ViperRoos: Developing a Low Cost Local Vision Team for the Small Size League

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Abstract. The development of cheap robot platforms with on-board vision remains one of the key challenges that robot builders have yet to surmount. In this paper we describe the prototype development of a low cost (<US$1000), on-board vision based, robot platform that has been used in robot soccer competitions as a test of its capabilities. The robot platform, named the *VIPER* robot, represents an integration of state of the art embedded technology to produce a robot that has reasonable computational abilities without compromising its size, cost or versatility. We describe the hardware architecture of the system, its motivation through to its implementation. In addition, we reflect upon the performance of a team of *VIPER* robots that participated in the RoboCup2000 competition as a measure of the robustness and versatility of the robot platform. Based on these reflections, we describe what remaining developments are required to evolve the system into a truly capable and versatile research platform.

1 Introduction

Robot soccer is an exciting new research domain aimed at driving forward robotics and multi-agent research through friendly competition. In this paper, we describe the development of the Viper robot and its performance at RoboCup 2000. The Viper robot is a prototype robot platform with on-board vision developed for the annual RoboCup competition. Although primarily intended for robot soccer competition, the Viper robot platform provides a versatile research base for investigating autonomous robot intelligence issues at low cost.

Building a small, versatile mobile robot with on-board vision capabilities for the robot soccer competition is challenging as the system must be both robust to the strenuous RoboCup environment and provide high-performance characteristics while fitting inside a small volume. Although there have been numerous attempts at building cheap robots with on-board vision capabilities, few approaches are suitable for small size RoboCup competition either because of size, cost or some other constraints. We believe that a fully custom design, utilizing

A. Birk, S. Coradeschi, and S. Tadokoro (Eds.): RoboCup 2001, LNAI 2377, pp. 305–311, 2002.

the wide range of embedded processors that are currently available, provides the best approach to satisfy the many constraints required for a successful RoboCup robot platform. In contrast to most other robot hardware (e.g. [1, 5]), the Viper robot divides the problem by using different embedded processors to handle the contrasting needs of vision and motion control processing. As most high end embedded processors are not suited to motion control and vice versa, this approach enables one to choose from a much wider range of processors thus producing a better overall product.

In the next section, we describe the Viper robot platform and the specifics of the prototype Viper system developed for RoboCup2000. Section 3 describes the performance of the system, from a user's perspective, at the RoboCup competition. Section 4 discusses the design approaches of other robots, followed by section 5 which determines what remaining work is required. Finally, section 6 concludes the paper and lists the future direction of the Viper project.

2 The VIPER System

The Viper system consists of the mechanical chassis, motors, the electronics, associated batteries, the software environment on the robot and the development support facilities that run on an off-board PC. The robot is fully autonomous, in the sense that all sensing, computation and actuation are performed on-board. In this section, we describe the physical hardware of the robot, its computational arrangement and capabilities, and the software environment that was developed for the RoboCup competition.

2.1 Mechanical Structure

Mechanically, we desired a robot that would be robust to the RoboCup conditions while offering high-speed maneuverability. Based on our prior RoboCup experiences, the Viper robot was chosen to build upon the same mechanical base of the RoboRoos' robots, a global vision robot soccer team used successfully in previous RoboCup competitions. To conserve space we will not discuss the mechanical details here but instead refer the reader to [2, 7] for further details. Fig. 1 shows the Viper robot with its primary mechanical components labeled.

2.2 Computational Structure

Vision and motor control have very different requirements in terms of electronic hardware. Vision, a processor intensive task, simply requires a fast processor with interface to the CMOS image sensor. Motor control requires a processor with peripheral set that is capable of performing timer-related operations without CPU intervention. Due to these contrasting hardware requirements, the Viper's computational architecture is divided into two parts. A vision board performs all operations related to vision and communication to other robots. Meanwhile, a second processor board performs all motor control operations. The two, distinctly

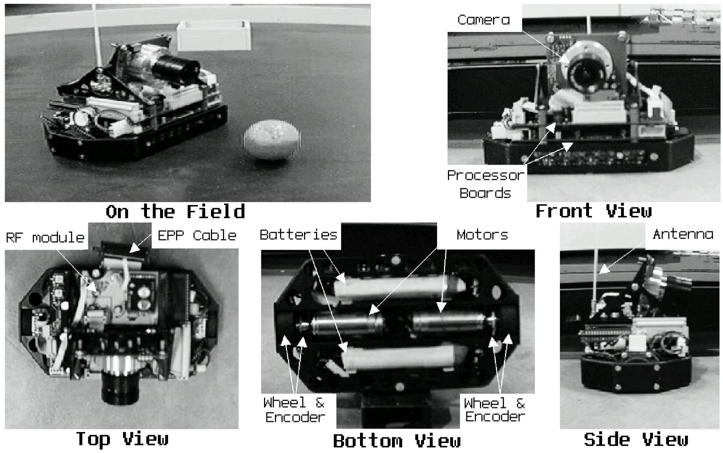

Fig. 1. The major components of the VIPER robot.

different processor systems interact over a 60kbps asynchronous serial link. Fig. 2 shows the conceptual arrangement of the two processor boards. The following sections describe each component of the system.

