CORE-TX: Collective Robotic Environment – the Timisoara Experiment[1]

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Abstract: In a ubiquitous environment, intellignet functions are embedded in objects around the user, thus enabling him to create variuos functionalities by combining those objects. The collaborative robotic environments are a new approach to the coordination of multirobot systems which usually consist of numerous, relatively simple, small sized robots. The CORE-TX system (COllaborative Robotic Environment – the Timisoara eXperiment) is conceived as a complex platform composed by a heterogeneous set of autonomous microsystems with embedded intelligence, a collaborative communication environment and a central entity with supervising functions. This paper describes the general architecture of the CORE-TX system, the system model; this paper also contains a brief comparison bBetween CORE-TX and state-of-the-art collaborative environments.

Keywords: collective robotic environments, emergence, robotic behavior

1 Introduction

The evolution of information processing equipment and the need of adaptable digital control systems generate an extraordinary spreading of digital equipment in all fields of life including military applications, service industries, space exploration, agriculture, mining, factory automation, health care, waste management, disaster intervention and the home. The majority of that equipment scattered over all human activities need to be more or less autonomous which means that some degree of intelligence of intelligence must be embedded into them.

There is a trend nowadays that that the level of intelligence embedded into these autonomous equipments must be at a minimum in order for the systems to scale well and have a low cost [1]. This means that they do not necessarily seek to produce human-like thought patterns or cognition. The intent of the researchers is not to create units that think intelligently, but act intelligently. The equipment designed with this principle can accomplish real world tasks without knowing exactly how to do them. The main goal is to successfully complete a task so it is important that the coupling between the perception and action to be as direct as possible.

2 Collaborative Robotic Environments

The collaborative robotic environments are a new approach to the coordination of multirobot systems which usually consist of numerous, relatively simple, small sized robots [2]. The purpose of these collaborative environments is to study the design of robots, of their physical body and modeling their behavior. Because of the simplicity of their physical framework, only simple behaviors can be associated with each robot. One of the goals of the collaborative robotic environments is to develop such manner that the collective of robots emerge a complex behavior based on the interaction of the local, simple behaviors.

Emergence is the process by which complex behavior patterns are formed starting from extremely simple rules [2, 3]. The new field of emergent behavior is mainly based on the study of the natural world in order to retrieve simple natural algorithms that can be applied in other fields of interest. The simplicity of these patterns and the interaction between them solve can solve some of the most important problems in embedded systems: energy consumption, communication protocols, efficiency and reliability features etc.

Collaborative robotic environments are different from normal distributed systems because they emphasize on large numbers of robots, scalability and very advanced communication protocols which are based mainly on local wireless communication.

2.1 CORE-TX Model

The CORE-TX system (COllaborative Robotic Environment – the Timisoara eXperiment, read as "cortex") is conceived as a complex platform composed at the architecture level by a heterogeneous set of autonomous microsystems with embedded intelligence, a collaborative communication environment and a central entity with the role of configuration, control and supervision of the whole system (see Figure 1). The superior layer of abstraction for the CORE-TX model is represented by the BRAIN entity (Background Robotic Activity Induction Node), which is implemented on a host computer (PC) that has communication connectivity (the use of radio/wireless systems is intended) and which runs a system of original software packages.

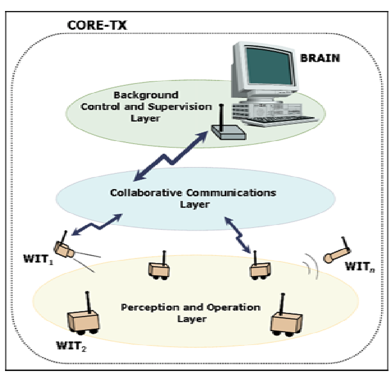

Figure 1

The CORE-TX System architecture

At the operation and perception layer, the CORE-TX system interacts with the environment through autonomous microsystems with embedded intelligence called WIT (Wireless Intelligent Terminal). The WIT elements may have perception functions (intelligent sensors), operating functions (autonomous mini-robots) or combined.

