Introducing a New Minirobotics Platform for Research and Edutainment

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Summary. This work describes a novel minirobotics system which incorporates mature technology proven efficient over the years in multi-agent robotic soccer competitions and introduces new collaborative development concepts shifting essential research issues from the playing agents themselves to the development of a new versatile research and educational platform. This shows how team's efforts for winning a robotics competition can be transformed into a cooperative development driving force towards a shared standard system with applications much beyond the robotic games themselves. We describe in detail the technical aspects supporting this multi-agent robotic framework, integrating cutting-edge and low cost watch technology in the form of a miniature multi-robot system which mixes reality and simulation.

1 Introduction

This paper describes a porject intended for fostering education, research and development using robotics competitions as a driving force. The system is based on a miniature multi-robot system which mixes reality and simulation through an original Augmented Reality (AR) environment. The project has a two-folded focus: research and education. The main goals of the are:

- to gradually improve the platform so that it becomes a powerful and versatile standard for multi-agent research and education.
- to explore educational possibilities and real world applications based either on the system as a whole or on some parts of it (e.g. the robots alone).

Several other mini-robotics platforms were already introduced in the past, being Alice one of the most well known projects on this class of robots [1, 2]. Our focus was on standardization, versatility and affordability, taking advantage of well established industry technologies to allow the development of an inexpensive platform. In order to do that we used the know-how of the cutting-edge and low cost watch technology as a basis for building an affordable miniature multi-robot system mixing reality and simulation. This allows the employment of a large number of robots in a rather reduced space with a very low budget and amazing portability. Both the robots and the system are to be constantly upgraded and improved, being developed together with CITIZEN. Three dominant characteristics of the project are: (a) affordability, (b) standardization and (c) open architecture.

The rest of this paper is organized as follows: Section 2 gives more detailed technical information on the current implementation of the system, section 3 introduces the project's collaborative nature and discuss three different competitions using the system, and finally, section 4 discusses, from a wider perspective the advantages of this project and gives some final remarks from the authors.

2 Technical Aspects

Robots obey commands sent by a central server through an IR beam, while their actual position and orientation is fedback to the server by a camera located on the top. Meanwhile a number of visual features are projected onto the field by using a flat display. See figure 1-a. All the robots are centrally controlled from one CPU but their decision making algorithms run on separated networked clients, making the robots behave autonomously virtually isolated from each other. This system merges technical characteristics and concepts from two of the most mature RoboCup leagues, Simulation and Small-Size [3], and adds a new key-feature: augmented reality.

2.1 The position feedback

The position of the robots (and eventually other objects, such as ball) is detected from the processing of high-resolution camera images. The localization system can be divided into three main subsystems: (a) undistortion, (b) blob detection, and (c) identification & orientation. Each one is described below.

Undistortion:

Despite the fact of the robots being real three-dimensional objects occupying volume in space, the domain of possible locations for their bodies over the plane of the flat screen is known to be confined into a two-dimensional space. Because of that the calibration problem can be reduced, without loss of generality, to a plane-to-plane linear transformation from the plane of the captured image to the plane of field itself. This transformation is a single linear 3×3 matrix operator which defines a homography in the two-dimensional projective space.

Blob detection:

After undistorted, the image is segmented into blobs of certain colors of interest. These colors are defined by a mask in the three-dimensional $Y \times U \times V$ space. Adjacent pixels, in a 8-neighborhood, belonging to the same color mask configure a single blob. The area (total amount of pixels) and center of mass (average (x, y) coordinates) of the blobs are extracted. Blobs whose mass values are not within a tolerance range from the expected are discarded. This procedure is used for finding the center of the colored marking patterns on the top of each robot – the red shape seen on figure 1-b.

