementation built up from intelligent building blocks to explore potential solutions for ambient intelligence environments. An essential property in our work is that intelligent building block as an agent needs to be centered on the individual while behaviors of building blocks structure as multi agents system is based on adaptive interaction of building blocks in such system.

Each building block includes processing power in order to share its current functionality to others as well as interact with environmental surroundings. Therefore, the collaboration of building blocks will augment processing power and interactive capabilities of cooperative systems. By implementing a series of experiments we suggest a new specific kind of devices to explore the design direction for ambient intelligence solutions, both of hardware and software. Further, we discuss possibilities discovered by embedded mobile agents model though embodiment of I-BLOCKS modular system, explaining how each building block as an agent enables communication, interaction and cooperative operation in structures of different building blocks.

2. INTELLIGENT BUILDING BLOCKS

We have developed a series of intelligent building blocks [1] in the first generation in which each I-BLOCK itself contains internal processing and communication capacities. In our implementation electronic control board is housed inside LEGO DUPLO bricks, which contains a PIC16F1876 28-pins 8 bits CMOS Flash micro-controller for processing. Each I-Block provides capacity of bi-directional serial communication via four physical connectors, two male connectors on the top and two female ones under the bottom. Energy power from a battery building block is supported via connectors on the top-part of bricks, where the connectors have been distributed to 8 studs on the top and in the bottom-part at 4 corners of bricks.

When building blocks are physically connected together

[1] LEGO and DUPLO are trademarks of LEGO System A/S

in specified order for a physical construction, they can communicate with each other via connection(s) of half-duplex communication. In the sending building block, packages of data are sent via at least one of four connections while receiving building block is received by attached communication connection(s). In typical setup, each building block will receive input from its neighbours on communication channels, processing this input data, and then sending the output data to communication channels as output. A construction of such building blocks will have specific functionality defined by the physical construction, input of each building block, internal processing of the individual one, and communication schemes. If input, processing, and communication are predefined, the user of such a system can decide the functionality of the system by manipulating the physical structure.

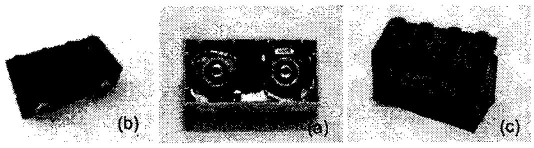

Fig.1. (a): A CPU building blocks including internal processor and communication channels. (b): Input building block that contains two LDR sensors as an input device in addition of CPU I-BLOCKS to allow measure light density. (c): Output building block that contain a servo motor allowing the top segment to turn in steps as a output device.

In order to make a I-BLOCK interact with other I-BLOCKS or inhabited environment, we have developed a lot of different types of I-BLOCKS that all have the same building technology of processing and communication capacities but numerous number of them are extended with the addition of sensors as *input building block* and actuators as *output building block* in the first generation. Input building blocks include standard building blocks adding LDR sensor, microphone, potentiometer, switches while output building blocks include standard building blocks combining with servo motor, DC motor, LEDs, sound generator, etc.
To evolve inter-interaction between building blocks or interaction of bricks in inhabited environment, the second generation of building blocks including multi-infrared sensors (M-IR), ultrasound sensor (US), accelerometer and radio frequency (ACC-RF), have been developed. The development arises much more capabilities of interactive communication between neighborhood structure of building blocks so that such structures are now able to communicate not only via physical connection of maximum of four building blocks on the top and the bottom connected together but also by using wireless communication among many of building blocks as well as structures of building blocks (e.g. up to 128 wireless channels if RF building blocks are used).
In the first generation of I-BLOCKS, basically different kinds of processing in the I-BLOCKS such as making the I-BLOCKS become arithmetic blocks, behavioral blocks, neural blocks were implemented. However, the I-BLOCKS of the first generation was limited in specific research fields because of their communication capacities as well as individual functionality of building blocks that are able to interact with human beings and environmental surroundings. In order to extend variety of application of I-BLOCKS in different fields, which one can discovered from modern AI principles such as biologically inspired systems, agent-based computing, complex system, etc...the second generation has been developed to partly fill up.