When the WIT enters the CORE-TX environment it presents its capabilities to the BRAIN entity. As some of the WITs may be mobile there is the problem of localization. The CORE-TX system is designed in such a manner that although the WITs can be individually addressed for application specific purposes, at the superior level of abstraction, the WITs can be identified by their location. It is important that the communication interconnections are not flooded with information regarding to the individual addressing of the nodes. The localization problem is left to an inferior level of abstractization that is responsible to route management.

The superior abstraction layer, the BRAIN, is situated usually on a powerful system (a high-end PC). The BRAIN layer supervises all the WITs, The BRAIN is also responsible for the user interface; this is the point of entry for any user information. The BRAIN is connected to the network of WITs through a gateway device / access point, actually a simple WIT with capabilities of communication with a PC (EtherNUT, embedded Ethernet, based Ethernet board).

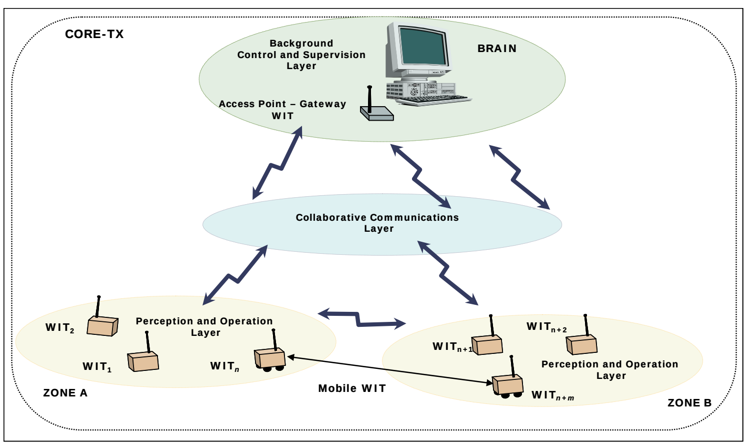

Figure 2

The CORE-TX model – zone version

The rest of the WITs are scattered in the given environment. They are conceptually divided into zones. This principle also assures the WITs localization based on the zone it belongs to. The problem of localization also arises here because, although some of the WITs are immobile (digital cameras, temperature sensors, etc.), some may be mobile (robots, mobile cameras, etc.); as the WITs move in the environments, they change zones so the CORE-TX model has procedures similar to the handover procedure of the GSM system [4].

This division into zones is very effective with regards to the communication reliability and efficiency because it hides unnecessary details. For example, if someone needs to know the temperature inside a room, the sensors assigned to that particular room zone will return an average temperature, and not the exact temperature of any given sensor. The principle presented above leads to the view of a WIT network as a distributed database [5]. Finding the required information would just lead to "zone-oriented" queries instead of "ID-oriented" queries.

2.2 WIT Model

The principles of modularity, autonomy and embedded digital intelligence (see Figure 3) are at the base of design and development of the WIT elements. From a formal point of view all of the WITs are identical. Although the WITs can be used for different purposes like the BRAIN access point, sensing modules etc, all the WITs share the same design. The WIT has a modular design, formed of different application boards that are interconnected using high-speed SPI interface. The minimum configuration of the WIT prototype under development at the DSPLabs Timisoara, is prezented in the followings.

The Mainboard or the Base Processing Module: this is the core element of any WIT: it is based around a Philips LPC2294 microprocessor [6]. The base processing module of WIT represents the central element of digital intelligence of the microsystem, serving as a platform for the HARETICK real-time operating kernel [7]. This module will serve as the base for running the actual application; this module will be the responsible for the general behavior of the WIT. The local processing of the data sampled from the environment takes place here. All the operation will be strictly controlled and planned in order to minimize the energy consumption. The battery pack: this module has no intelligence, and it is attached to the mainboard module. The WITs are assumed to be battery-powered, each WIT displays limited resources and the communication model has to present communication protocols that are lightweight and battery-aware [8]. The communication module: by default, the CORE-TX system uses wireless communication. This type of communication is implemented by the X-Bee PRO [9] modules. These modules use 2-way radio communication and the Zigbee standard (IEEE 802.15.4 [9]). The communication module guarantees the interconnection between WIT elements at a higher layer – that of the collaborative communications, thus containing the data transmission / reception interface and the processing according to the protocols that will be developed specially for this.

