Introducing Physical Visualization Sub-League

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Abstract. This work introduces the new sub-league of the RoboCup Soccer Simulation League, called Physical Visualization. We show how the fundamental collaborative concepts of this new sub-league shift essential research issues from the playing agents themselves to the development of a new versatile research and educational platform. Additionally, we discuss benefits of this new platform in terms of standardization, flexibility and reasonable price. We also try to characterize and discuss the place of this new sub-league within the RoboCup community. Finally, competition formats and roadmaps are presented and discussed.

1 Introduction

Physical Visualization (PV for short) is candidate to be a new RoboCup Soccer Simulation sub-league. The sub-league is intended for fostering education, research and development together with the RoboCup community. The PV is based on a miniature multi-robot system which mixes reality and simulation through an Augmented Reality (AR) environment. The project has a two-folded focus: research and education. The main goals of the PV 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).

We focused on 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. 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 sub-league's collaborative nature and discuss three different competitions using the system, and finally, section 4 discusses, from a wider perspective the place of this sub-league within RoboCup 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. This system merges characteristics and concepts from two of the most mature RoboCup leagues, Simulation and Small-Size [4], and adds a new key-feature: augmented reality.

All the robots are centrally controlled from one CPU but their decision making algorithms run on networked clients, making the robots behave autonomously virtually isolated from each other just like in simulation league. Position feedback is based on colored markers placed on top of the robots which are detected through a vision system in the same way used in small-size league. Robot control is based on strings of commands sent by modulated infrared signals (in this sense resembling U-league to some extent [1]).

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 computer vision system currently implemented can be divided into three main subsystems: (a) undistortion, (b) blob detection, and (c) identification & orientation. Each one is described in the following paragraphs.

Undistortion: Despite the fact of the PV 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 (see figure 1).

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 2-b.

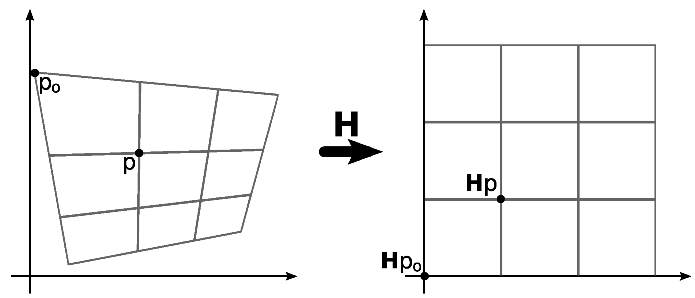


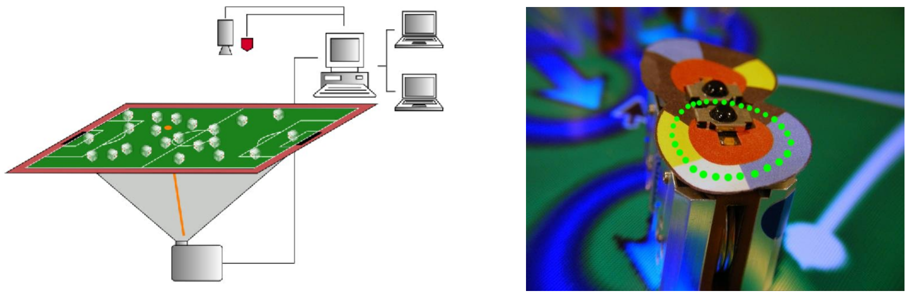
Fig. 1: Plane-to-plane projective undistortion based on homography transformation, where $\mathbf{H}$ is a 3×3 matrix operator and p and p_o are 3-dimensional vectors representing points in the two-dimensional projective space

Identification and orientation: The process here described is inspired on [5]. Once a potential blob is found, a radial pattern of colors is sampled within a pre-defined radius of its center. In figure 2-b these sampling locations are artificially illustrated by a closed path of little green dots. 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.

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

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 [6]. Huge improvements in versatility, flexibility, and standardization can be introduced by applying that concept into a more customizable system. The figure 2-a shows an illustrative drawing and figure 2-b shows an actual picture of our system in action. Given the reduced size and weight of the PV sub-league 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.



(a) (b)

Fig. 2: 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.

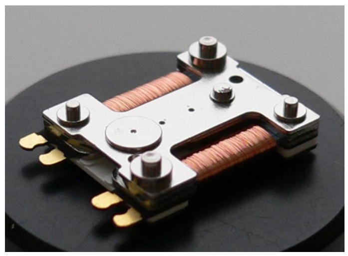
2.3 The miniature robot

Until now, a few developments have been made on very small sized robots, being ALICE one of the most prominent names (see [2] for a survey). The first versions of the miniature robot here used were originaly developed by CITIZEN as merchandize devices for demonstrating their new solar powered watch technologies [7]. Since March of 2006 three new prototype versions were already developed for matching the requirements of the sub-league. 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 3-b):

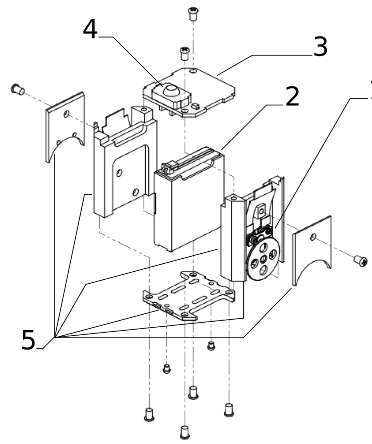
1. Motor – Customized from wristwatch motor unit. See further details in the dedicated sub-section 2.4.
2. Battery – Miniature one-cell rechargeable $3.7V$ lithium ion polymer battery with capacity of $65mAh$.
3. Control board – Currently based on the Microchip $8bit$ PIC18 family of microcontrollers, 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.

