

A Mixed Reality Approach to Undergraduate Robotics Education

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Abstract

Teaching robotics to undergraduate students requires a course framework that allows students to learn about robotics in stages, without being overwhelmed with details. Such a framework must also provide the students with a motivating application environment that challenges them to apply what they have learned. Robotics competitions have proven to be an excellent method for motivating students, so the framework should be portable and robust enough to be used for competitions, and flexible enough to provide a range of environments that can become more challenging as students become more adept. Finally, the framework should provide repeatability and control for evaluating the student's work, as well as for performing research. In this paper, we overview a mixed reality approach that meets these criteria, and describe its use in an advanced undergraduate course.

Introduction

While robotic soccer and similar challenge problems provide an exciting and motivating environment for presenting robotics concepts to undergraduates, great care must be taken in order that students are not overwhelmed with details. The introduction of vision alone, for example, can easily provide more material than students can comfortably adapt to during a single-semester course, and attempting to teach control, path-planning, and multi-robot systems concepts effectively while dealing with vision is a significant challenge. In (Anderson *et al.* 2003), we presented a framework for using robotic soccer with global vision as a basis for introducing undergraduates to robotics that formed the basis for the RoboCup E-League. While this approach has been used in and outside of RoboCup by ourselves and others (e.g. (Imberman, Barkan, & Sklar 2007)), in recent years we have been extending the approach to incorporate a mixed reality component. This has proved both highly motivating for students and a useful research platform in our own work. This paper describes the use of this mixed reality approach and the advantages we have found in employing it.

System Overview

A high-level overview of this approach is shown in Fig. 1. The obvious difference from other basic approaches to an

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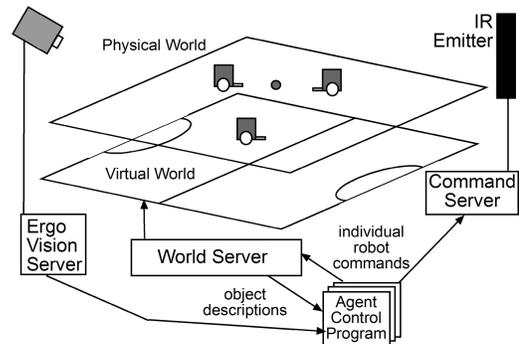


Figure 1: A mixed reality platform using global vision.

application such as robotic soccer is that there is both a physical and virtual layer to the environment a robot inhabits. Both layers provide elements of a robot's perception via vision, and the robot's actions can affect elements on either layer. Physically, this is implemented using a horizontally-mounted LCD monitor or television, the size of which is dictated by the size of the robots being used and the environment being implemented. An example of this using 2" remote-controlled IR tanks on a 40" panel is shown in Fig. 2.

The system is centered around a sophisticated global vision server, *Ergo* (Anderson & Baltes 2007). *Ergo* has a number of features that make it ideal for a student environment: because visual frames are interpolated to an overhead image, the camera can be set at any convenient angle, and because the system relies on background differentiation as the major means of recognizing objects, it operates under varying lighting conditions and requires little recalibration. The system also requires no predefined colors, further enhancing robustness under lighting variation compared to other vision systems, and requiring little set-up time.

As robots move across the environment, the vision server picks up both physical and virtual elements in the camera's field of view. Those elements that *Ergo* has been informed are of interest (in a soccer application, the robots themselves and the ball) are tracked, and the control programs for the robots are informed of the locations of these objects via ethernet. At the same time, a world server describes the state of the virtual world to the agent control programs, allow-

ing objects to be tracked outside of physical vision (e.g. the location of the soccer goals, game power-ups, or other elements that exist only virtually), and collectively the programs controlling the robots on the field have a unified set of perceptions to form a response. Like the structure of the E-league, the set of commands the control programs generate are batched and sent to a command server to be broadcast via an IR module to the robots (Anderson *et al.* 2003). To affect the virtual world, these same commands are also communicated to the World Server so that the effects of the robot on the virtual world can be calculated and displayed.

Setting up this environment for a given problem involves providing Ergo with descriptions of the objects to track, implementing the physics necessary in the World Server for altering the virtual world and its display, and developing agent control programs. In our coursework, only the latter is performed by students, but developing robot environments could also be used as a creative element in a course. The boundary between physical and virtual can be adjusted, allowing many potential variations in any domain. In soccer, for example, students can play with a ball on the virtual field with simulated physics, or a real ball for greater unpredictability in perception and physics. The mixed reality setup can be quickly changed from one problem to another, allowing a variety of domains to be explored in a single assignment. We employ a range of domains in our classes, including team-based games such as soccer, video games such as Pong and Pac-Man, and a racetrack.

Course Overview

The course for which we employ this system is a fourth year course involving a small set of students (12–15) working in groups. We begin by covering basic concepts in vision (e.g. color models, perspective geometry) while students learn to use the environment described above in a laboratory setting. They then write an interface to control the robots manually, while learning about control algorithms (e.g. fuzzy logic controllers, Egerstedt’s and Balluchi’s controllers) in class. Students then implement these control algorithms to run a series of laps on a racetrack to implement path following.

During this time, we cover sophisticated path planning methods such as quad-tree decomposition and Voronoi diagrams, and students then illustrate this work using by performing a treasure hunt in the virtual world, where a series of spots must be visited using path planning. While this implementation is underway, students learn about agent architectures and methods for making path-planning dynamic (e.g. re-planning). Students apply this knowledge by running races across the field, where randomly-moving obstacles (perceived through vision) must be avoided, while larger agent architectures are covered in class (e.g. behaviour-based approaches). Each of these steps involves applying the skills learned at the previous stage, and at this point students can demonstrate sophisticated interacting behaviours, such as passing a physical ball between quadrants marked on the virtual world, and playing simple games involving obstacle avoidance (such as Pong). Finally, these are combined into a capstone assignment that requires combining all the skills they have learned, such as two-on-two soccer or Pac-Man



Figure 2: Pac-Man using the architecture of Fig. 1.

(Fig. 2). Each of the stages involves a competition, which serves to keep students motivated, but the outcome of the competition does not form part of the students’ grade. We do require a working demonstration to continue on to the next assignment, however, since each stage builds on skills learned in the prior stages.

Conclusion

We have found this approach keeps students motivated and challenged, in that fast-moving, vision-rich environments can be employed without overwhelming students. Because switching worlds is simple, different environments can be used in the same assignment. The latter is very important, in that it keeps students thinking generally, as opposed to creating solutions that would only ever work for a single problem. This approach has also been very useful in supporting control in evaluation that is difficult to achieve in the physical world. In our dynamic obstacle avoidance exercise, for example, robots previously had to navigate a series of obstacles (paper circles), with the obstacles moved by hand during the course of the run. Our mixed reality approach allows continually-moving obstacles that can be properly randomized or perfectly repeated from trial to trial if desired, a feature that is also useful from a research standpoint. Finally, the flexibility of this framework shows promise in investigating student learning in different settings, such as competitive vs. non-competitive applications.

References

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