In addition to the minimum configuration described above, numerous extension boards can be added to the mainboard by the use of the high speed SPI interface. These extension boards will be based on the Philips LPC2103 microprocessor [6].

WIT's operation and support module guarantees the support (static or mobile – with the help of a set of active wheels and motors) for the microsystem. As an additional option, the development of a mobile arm operation system has been taken into consideration. For this type of extension board a separate power supply is needed in order to move the actuators. The perception module contains the sensors of the WIT microsystem as well as the sensor data preprocessing part. This module was developed using advanced techniques of designing and implementing digital signal acquisition and processing systems.

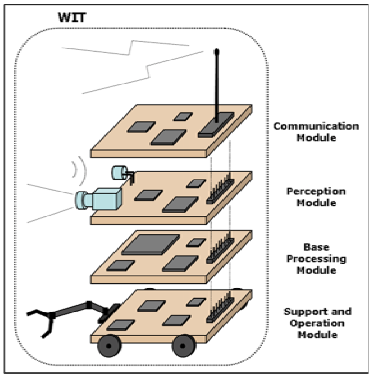

Figure 3
The WIT Model

All the modules of the WIT microsystem have all the input and output pins available for testing, all of the modules have connectors for the extension bus (high-speed SPI) that will also distribute the power from the power supply located in the proximity of the mainboard to all of the extension boards (with the exception of the actuator board that will have its own power supply for reasons of efficient energy consumption). The addition / elimination of a certain module from the microsystem will be done according to the "plug-and-play" principles, the current configuration of the WIT element being recognized and performed by the base module.

At least one WIT will have an extension board that permits him to be connected to a PC computer - BRAIN. This "special" WIT will be the access point of the CORE-TX environment. Although wireless radio communication is used in the CORE-TX system, there are other communication possibilities: acoustic communication (using a sonar module for multiple purposes: localization of the neighbors and communication) and visual communication (using infrared diodes). All the WITs can be programmed through the wireless interface using the IAP protocols (In-Application Programming).

2.3 BRAIN Model

The BRAIN (Background Robotic Activity Induction Node) is a supervisor software system that coordinates all activities that take place inside the CORE-TX environment. It is designed to assure the next main functions that are described in the next paragraphs. Some of the most important functions are the specification, analysis and development of particular behavior patterns [10, 11] for the whole collaborative system. Special software modules are designed in order to formalize the description and development of behavior patterns inside the CORE-TX environment. These software modules are based of a behavioral language interpreter. This interpreter is, in turn, based on a formal language used to describe the behavior patterns of the WITs and of the system in general.

The next main function of the BRAIN layer is the reconfiguration / autoconfiguration of the whole collaborative environment through “auto-discovery” and “plug-and-play” techniques. There is no configuration necessary for almost any change in the system. Each new WIT that enters the system is immediately recognized by the BRAIN system, necessary changes are made into the general system and the respective WIT is loaded with the new behavioral pattern. The technique used for this auto-discovery of the WITs is similar to the “port knocking” technique: a fixed communication endpoint is used to listen for incoming connections; this endpoint is known for all WITs. A new WIT tries to communicate through this endpoint with the BRAIN. When the communication is established, the WIT receives from the BRAIN system through the specified endpoint the specific endpoint that will be used in the communication between the two entities, and then the conversation closes. The WIT then tries to establish communication through the new endpoint.

Another function of the BRAIN system is the general coordination and the monitoring of the system’s behavior through induction / directives ("background induction") techniques and through querying the state of the elements. The BRAIN system is directly responsible with monitoring and supervising the entire CORE-TX system. All WITs report their activity directly to the BRAIN system.

Another important function of the BRAIN layer is interfacing with the system’s operator, extraction, aggregation and correlation of network data, displaying the state of the whole system and the tendencies of its behavior, etc. The BRAIN system is used as the only entry point into the CORE-TX system. Any commands that are released by a normal user of the CORE-TX system must go through the BRAIN which dispatches them through out the CORE-TX system.

