Robotic-Control Blocks (RCB) for Research and Education

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Abstract This paper proposes a new hardware platform, called Robotic-Control Blocks (RCB), for robotic research and education. RCBs are being developed to address the requirements specific to Psychodynamic Architecture developed in the framework of the ATR Artificial Brain Project. The presented CPLD-based implementation is an interim solution. RCB-set contains blocks that can be interconnected to create a control system of custom complexity. Some of them are designed to cooperate with certain sensors and/or actuators. At its proof-of-concept state, RCB process three kinds of tensions: "boredom", physical contact with an external object, and being stuck in an endless loop. The basic functionality can be easily scaled using more kinds of blocks (only simulated to date) and additional copies of universal behavior-mixing blocks. Implemented as dedicated chips and enclosed in aesthetic cases, RCBs right now might be used in classroom as an inexpensive aid free of tedious programming.

Keywords- Discrete Control Systems, Modular Robotic Hardware, Mobile Robots, Robotic Education Aids

1 Introduction

Physical blocks covering elementary control functions give children the opportunity to learn principles of robotics without tedious programming. Maybe the most devoted promoter of this approach is Henrik H. Lund of the University of Southern Denmark who, inspired by works of developmental psychologists, elaborated Intelligent Building Blocks (I-Blocks) enclosed in popular LEGO DUPLO® elements. Particular I-Blocks represent several useful sensor/motor functions. Standard I-Blocks for processing and communication are equipped with a PIC16F876 micro-controller. Special I-blocks contain internal sensors, micro-motors, etc. [1]. The solution we propose, called Robotic-Control Blocks (RCB), being developed at the Advanced Telecommunications Research Institute International (ATR), Kyoto, Japan in the framework of the Artificial Brain Project, shares with I-Blocks the program-by-building paradigm, however, some assumptions differ substantially. Our project (albeit still in its infancy) is striving to attain the research frontiers in human-machine communication in quest for emergent communication [2]. While I-Blocks are to serve, first of all, as amusing education aid, the primary issue in RCB is practically unlimited scalability that is indispensable in building intelligent robots, however, small RCB sets also can be used in classrooms. As for other differences, unlike I-Blocks (that contain advanced pre-programmed micro-controllers), each RCB has only as many gates as it is really necessary to accomplish its task. Unlike the I-Block approach (aimed to provide components of both "brains" and movable "bodies"), RCB approach deals only with "brains" to be connected to given commercially available "bodies".

This paper first briefly explains the underlying concepts and theories motivating the development of the Robotic-Control Blocks (RCB). A new hardware test bench for RCBs is also presented and examples of RCB-based control systems are given. This is followed by a detailed explanation of the prototype sets of RCBs that have been developed and tested. Finally, the future research of RCBs is discussed and concluding remarks are also included.

2 Robotic-Control Blocks (RCB)

The idea of RCB emerged in face of various drawbacks, such as expandability, speed, and financial considerations, that arose in 2002 during development of first psychodynamic mobile robot, called Neko-1. The robot used a Parallax Basic Stamp II microprocessor to collect the data from three infrared proximity sensors and an ultrasound sensor and then sent out serial packets containing the data via a radio frequency transmitter. This data was processed by a C++ program running on a PC client which then sent out serial packets back to the robot with speed inputs to the two motors. Although the robot functioned correctly and depicted behaviors of boredom, excitement, and fright, all of the processing was still software based and accomplished using a PC [4]. This robot was not self-contained and mainly re-emphasized the correct functionally of the software simulation since rather than sending the processed data to a graphic user interface, it was now being sent to an actual robot.

RCB set includes various Function Control Blocks (FCB), identical Behavior Mixing Units (BMU), Drivers, Voltage-to-Signal Converters (VTSC) and Signal-to-Voltage Converters (STVC). In the current version of RCB hardware each FCB covers both accumulation of a given tension and a related behavior. BMUs can form a column defining priority when two or more FCBs produce pulse trains. Drivers decode behavior-defining pulse trains and produce pulse trains defining actions of particular motors.

VTSCs convert analog voltage values of taken from attached sensors into standard pulse trains. STCVs convert pulse trains into appropriate analog voltage values controlling attached motors. A system overview of the blocks is shown in Fig. 1. The RCB-based system can be expanded from the bottom-up by adding more various FCBs and from-centre-to-sides by adding more different sensors and actuators. In future versions the functions will be separated, making the set much more flexible. Although the presented BMU-based "working memory" covers only a kind of behavior subsumption, the simulated version includes a block in which tension compete for access to related behavior blocks [3].