3. BEHAVIOUR-BASED ROBOTICS

Behavior-based robot is a research branch of robotics that does not use an internal model of environment. For instance, there is no predetermined programming in the robot that may be a mobile robot, but all the information is gleaned from input of the robot's sensors. The robot uses that information to react with the changes in its environment.
In the implementation, we constructed a LEGO mobile robot for purpose of tracking the way between corridors. LEGO materials are used to build the robot in which two DC motors are main factors to control behavior of the robot. To control two motors, two LEGO motor building blocks are necessarily implemented to connect. The building blocks are setup to attach the LEGO motor connectors to analog port of the PIC that is usually used for analog communications.
In order to track the way between wall corridors, principle of ultrasonic ranging finder that is used to estimate the distance from mobile object to opposite obstacles has been recognized as good solution in the cases. A couple of US building blocks are directly assembled to motor I-BLOCKS in the way that is perpendicular to forward direction of the mobile robot. The operation of US I-BLOCKS is to estimate the distance from the robot to the corridor wall and transfer the result to Motor I-BLOCKS via physical connection(s). To calculate the instantaneous distance, the US building block has to contain a pair of transmitting and receiving ultrasonic sensors controlled by a processor in which the processor will generate a range of amplified sonic signals (sonic burst) from starting trigger pulse before sending via transmitter while the receiver is waiting for receive echoes. The distance will be proportional to time period of traveling of signal in ratio of ultrasonic speed in air (approx. 346m/S).

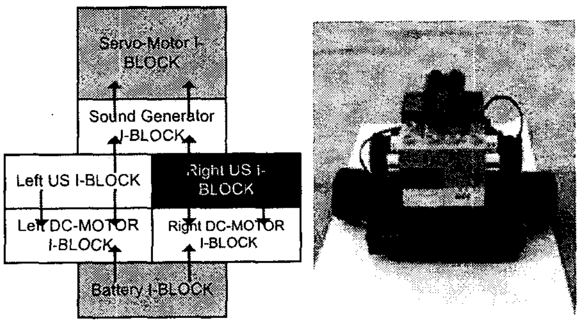

Fig. 2. Left: Block diagram of the modular structure of the I-BLOCKS for Behavior-Based Robot. Right: Real robot "Corridor Tracker"

Developed by the concept of "*behavior-based robots*", US I-BLOCKS works as sensor modules that interact with environmental surroundings to support input data and Motor I-BLOCKS operate as actuator modules that control behavior of the robot. In particular, due to homogeneous characteristics of the same type of I-BLOCKS, Motor I-BLOCKS uses the digitalized values measured the distance from the robot to the corridor wall by US-BLOCKS where the values is within a range of 255 scales (one byte). To raise exciting of scientific meaning for the experiment, a sound generator I-BLOCKS and a servo motor I-BLOCKS are attached under the bottom and on the top of the module structure, respectively. The sound generator will generate sound in different frequencies while the servo motor will present steps of rotating direction, depended on the input value sent out by the two US I-BLOCKS. The I-BLOCKS will keep a stable state when the robot goes straight but its states will adaptively change when robot turns left of right at the corner, expressing though higher or lower frequency of sound and arrow direction that show a truly going way of the robot. The structure of connected building blocks and the "corridor tracker" robot are represented in the figure 2.

4. AUTONOMOUS COOPERATIVE VEHICLES

Exploration of behavior of mobile robots is traditional research but a focus of cooperative behaviors of mobile robots assembled from distributed functionality modules is rarely interested in. We developed an experiment of mobile robots that can be assembled from specialized I-BLOCKS in order to explore group interactive behavior. To reach the traditional solution of robot technology that is usually developed by different modularity of sensors and actuators, a robot (named as CD-ROBOT) is configured from modular components including sonar ranging finder, radio frequency communication, DC motor driver, accelerometer and extra components. The modular component are connected and controlled by PIC16F876 microprocessor in mainly additional factor as presented in the figure 3.