The BRAIN system has a specialized module for the user interface. It is through this interface that a user can interact with the CORE-TX system. It has a graphical user interface that wraps the user intentions and commands to BRAIN directives.

2.4 Communication Model

The collaborative communications layer assures the physical support and the protocols necessary to exchange messages and data between the CORE-TX system elements. To implement and develop the physical medium and the communication protocols the characteristics imposed by the CORE-TX system model as regards to its elements mobility and autonomy are taken into account. As a result, the use of radio / wireless interfaces, interconnection concepts, identification and “multi-hop” routing and “ad-hoc networking” are designed as well as the development of simple communication protocols, that are modular and flexible and allow the exchange of messages in collaborative mode. The communication model of the CORE-TX system follows the principles described in the following paragraphs.

Wireless communication is used in the form of radio communication, Zigbee / IEEE 802.15.4 standard, X-bee PRO modules. There is no necessity of the direct contact between any nodes; multi-hop communication is used, routes are established dynamically. The established routes are stored for further used. Because the WITs may be mobile, may enter or leave the CORE-TX system randomly, the routes are updated regularly, and have a limited lifetime. Any communication protocols can be used just by updating the firmware of the WIT communication boards and by installing the required plug-in for the BRAIN system. Real-time communication protocols are preferred, as the CORE-TX system and the WITs in particular are interacting directly with the environment, thus requiring in most cases timely behavior of the entire system.

For a CORE-TX system deployed in a large environment it is possible that not all WITs can communicate with each other. Where there are no connections, it is possible to use an individual WIT as a simple relay system. In this fashion, the BRAIN’s access point can be connected to the whole remaining WITs through only 1 supplemental WIT, probably the closest one (the one for which the RSSI-Radio Signal Strength Indicator) is at a maximum. The messages are then disseminated in the node network until they reach their destination.

2.5 CORE-TX Environment Simulator

A simulator for the CORE-TX environment has been designed. It can be integrated into the BRAIN module. It can simulate any number of WITs with any configuration as the WITs and extension boards are loaded as plug-ins into the simulator application.

By integrating the simulator into the BRAIN module, the behaviour patters that are interpreted by the BRAIN can be loaded into the simulation. Also, the simulator can interact with real world WITs in order to extend the capacity of the simulation: the BRAIN module can interact with a number of real WITs and a number of virtual WITs at the same time (at BRAIN's abstraction layer all WITs are considered real, the simulator manages the behavior of the virtual ones).

3 Comparison Between CORE-TX and State-of-the-Art Collaborative Environments

3.1 K-TEAM K-Robots

The K-Robots developed by the K-TEAM Corporation [12] were initially designed to be used in multidisciplinary research centers in the field of emergent behavior, collective robotics, artificial intelligence. These robots are well equipped for use in a variety of research applications like collective robotics, bioinspired robotics and evolutionary robotics.

The Khepera robot is the smallest of their robots. It has a compact size. It is built around the Motorola 68331, 2 DC brushed servo motors with incremental encoders, proximity infrared sensors and it has a proprietary extension bus, the K-Extension Bus.

The Koala II robot is larger, more powerful, and a better platform for implementing custom electronics on the robot, on-board video processing applications, and for rough terrain. It has a Motorola 68331 microcontroller, 2 DC brushed servo motors with integrated incremental encoders, proximity sensors, ambient light sensors, sonar sensors.

The KoreBot board is a modular hardware controller which allows the creation of custom robots. It is based around the Intel XSCALE PXA-255 400MHz microprocessor, it has RAM memory, compact flash and USB connectors.

All the robots and the board that were presented above come with a variety of software bundles: GNU C Cross-Compiler, KTProject compiler front-end, and for remote operation the use of LabVIEW and/or MATLAB is recommended. There is also a simulator called Webots that has been created by the same K-TEAM that has the possibility of displaying the simulation of the various K-TEAM robots in a 3D graphical environment.