The input for each sensor is encoded using a VTSC, processed, and later decoded using a STVC before being connected to the actuator. In order to allow for analog values, all the input signals are quantized and framed as a value between 0 and 255. The VTSC samples the input of the analog sensor and sends out the corresponding amount of pulses during a predetermined time frame. This is similar to duty cycles using pulse width modulation, however, in RCBs the pulses do not have to be sent consecutively and can be sent anytime during the predetermined time frame. The exact location of the sampling frame does not matter, therefore, the individual FCBs do not have to be synchronized.

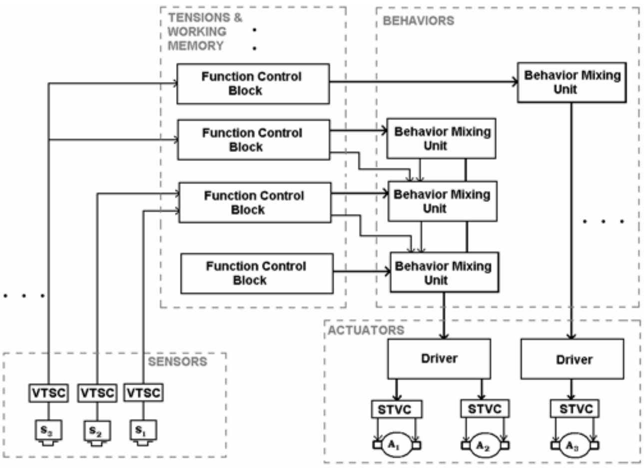

Figure 1. Robotic-Control Blocks Overview

The predetermined time frame was selected to be one millisecond, which corresponds to the approximate pulse of a biological neuron [5]. There is not single 'correct' predetermined time frame since the biological neuron conducting velocity is affected by many factors such as myelin, age of the neuron, etc. Furthermore, an exact time frame is not necessary for simulating PDA concepts in its simplest form. Assuming a one millisecond time frame, the minimum clock frequency required is 256 kHz in order to correctly quantize analog values as discrete neuron pulses.

Complex programmable logic devices (CPLDs) were used to implement each function block. The devices were chosen because they are well suited for combinatorial-intensive logic designs and the devices can be reprogrammed easily using hardware description languages. CPLDs provide a sound economic alternative for developing a prototype in a short period of time. Other options were field programmable gate arrays, which are suited for register-intensive logic designs, and individual digital circuits, which are very time consuming to design and can not be easily altered.

3 Development and testing

The development and testing of RCBs was divided into three distinct tasks in order to prove the functional concept. First, a simple unintelligent robot was created that goes straight ahead at all times. This is the most basic arrangement of RCBs and comprises of only a few blocks and two motors. All other current block sets expand the capabilities of this fundamental robot kit. Next, an obstacle avoidance expansion set was developed. It utilized two touch sensors to detect objects that impede the robots forward motion. A simple emergent phenomenon occurs when using the obstacle avoidance expansion set, which led to the design of the third expansion set, a meta-sensing expansion module [6]. The development of these three RCB sets will be discussed in this section.

A. Prototype Robotic-Control Block

In the future, each RCB will be implemented on a single dedicated IC. However, the current prototypes were designed on 2"x3" through-hole prototype boards. All the blocks, excluding the Power Block and the Clock Block, have ground, V_{DD}, and clock input signals. Furthermore, all blocks also output those same three input signals which allows for easy interconnecting, or daisy-chaining, of the RCBs. Each block also has necessary input and output signals, depending on the function of the block. The Power and the Clock Block are special blocks since they help generate the ground, V_{DD}, and clock signals. A functional diagram of a single regular RCB is shown in Fig. 2.

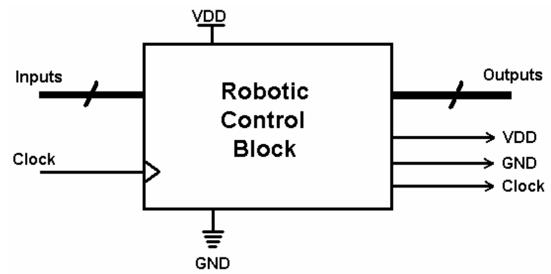

Figure 2. Prototype Robotic-Control Block

B. Basic Robotic-Control Blocks Set

In order to be compatible with the existing pulsed para-neural networks concepts, the fundamental set of RCBs is very primitive since it is supposed to represent instinctive functions. The basic set only includes the blocks necessary to power-up the robot and for the robot to move in a forward direction. It has actuators, two Lego® motors, but no sensors. Table 1 describes the blocks included in the basic RCBs set, while Fig. 3 shows the functional diagram of the robot that can be constructed using the supplied blocks.