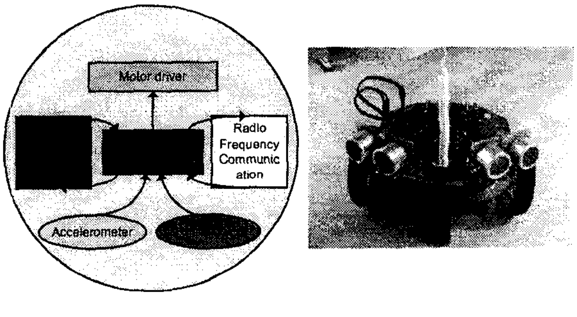

Fig.3. Left: Block diagram of functional modularity, Right: CD-ROBOT designed in LEGO standard

The power supply is inter-connected by 9V batteries put under the electronic main-board. The robot constructed is basically designed in LEGO standard, e.g. LEGO motor, LEGO DUPLO base that can physically connect to any I-BLOCKS for additional sensing and actuation information. There are a lot of open sockets directly connected to PIC, which can be used to not only measure signals but also connect other extra modular components with respect to characteristics of the interactive environment.

Further, to explore grouping behavior of mobile robots, we assembled two LEGO cars by using LEGO materials and specialized I-BLOCKS. Each LEGO car is configured by at least a radio frequency and two motor, a power supply building blocks but they can be attached other building blocks obtaining different functionalities as presented in the figure 4.

On demonstration, we first experimented possibility of automatically tracking a way between corridors using sonar characteristic of measuring distance of all mobile robots. In the CD-ROBOT, based on the design two ultrasound range finders symmetrically attached controlling board at 60, or 90 degrees with forward direction of the robot will real-time measure the two distances from robot to corridor sides. The measured results are transferred to CPU and processed there to control speed of two DC motor. This is really solution of *centralized processing* system in which information all is centralized to a unique processor so that the behavior of robot is controlled by only processor. But, in the other mobile robots assembled by LEGO materials and specialized building blocks, the measured results from US I-BLOCKS are transferred to CPU I-BLOCKS at two different ports. The results are compared at CPU building block as a speed manager and then sent out to Motor I-BLOCKS in order to control speed of motors. This is a solution of *decentralized processing* system (distributed processing) in which information is processed in specific functionality module before transferring to other modules so that the behavior of robot is depended on distributed processing of input information of sensing modules, processing and communication between modules and output information of actuation modules. In both of cases considered, the speed of two LEGO motors are controlled by rules: the robot turns right if the left measured distance is shorter than right one, and vice versa.

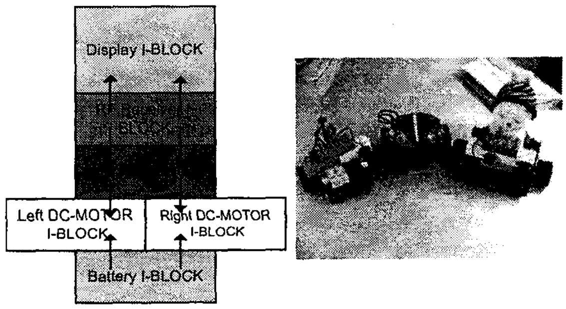

Fig.4. Left: Block diagram of the modular structure of the I-BLOCKS for "slave" robots. Right: Cooperative Autonomous Vehicles

In exploration of grouping behavior of mobile robots, we have been interested in both of technological solutions of local communication and global communication for development of autonomous cooperative vehicles. But, in the paper, only global communication technology is significantly considered. Towards the direction, CD-ROBOT behaves autonomously in interactive relationship with the environment as a master and the other LEGO cars work as slaves. Information collected from behavior of the CD-ROBOT is packed in a data package that is encoded before transferring to the other LEGO cars by radio frequency technology as a global communication system. The information is encoded as left and right controlling commands used to control behavior of the CD-ROBOT. The other LEGO cars will receive that controlling information by using RF I-BLOCKS, transferring to CPU I-BLOCK that works as a decoder to decode the left and right information, sending out left and right ports connected to two Motor I-BLOCKS to control two robot's wheels. A structure of I-BLOCKS can be seen in the figure 4a while the mobile robots can be observed in the figure 4b.

However, any robot may become a master while the others working as slaves by using *"programming by building"* language. This is newly discovered aspect of development for heterogeneous teams of modular mobile robots.

5. MODULAR CONTEXT-AWARE UBIQUITOUS COMPUTING SYSTEMS

In last decade, concept of *context* in is often used as a synonym for *location* of a mobile object, that implies relative position of the object as well as derivatives of positional information namely velocity and acceleration. However, in the abstraction of ambient intelligence environment, location of a mobile object is only a rich source used to enrich for applications of context-aware systems in which other types of information augmented can be aware of current state of mobile objects such as temperature, light density, etc collected from interaction with environmental surroundings. In the section, we described a reconfigurable modular location-aware system implemented to awake of positional information of a mobile object. After that, the system is extended to become a context-aware ubiquitous computing system developed as a wireless sensor network that sensing modules used to capture the changes of environment and actuation modules to perform the system activities. The modules used for setting up the system are mainly a series of I-BLOCKS implemented in the second generation to compensate inadequate possibilities of the first generation in wireless communication technology solutions.