Discussion

Compared to the CORE-TX system, the K-TEAM robots present the following disadvantages.

The K-robots don't have a central supervisor entity; each and every robot has to be programmed individually. In the CORE-TX system, the WITs can be programmed through the wireless connection; their presence near the user or the programmer is not necessary.

The CORE-TX system is an integrated system: all of its modules are integrated into the same environment. The CORE-TX system contains all necessary modules for the system to work properly; no third party applications are needed.

The BRAIN system supervises all the other modules; all interaction goes through the BRAIN system. There is a single point-of-entry into the CORE-TX system; this increases the security of the CORE-TX system. The K-robots act independently, at most can inter-communicate, but do not have a central supervising entity by default.

The CORE-TX system implements a formal language that is used to describe the behavior of the system. This language is simple, easy to use, it is not necessary for a user to know notions of computer programming in order to write programs / behavior patterns for the system. The K-robots can be programmed by using the C language as K-TEAM developed a C compiler; this restricts the programming / configuration of these robots to programmers.

Some of the K-robots use a proprietary extension bus that restricts the expansion boards that can be added. The CORE-TX system uses the SPI interface.

The K-TEAM robots present the following advantages when compared to the CORE-TX system: the K-robots can be programmed using the C language, which is a known, stable, powerful programming language. Numerous software libraries managing PWM, FIFO devices etc have been released by the K-TEAM.

3.2 ANTH - ANtennary THings

In principle ANTH is a real-space programming framework for ubiquitous computer environments [8]. At the base of the ANTH framework, there is an ANTH chip that provides the user with 3 main functionalities:

- Interfacing function that controls the interconnection with another device;
- Communication function that builds a network infrastructure for device cooperation;
- Computation function that processes the applications;

Discussion

Compared to the CORE-TX system, the ANTH devices have more efficient energy consumption algorithms as most of them are based on a battery-less technology. Also most of the ANTH devices require some kind of precise localization [13, 14, 15]: GPS when the devices are used outdoor, and ultrasonic localization when the devices are used indoor. For indoor localization, the ANTH framework use various techniques like: Cricket [15] or DOLPHIN [13] which are based on the Time-of-Arrival techniques.

The main function that makes the ANTH framework different from the CORE-TX system is that within a CORE-TX environment different behaviors can be induced into the scattered WITs; the ANTH framework is very inflexible in this regards, the concept of behavior is completely not implemented. The ANTH framework connects various devices in a ubiquitous computing environment like: a lamp, a remote button, a ambient light wireless sensor that work together (the user presses the button and the lamp is turned on and off, the lamp is turned on automatically if it gets darker in the room thanks to the wireless sensor). The example prezented above shows that the ANTH framework is composed of heterogeneous items that can work together but may not have a clear functionality when left to work individually (a lamp without a button, a sensor without a controller etc).

Conclusions

This paper has prezented the general architecture of the CORE-TX system. This system is its complete form is destined to be used in research environments. CORE-TX environments that have been adapted for special functionalities can be sold commercially.

The CORE-TX system introduces the idea of a homogeneous environment where are devices are considered to be identical at an abstract level, although they can be very different at the physical level. These devices, the WITs, interact under the supervision of a specialized module (the BRAIN system), but can also act independently, conforming to their firmware.

One of the most important principles used in the design of the CORE-TX system is the possiblity to induce, change, monitor, supervise behavior patterns.

Emergent behavior patterns are taken from the natural, real world through the direct study of swarm entities (the insects, especially social insects form groups with a large number of members which allow the display of complex emergent behavior). The emergent behavior patters which are retrieved from the natural world are then applied in the field of distributed systems and solve a series of inherent problems of those systems, especially for the intelligent sensors, sensor networks and collaborative robotic environments.

The collaborative robotic environments are a new approach to the coordination of multirobot systems which usually consist of numerous, relatively simple, small sized robots and the CORE-TX system is such an environment, conceived as a complex platform composed by a heterogeneous set of autonomous microsystems with embedded intelligence, a collaborative communication environment and a central entity with supervising functions.

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