TABLE I. BASIC ROBOTIC-CONTROL BLOCKS SET

Block Name	Qty.	Description
Power[1]	1	Outputs a V_{DD} and ground signal
Clock[1]	1	Outputs a clock signal
Forward	1	A Function Control Block that produces pulses so the robot moves forward
Behavior Mixing Unit	1	Selects which behaviors is sent to the Motor Driver
Motor Driver	1	Decodes the behavior and processes the signal for each motor
Signal-to-Voltage Converter	2	Produces a voltage corresponding to the frequency of the pulse train

1. Power and Clock Blocks are not shown in Fig. 3 since their signals are inputted to all blocks

C. *Obstacle Avoidance Robotic-Control Blocks Set*

The first expansion set of RCBs allows the robot to maneuver around objects that impede its constant forward movement governed by the Forward Block. This expansion set has the blocks necessary to receive the touch sensor inputs and encode them using pulse trains. These pulse trains are then processed by a FCB, the Obstacle Avoidance Unit (OAU). A BMU is also included to allow for further expansion of the system. Table 2 describes the blocks included in the Obstacle Avoidance RCBs set, while Fig. 4 shows the functional diagram of the robot that can be constructed using the supplied blocks.

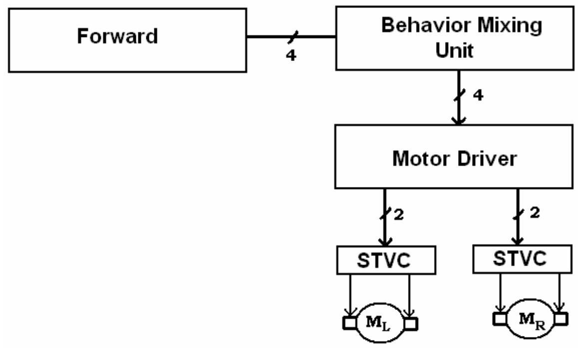

Figure 3. Basic Robotic-Control Blocks Set Schematic

TABLE II. OBSTACLE AVOIDANCE ROBOTIC-CONTROL BLOCKS SET

Block Name	Qty.	Description
Voltage-to-Signal Converter	2	Produces a pulse train corresponding to the analog voltage detected at its inputs
Obstacle Avoidance Unit	1	A Function Control Block that produces pulses so the robot avoid objects impeding forward movement
Behavior Mixing Unit	1	Selects which behaviour is sent to the Motor Driver

D. *Meta-Sensing Robotic-Control Blocks Set*

One of the problems with the OAU is that the robot would get stuck in endless loops. It would be functioning correctly and still be moving around, however, it would repeat the same action endlessly. This unfavorable phenomenon emerges from the robots basic rule set. It can be eliminated by meta-sensing, i.e. trying to detect the endless loop behavior. The meta-sensing expansion block set utilizes these concepts to avoid being stuck in an endless loop. Table 3 describes the blocks included in the meta-sensing RCBs set, while Fig. 5 shows the functional diagram of the robot that can be constructed. The role of the Meta-Sensing Unit (MSU) is to monitor the activity of the robot, specifically that of the OAU, to make sure it is not operating in an endless loop. Once the MSU detects an endless loop, it takes control of the robot and attempts to force it out of the loop by sending pulses on the correct signal lines.

E. *Test Robot*

All of the three developed block sets were not only tested for individual functionality but each set was put together and tested using a constructed robot with two Lego® touch sensors and two Lego® 9V motors. The RCBs Robot with all three sets interconnected is shown in Fig. 6. When the robot was powered up with only the basic set attached, it went straight forward as expected. Next, the Obstacle Avoidance Set was attached. The robot managed to rotate when it hit a wall or another obstacle, however, it sometimes got stuck in the corners of the room, which was the reason for implementing the Meta-Sensing Set. Once all the developed RCBs were correctly interconnected, the robot was able to wander around a room with various obstacles on the ground for extended periods of time without any difficulties. It would hit the obstacles, rotate, and continue to move forward.