2.4 The micro step motor

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



(a)



(b)

Fig. 3: On the left a close-up picture of the step motor, on the right an exploded view of revealing the robot parts.

CITIZEN developed a new special class of step motors combining high-speed rotation and nano-scaled geared reduction.

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. All robots share the same firmware but dynamic IDs are be assigned so that commands to an individual robot can be discriminated. Each of the two wheels can be controlled to run at two different speeds, in both directions or stopped (total of 5 possible values). Commands have to be sent by the server to one robot at a time, in an ordered fashion. This implies that bigger number of robots result in longer control lags. Therefore the protocol format was designed so that the command could be sent in a very short time.

The current command protocol has a length of 12*bits*: ID (5*bits*), left command (3*bits*), right command (3*bits*), and bit parity check (1*bit*). Less frequently used instructions are multiplexed from a sequence of two or more commands.

3 Competitions with cooperation

The original and dominant point of the proposed sub-league is its concept of collaboration towards the development of a central platform for the benefit of all. While in other leagues essential research issues are traditionally faced in the playing agents themselves (AI, biped walking, vision, etc.), in the PV the research issues are in the improvement of the system – in the development of the platform and its robots.

3.1 Electronics & Firmware Competition

Goal: Allow the evolution of the robot's technology and improve all non-software related aspects of the system.

Summary: Teams have the opportunity to contribute with new ideas for the electronic aspects of the system as well as robot's firmware. Those with background in fields more closely related to the hardware would be able to include in their projects the improvement of certain aspects of the system either for didactic purposes (e.g. class on microcontrollers) or for research. Meanwhile, teams with background in fields more related to computer science would be able to acquire valuable experience by accompanying or even contributing to these projects.

New electronic entries developments could be made on any of the current components of the system, including the robot, or by introducing a new electronic element to the system. All source code, CAD drawings, circuit schematics and documentation should be made available to other teams so that they can use and improve at their own.

In the control circuit of the robot several restrictions will be imposed regarding position of mounting holes, size and shape of the board, max bounding volume, limit weight and place of certain components would be applied in order to ensure compatibility with current micro-mechatronic architecture. For instance, connections to the motors would have pre-defined place and electrical characteristics that should remain unchanged. Within those constraints completely new architectures can be proposed.

Entries would be ranked according to a qualified review process preceding RoboCup and based on slide presentations realized during the event. The contributions from the winner of this competition would not necessarily become the new standard for the following years. Nevertheless, contributions published from winner and non-winner teams might be considered for incorporation depending of various criteria to be evaluated (e.g. practicability, price).

3.2 Educational AI Games Competition

Goal: Create a pool of interesting didactic software applications in the form of games using the system for educational purposes.

Summary: Entrants would come up with different game ideas using the system in which they teach concepts related to common subjects ranging from basic computer programming to very specialized topics related to multi-agent systems and artificial intelligence.

The entries would consist of the proposed games along with their source code, supporting tools or API (if any), documentation and accompanying teaching materials. In order to ensure that other teams could easily profit from these contributions the entries would need to be necessarily based on the current official system only. While the eventual introduction of accessories such as balls maze walls or colored objects would, in general, be permitted, no external specialized electronic devices would be allowed. Live demonstrations and poster presentations would be performed during the RoboCup event, and together with prior qualified reviewing would rank the entrant.

Again, just like in the competition described in sub-section 3.1, winner applications would not necessarily be incorporated as league games for the following years. On the other hand, contributions could be considered for incorporation regardless of the competition results, depending on their quality, topics covered and other criteria.

3.3 Rapid (Soccer) Team Development Competition

Goal: Allow undergraduate students to develop complete RoboCup teams of their own within the typically limited time window of their courses.

Summary: The teams would be based on a simplified didactic game framework allowing easy development requiring only a very limited amount of knowledge. All contestants would have an equally limited amount of time for the development of their teams, thus giving similar advantages to teams with limited time to spare. Game rules and supporting software would be officially released just a predefined amount of months before the RoboCup games.

This comes to fill the gap between RoboCup Junior and the other RoboCup Senior leagues. Refer to [1, 3] for a previous attempt to include more undergraduate students, where a new league directed exclusively towards them was proposed (the U-league).

In the Rapid Soccer Competition institutions and laboratories equipped with the PV system would be able to let their alumni experiment their ideas into a RoboCup environment regardless of their time constraints (i.e. having more time to spare would post no advantage). Ideas previously introduced in the Educational AI Games competition could be entirely or partially incorporated into the system. Competitions would take the form of a tournament which would spam over the duration of the RoboCup event. At the end tutors would be invited to share the experiences they had when using the system within their courses and discuss improvements for the subsequent years.

4 Discussion

This paper introduced the main technical and conceptual characteristics of the PV sub-league. In particular, it was emphasized in the beginning of section 3, that the central innovative aspect of the proposed idea was the shift of focus from the playing agents to the shared system. Furthermore, the three proposed 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.

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