Many localization applications of people or movable objects have been essentially enhanced in the world. Most of them use ultrasonic system cooperating with other communication technologies. Ultrasonic location systems commonly use the measured propagation delay, or time of flight, of signal between ultrasound transmitters and receivers to perform positioning. The propagation delay is related to the physical distance between the transceiver and receiver by the speed of sound traveling in air. A number of propagation delays are collected between fixed transceivers or receiver units with an unknown location. By using algorithms based on the principles of *trilateration/multilateration*, the location of the movable unit can be found. Either ultrasonic transmitters are placed at known locations in the indoor environment and receivers are worn by people or affixed to objects to be tracked, or vice versa.. Such system is normally big, complex, unreconfigurable and fixed because of unification of components.

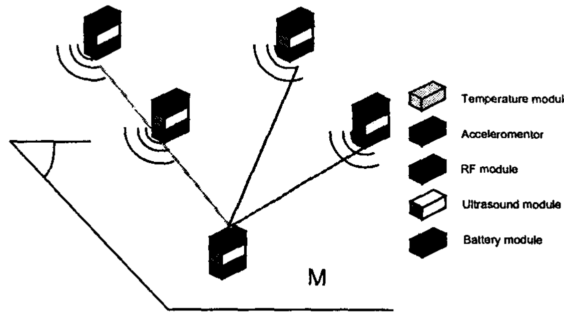

Fig.5. The systematic model of modular location-aware computing systems that is extended to reconfigurable context-aware computing system by assembling sensing and actuation I-BLOCKS

In this section we, however, developed an indoor location system that is configured by different building blocks including self-processing and communication capabilities. Here, we define a communicating unit that is physically constructed by assembly of an ultrasound, a radio frequency, a display and a power supply building blocks. In such system, US I-BLOCKS obtaining both of transmitter and receiver are employed to calculate a transmitter-to-receiver distance by estimating of the signal's propagation speed while radio frequency building blocks is utilized to generate synchronous pulse for distance measurement. The measured distance may be easily displayed on LCD screen of Display I-BLOCKS. In order to perform *multilateration* algorithm, at least three communicating units are needed to be fixed at the identified coordinate but we located four ones at corners of the identified square. This setup increases the operating range of the system, to compensate for occasion when one signal is lost and four times accuracy of distance calculation (by average value of four sequentially different *trilateration* measurements).

Because of combination of both transmitter and receiver in the ultrasonic building block, the system we set up may be operating at two modes: Mode 1: Fixed receivers receiving simultaneously cooperating with mobile transmitters; or Mode 2: Fixed transmitters sending signal to mobile receiver at different time slots assigned. In this system each data packet sent out or received by such unit has to be encoded ID number that is own number of such unit.

$$d_i = \sqrt{(X - x_i)^2 + (Y - y_i)^2 + (Z - z_i)^2} \qquad (1)$$

We experimented with Mode 1 instead of mode 2 because of practical simpleness and fast measuring speed. Formula 1 shows *multilateration* algorithm of a set of the transmitter-to-receiver distances, used for this experiment, where a roaming transmitter's location *(X, Y, Z)* can be related to the distance d_i to a given receiver *i*, and the receiver' surveyed 3D location (x_i, y_i, z_i). For executing this location awareness, a radio synchronization pulse from the RF I-BLOCK of the mobile unit is broadcasted simultaneously to all of ceiling fixed receivers in order to synchronize such system. After receiving the synchronous signal from mobile unit, the RF building blocks are transferring command pulses to US building blocks in order to start sending an ultrasound signal while RF I-BLOCK at all of receivers generate a pulse to start timers synchronously. The speed of radio is approximately equal to light traveling so all of communicating units are treated as operating synchronously. Receivers will collect a set of transmitter-to-receiver distances and then transfer such results directly to mobile unit. The mobile unit will use the *multilateration* algorithm and such results to compute an estimate of its position. Besides, the position may be not only presented on display I-BLOCK but also sent to PC for real-time simulation via serial communication ports of PC communication building blocks by using wire/wireless communication technology. In addition, we planned to real-time simulate position of mobile unit on graphical interface in the future.