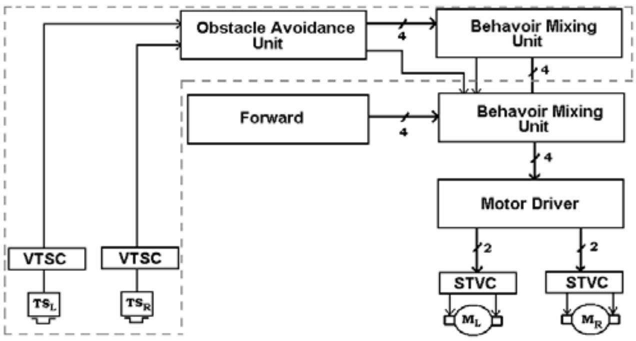

Figure 4. Obstacle Avoidance Robotic-Control Blocks Set Schematic

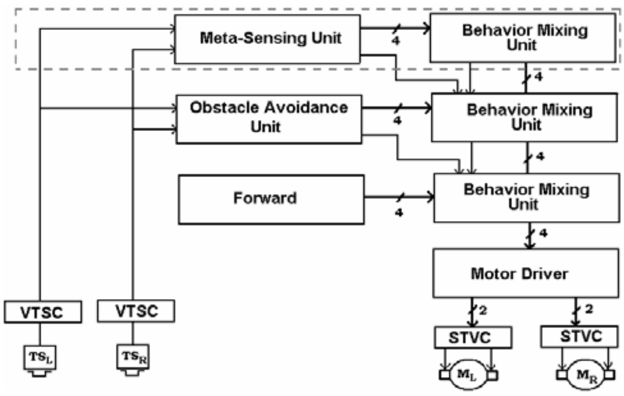

Figure 5. Meta-Sensing Robotic-Control Blocks Set Schematic

F. Future Blocks Sets

There are many different possible blocks sets that can be developed and added the current RCBs. Since the agent is a pleasure seeking creature, the robot needs to have methods to discharge tensions of boredom. One idea for a future block set is to make the robot be excited and chase green objects and be scared and run away from red objects. The escaping action will have a higher priority than the pursuit action. The existing obstacle avoidance and meta-sensing actions would obviously have a higher priority than either of the two new actions. If the robot did not see any green or red objects, it would continue to roam around pseudo-randomly in search of them.

There are many other possible blocks set that can be designed to enrich the repertoire of the robot. It can detect a hungry state, which is equivalent to a battery low sensory signal, and then search for a battery charger station before continuing to roam its environment. Another possible set can be found on simulating concentrated and distracted tensions based on the principles of Piaget's theory how 0-2 year old children perceive new objects of interest [3].

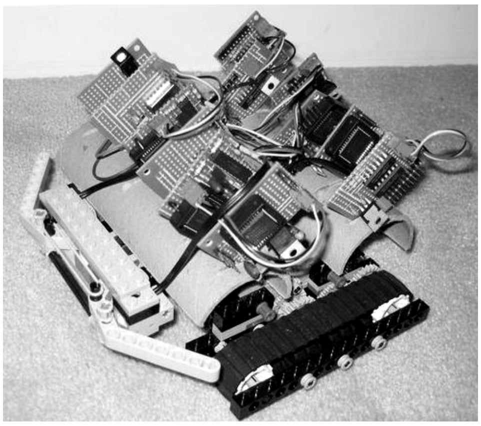

Figure 6. Robotic-Control Blocks Set prototype robot

RCBs can also have advanced behavior-based architectures with the possibility of many complex functions [8]. Different types of learning schema can be implemented such as genetic algorithms and fuzzy behavioral control. The agent can expand to accommodate dozens of different sensors and tensions which can be discharged through various behaviors by means of actuators. These advanced blocks may allow for functions that vary from voice generation and recognition to cognitive learning and evolution. Future advanced blocks will only have basic rules coded into them, so-called instincts, and will evolve over time to into complex functions.

4 Concluding remarks

After the completion of the first prototype set, some changes and future developments to the current block sets became evident and are possible. First of all, since the blocks were developed on through-hole prototype boards and wire connections were used, some of the connections are fragile. The power, ground, and clock headers are designed to be irreversible; however, proper irreversible headers should be added for the signal lines. Using a single voltage to power all devices would also simplify the design. This could be accomplished by using only a 5V or 3.3V power supply and then use charge pumps for higher voltages when necessary. Once the design for each and every block is finalized completely, the RCBs should be transferred to printed circuit boards or a CMOS IC which will make them more durable and aesthetically appealing.

The development and testing of Robotic-Control Blocks (RCB) has been quite successful thus far. Since the blocks adhere to psychodynamic architecture and substitute Pulsed Para-Neural Networks, they are a suitable hardware test bench for ATR Artificial Brain Project. The basic RCBs set worked as expected. By adding the Obstacle Avoidance Set and Meta-Sensing Set on the run, it was shown that a number of new tensions and behaviors can be added. The practically unlimited scalability is the most important virtue of RCB approach. Furthermore, the blocks are self-contained, operate in real-time, and do not require a PC. The development should be considered a step in the correct direction but more research and development in other fields is still necessary before achieving the ultimate goal of emergent thought. When a bigger block set is created and evolution is incorporated into the system, the covered functionalities will deserve to be moved into a future-generation evolvable hardware. Regardless, if implemented as dedicated chips and enclosed in aesthetic cases, RCBs right now may be used in classroom as an inexpensive aid free of tedious programming.

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