Identification and orientation:

The process here described is inspired on [4]. Once a potential blob is found, a radial pattern of colors is sampled within a pre-defined radius of its center. In figure 1-b these sampling locations are illustrated by a dotted circunference path. This pattern is cross correlated with a database of stored patterns, each of which uniquely defining a robot's identity. Let's denote $x(i)$ to be the color in the pattern x at the angle i. The cross-correlation r_{xy} is calculated accordingly to the equation 1 for each pattern y the database, and for each $\Delta\alpha$ in the interval $[0^o, 360^o)$. If, for a pattern x, the minimum value of $r_{xy}(\Delta\alpha)$, for any y and $\Delta\alpha \in [0^o, 360^o)$, exceeds a minimum threshold, then the corresponding y gives the identity of a robot, and $\Delta\alpha$ gives its orientation.

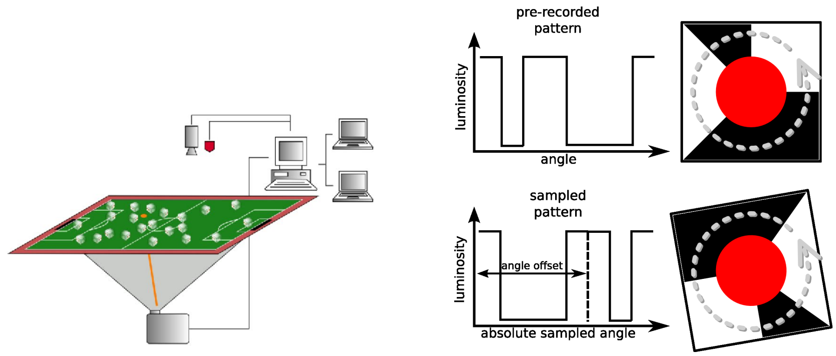
$$r_{xy}(\Delta\alpha) = \frac{\sum_{i=0^o}^{360^o} [(x(i) - \bar{x}) \cdot (y(i - \Delta\alpha) - \bar{y})]}{\sqrt{\sum_{i=0^o}^{360^o} (x(i) - \bar{x})^2} \cdot \sqrt{\sum_{i=0^o}^{360^o} (y(i - \Delta\alpha) - \bar{y})^2}} \quad (1)$$

2.2 Augmented reality

The idea about the augmented reality setup is an extension of a previously published similar concept where robot ants would leave visually coloured trails of "pheromones" by the use of a multimedia projector on the ceiling of a dark room in a swarm intelligence study [5]. Huge improvements in versatility, flexibility, and standardization can be introduced by applying that concept into a more customizable system. The figure 1-a shows an illustrative drawing of our system in action. Given the reduced size and weight of the robots, the application of a conventional flat display as the field becomes feasible – depending on the application, displays as small as 20-inches are more than enough. This adds much versatility to the system without adding much costs and without complicating the required setup.

2.3 The miniature robot

Until now, a few developments have been made on very small sized robots, being ALICE one of the most prominent names (see [1] for a survey). The



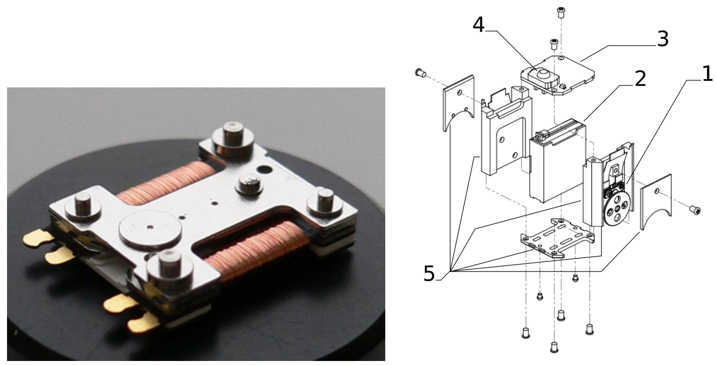
(a) (b)

Fig. 1: On the left an illustration of the overall system including the feedback control loop (infrared transmitter, camera, server) and the augmented reality screen. On the right an actual close-up picture of two robots playing using such setup. (See last paragraph of sub-section 2.1 for explanation about the green dots)

first versions of the miniature robot here used were originaly developed by CITIZEN as merchandize devices for demonstrating their new solar powered watch technologies [6]. Since March of 2006 three new prototype versions were already developed for matching the requirements of this project. The most current version of the robot has dimensions of $18 \times 18 \times 22mm$, no sensors, an infrared receiver and is driven by two differential wheels. This first robot was purposely designed to have rather simplistic hardware configuration as a starting point, a seed, to be followed by numerous upgrades in the long term. The main robot components are (numbers in accordance to figure 2-b):