Fig.6. Communicating units of ultrasonic, radio frequency, display and power supply building blocks

Furthermore, beyond location awareness, we implemented a context awareness system established by intelligent building blocks. In inhabited environment, we actually wish that the most of computing technologies could be disappear but such a disappearance that is only a fundamental consequence not of technology, but of human psychology. By using *"programming by building"* language we constructed ubiquitous computing appliances that make users free to use them without thinking and so to focus beyond them on new goals.

An open concept of context awareness is developed through implementing dynamic distributed structures assembled from a different various numbers of sensors and actuators building blocks. As numerous number of context awareness system issued, sensing technologies is applied to construct these dynamic structures e.g. LDR sensors, microphones, touch sensor, IR sensor, sonar sensor, accelerometer sensor, etc… that may be used to capture surrounding data. All of different kinds of sensors are embedded in artifacts that have capabilities of self-processing and inter-communication in order to make multi-sensor integration for contribution of a sensor or group of sensor to perception of a given context. With specialized specification of integrating the number of predefined building blocks the dynamic structure is completely capabilities of situational interaction with their environment and humans.

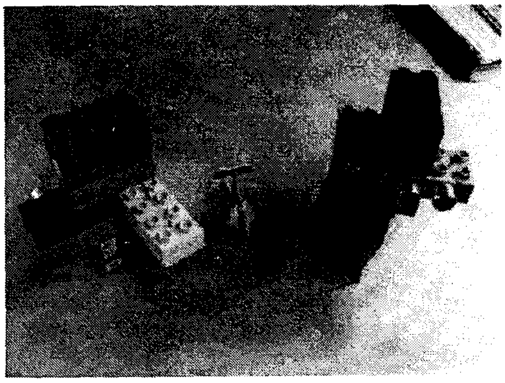

Fig.7 Two dynamic structures of the modular distributed system

6. DISCUSSION

Ambient intelligence allows people to freely utilize newly technological solutions in which devices, that are small, smart, easy to develop and easy to use, are integrated into everyday object in our surrounding environment. When existing many different research directions to approach technological solutions for ambient intelligence applications, we have discovered a new sense of direction inspired from adaptive possibilities of agent in a multi-agent system. In the direction, we have developed distributed modular systems in which each module includes individual functionality of communication capabilities among them and interactive possibilities with environmental surroundings, where each module of the systems will adaptively act as individual agent in agent-systems. Based on investigating advanced aspects of agent-based computing, a wide range of application of distributed modular systems in different fields including robotics, human-computer interaction, human-robot interaction, context-aware computing, etc has been implemented to demonstrate on the research trends.

In the first scenario, users, children in particular are easy do *"programming by building"* in order to build up a "corridor tracker". Imagine that children without understanding of computer and/or robot play assemble toys with a book of image instruction. Taking two minutes, the robot constructed obtains sufficient characteristics to behave as an edutainment robot. Still using modules extra increased by other functional modules and LEGO material, a group of robots that can cooperatively behave have been developed. The subject of cooperative autonomous vehicles is always difficult to find a good solution but very interesting to discover new aspects of the evolution. In the second scenario, the global communication has been used to make communicating interaction among robots in which behavior of each robot is possibly depended on other robots' behavior or is employed to control behavior of other robots. We have evolved infrared sensor fusion modules to investigate cooperative behavior of mobile robots by using the concept of local communication that each robot can communicate with others in its vicinity. Each solution abovementioned has more or less advantages and disadvantages: local communication is direct, fast and easy to recognize relative position and orientation among robots but it only effects in its vicinity; global communication can operates in wide area but it is low speed and indirect communication of position between robots. Hence, the best solution for autonomous cooperative robots should be combination of advantages of the technologies. However, it is very interesting thing here that user takes five minutes to assemble a cooperative autonomous vehicles with available smart modules and materials where computing devices is completely invisible and disappearing. All of them are embedded into everyday objects.

In exploration of another direction of technological solutions for wireless sensor networks, we have first implemented a modular location-aware system in which communicating units is assembled by functionality modules including a power supply module, a module to measure ranging distance and a module to synchronize the system. Based on the design, positional information of a mobile object working in system's area will be probably recognized. Furthermore, to know the current state of mobile object or any object in the systems such as temperature, light, etc we have extended the position-aware systems into a reconfigurable modular context-aware system in which information of current ambient state is depended on configuration of communicating units in the system, whereas the configuration is completely assembled by user who can easily attached a temperature I-BLOCK or LDR I-BLOCK, for examples, to each communicating unit. In the system of networked sensors, communicating units are working as *notes* in order to support state information captured and processing by sensor I-BLOCK to other nodes and user. If necessary, it can also autonomously change the adaptive configuration of a node by executing actuator I-BLOCKS attached in the node configuration. Actually, the wireless sensor network is completely reconfigured as a distributed modular system on the purpose of users and surrounding environment that it interacts with. Further, the totally processing power of the sensor network might be depended on assistant interactions among nodes. This is possible manner, based on the functional modules preprogrammed.

7. CONCLUSION & FUTURE WORKS

In this paper, we present the varieties of experiments related to different research fields. In different approaches, adaptive relationship between building blocks is appropriative to adaptive interaction of agents in the multi-agents system. But, all of such experiments have been involved from intelligent building blocks by using *tangible programming language,* so called *"programming by building"*. Based on substantial experiences gained, traditional concepts used I-BLOCKS has been evolved though a variety of application in different research fields in which some of them is beyond their original concepts. Further, we wish to contribute further to the development of new perspective of how to build a distributed modular system from modules that have capabilities of self-processing and communication.

In the technological solution developed for ambient intelligence applications, we are emphasizing on research approaches of distributed modular systems which user are easy to create an intelligent system, based on smart device available. However, the modules used for applications abovementioned obtain limitation of mechanical connection, strength of processing and communication. Therefore, we have currently evolved a new prototype of I-BLOCKS which are cubic modules including six physical connection interfaces and a more powerful microprocessor to increase processing power for individual module as well as systems. In the future, we will develop a couple of reconfigurable adaptive modular robots that can possible obtain complex behaviors.

In conclusion, the paper describes a new exploration for ambient intelligence applications based on distributed modular systems, which are built up from module including adaptive and interactive possibilities with surrounding environments and communication capabilities among them. Specially, all of the systems are always *open distributed systems* (ODS), which can easy change morphologies, characteristics and properties because they are almost developed from hardware devices called *"modular artefacts"*[3] and software implementations called *tangible programming language* (also called as *programming by building).*

Acknowledgement

Part of implementation presented in the paper has been developed by Trung Dung Ngo in his thesis works. We are pleased to acknowledge Jacob Nielsen collaborating in programming. The work is an added part of Danish National Research Council project "Intelligent Artefacts".

References:

[1]. Lund.H.H. Intelligent Artefacts. In Sugisaka and Tanaka, editors, *Proceedings of 8th International Symposium on Artificial Life and Robotics.* ISAROB, Oita, 2003.

[2]. Ferber .J. Multi-agent systems: An introduction to distributed artificial intelligence, *Addison Wesley,* 1999.

[3]. Ngo.T.D, Lund.H.H. Modular Artefacts. *Component-Oriented Approaches to Context-aware Computing*, ECOOP'04, Oslo, Norway, June14, 2004

[4]. Weiser.M, The computer for the 21st century, Published in Scientific American, 1991.

[5]. Hazas.M, Ward.A. A high performance privacy-oriented location system. *In processing of the first IEEE International Conference on Pervasive Computing and Communications (PerCom2003), pages 216-223,* Dallas-Fort Worth, USA, March 2003.

[6]. G. Riva, P. Lorenti, M. Lunghi, F. Vatalaro, F. Davide. Presence 2010: *The Emergence of Ambient Intelligence, Ios Press*, Amsterdam, The Nertherland, 2003

[7]. A.Schmidt. Implicit Human Computer Interaction Through Context. *Personal Technologies* Volume 4(2&3), June 2000. pp191-199

[8]. C. Plessl, R. Enzler, H.Walder, J.Beutel, M. Plazner. L.Thiele. G Troster. The case of reconfigurable hardware in wearable computing, *Pers Ubiquit Computing*, 2003.

[12]. R.C. Arkin. Behavior-Based Robotics. *MIT Press.* CA, 1998