1. Motor – Customized from wristwatch motor unit. See further details in the dedicated sub-section 2.4.
2. Battery – Miniature one-cell rechargeable $3.7V$ lithium ion polymer battery with capacity of $65mAh$.
3. Control board – Currently based on the Microchip $8bit$ PIC18 family of microcontrollers, each robot comes equipped with a PIC18LF1220 which features 4kb of re-programmable flash memory.
4. IR sensor – An IR sensor is used in order to listen for commands from the PC. The sensor operates at the $40kHz$ bandwidth modulation (same of most home-appliance remote controls).
5. Body – The resistant durable body of the robot is micro-machined in aluminum using CITIZEN's high precision CNC machines.

The robot parts are made in aluminum using precision CNC machines. The precise and detailed design allow the tight and compact assembly of all parts into a very solid unit. The robots are assembled by hand and all main components are put together using screws for easy replacement.



(a) (b)

Fig. 2: On the left a close-up picture of the step motor, on the right an exploded view of revealing the robot parts.

2.4 The micro step motor

The miniature robots use two motors to drive its differential wheels. Simply of-the-shelf wristwatch motors would not be able to bear with the torque requirements for moving the heavy body of the robot. For couping with that CITIZEN developed a new special class of step motors combining high-speed rotation and nano-scaled geared reduction. The result is highly reliable motor with very low power consumption fitting into the same thin packaging.

Feature	**Value**
Dimensions (mm)	$7.0 \times 8.5 \times 1.9$
Configuration	2 coils $\times$ 1 rotor
Gear ratio	1 : 240
Torque ($gf \cdot cm$ at $2.8V$)	between 2.0 and 4.0
Power consumption at $200rps$ (mA)	between 4 and 12
Nominal rotation (rpm)	12.000
Direction	both standard and reverse

Table 1: Technical specifications of the step motors used in the miniature robots

2.5 Robot's firmware and control protocol

The current control protocol was programmed in C and compiled using the proprietary MPLAB C18 compiler. Eventually the code might become supported by the GNU C compiler if the robot's microcontroller changes in the next comming years.

All robots share the same firmware but dynamic IDs are be assigned so that commands to an individual robot can be discriminated. The current command protocol has a length of $12bits$: ID ($5bits$), left command ($3bits$), right command ($3bits$), and bit parity check ($1bit$). Less frequently used instructions are multiplexed from a sequence of two or more commands.

3 Competitions with cooperation

In the strict technical sense, the system introduced here add very little if compared to other existing robotic platforms. Novelty was not the main focus of the project. We rather concentrated our efforts in the design of the system in order to make a very simple to use, entertainning and educational software platform. For that purpose, along with the system itself we also introduce a very new aspect for the robotic competitions, bringing the joint development of the system to the foreground instead of just developing playing agents that exploit that system.

The multi-agent interface should be simple to use and adequate for educational purposes. Team agent code is expected to be developed by seasonal students in an educational way while permanent members of participating teams (professor, staff and graduates) pursue longer term projects that contribute for the sub-league itself and for its platform versatility in a variety of fields.

Keeping these ideas in mind we prepared, three competitions, two of which are based on developments achieved by the teams and only one is based on the traditional game tournament format. The three competitions are briefly described below:

- Electronics & Firmware Competition: Development of new or improvement of existing electronic control board for the robot (e.g. new sensors, more powerful CPU) and/or more sophisticated firmware;
- Educational Games Competition: Design of creative and didactic games using the PV sub-league's system;
- Undergrad Team Development Competition: Making of teams for playing in a tournament of a given game, mainly focused on undergraduate students.

These three competitions form a kind of self-sustainable "ecological" cycle. These competitions are indroduced in the next sub-sections. like shown in the figure 3. Arcs 1 and 2 represent respectively the new needs that inspire hardware development and the new possibilities these developments tend to provide (in future years, if they are incorporated into the the standard system). Arcs 3 and 4 work in a similar way, but within the official hardware of the system to which all teams shall have access. Arc 3 represents a selection of interesting ideas from educational games presented in previous years that are put in practice in a big tournament among undergraduates from various teams,

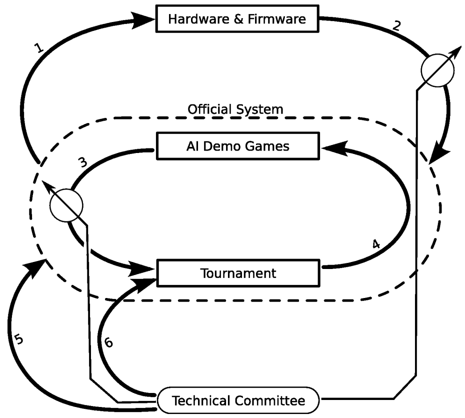


Fig. 3: Typical self-sustained development cycle expected

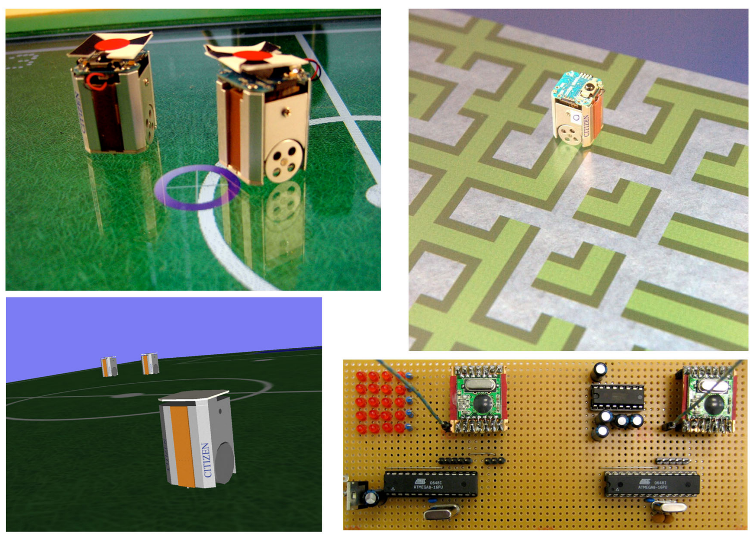


Fig. 4: Examples of developments implemented during RoboCup 2007, clockwise, from top-left: The virtual ball soccer, a virtual dynamically changing maze game, a radio communication module for the robots and a simulation environment.

bringing again new ideas for even more interesting games in arc 4. Arc 5 and 6 represent the volunteer contribution of the technical committee for ”cluing” all pieces together and making the system work. The idea is to maximize the flow in arcs 1, 2, 3, and 4 while minimizing the contributions through arcs 5 and 6, in the form of a self-sustained evolution cycle for the sub-league.

The figure 4 shows a few of the many developments implemented by the teams for the competitions during RoboCup 2007.

4 Discussion

This paper introduced the main technical and conceptual characteristics of a new miniature robotic platform. In particular, it was emphasized in the beginning of section 3 the advantages of shifting of focus from the playing agents to the shared system. Furthermore, the three competitions showed in a more clear way how this collaboration shall be fostered toward the constant development of a versatile system for education and research.

The collaborative development of the development competitions introduces an explicit cumulative nature to the team's contributions, thus making the teams themselves the force directly responsible for the progress of the standard system. Advantages such as portability, versatility, easy of use (to cite a few) allied to a constantly increasing pool of didactic applications shall make this platform very suitable for multi-agent applications and for experimenting concepts and theories in an intermediate step toward the more complex problems, not requiring expensive hardware re-design. Moreover didactic material is likely to be of use across various different fields ranging from AI to robot navigation, ranging from graduate research subjects to high school introductory classes. And finally, the degree of miniaturization of the robots allied to the innovative AR arena bring a whole new dimension for applying concepts of autonomous multi-agent systems.

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