Camera. The camera chosen for the Viper robot was a Photobit PB-300 CMOS image sensor. A CMOS image sensor was chosen over a CCD sensor for its lower power consumption and fully digital interface. The camera provides color images of 640x480 pixels arranged in a Bayer 2G format through a parallel interface. Due to the SH-3's limited bus bandwidth, the full data rate of 30fps was limited to around 10 fps. The camera supports electronic panning and windowing. Additionally, the chip allows full control over exposure time, color gains, color offsets, horizontal and vertical blanking through a standard synchronous serial (I^2C) interface.

Vision Board. To perform the necessary vision capture and processing requires an embedded processor that has both a capable CPU core and a wide ranging peripheral suite that supports glueless interfacing to high-density memories, Direct Memory Access (DMA) for image capture and other large-scale memory transfers, and serial communications. There are a number of embedded processors currently on the market that fulfil these requirements at low costs. We chose the Hitachi SH-3 processor as a stepping stone to the fully code compatible SH-4/5 processors when they became avaliable.

The SH-3 processor is a 32-bit RISC processor that can perform at up to 80MIPs. The processor has a peripheral suite that facilitates glue-less connection of numerous memory types, three serial connections, and a four-channel DMA controller. Color image data from the image sensor is transferred via DMA. There are three main communication channels on the vision board. An asynchronous serial link connects the vision and motor boards, while another asynchronous serial links provides communication to the PC and other robots though a wireless, half-duplex RF module at the nominal 19.2kbs. Finally, an EPP interface to the PC enables real-time video debugging with a custom written GUI debugging software on a PC.

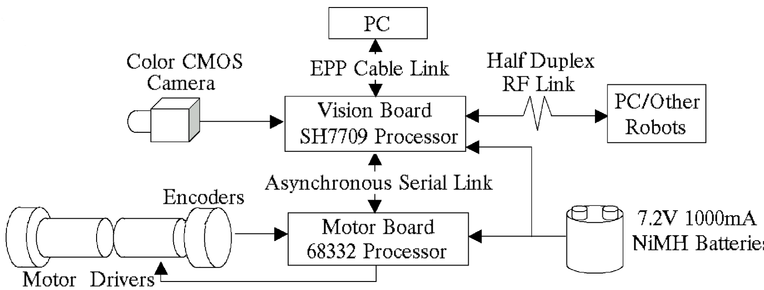

Fig. 2. The processor architecture on the Viper robot

Motor Board. There are a number of embedded micro-controllers designed specifically for motor control primarily for use in the automotive industry. We chose the Motorola MC68332, a 32-bit CISC processor that gives around 5MIPs performance, for the motor controller board given its wide range of peripherals, reliable development system and low cost. The on-board Timer Processor Unit peripheral is a powerful timer utility that requires no CPU intervention to perform a wide variety of timer functions with 16 independent output channels. This powerful timer module drives the two motors through MOSFET H-Bridges with Pulse-Width-Modulation signals and keeps track of the encoders with Quadrature Decode (QDEC) operations. Each QDEC provides 2000 'clicks' per wheel revolution giving a fine grained resolution of 47μm and a velocity resolution of 47mm.s^{-1} when sampled at 1kHz.

2.3 Software Development Environment

The software, both on-board and off-board was written specifically for the Viper robots to achieve optimal performance. For a more detailed description of the Viper software used at RoboCup 2000 please refer to [3]. All software is written in C with some of the boot and time critical code written in assembler. Both processors have a library of device drivers that provide a single layer of hardware abstraction without significantly hindering computational efficiency. In addition to the device driver library, the vision processor has a library of vision related function optimized for the SH-3 processors. As an aid for debugging, we have written a custom GUI software under PC environment to provide real-time video debugging, fast vision calibration via the EPP connection and interaction with the robots via the RF-link.

3 System Performance

In general the robot hardware performs at or beyond our initial expectations. Once built, the hardware proved robust and reliable with no real maintenance required for the operating period of 18 months.

The ViperRoos is capable of processing images at the frame rate of 10Hz, and this includes RGB to YUV color space conversion, subsampling and color segmentation based on a pre-generated YUV lookup table. Blobs are found in the segmented image and categorized into objects based on their dominant color. Beside the usual objects such as the walls, goals, robots, or the ball, the vision board also output an obstacle map for collision avoidance. The motor board performs all motion control routines and the behavior architecture that produces the actual soccer game play of the robot.

As a demostration of the Viper system's capabilities, and as its primary design aim, a team of three Viper robots (two field robots and one goalkeeper) was entered in the RoboCup2000 competition with the team name *ViperRoos*. In any performance metric, the ViperRoos were clearly amongst the best of the local vision teams at RoboCup2000. The robots even proved somewhat competitive against the weaker global vision teams. In terms of raw competition performance, the ViperRoos performed admirably for their RoboCup debut. The team finished the round robin stage with one win and two loses against three global vision teams. In a specialized local vision only competition the robots performed well but no goals were scored either for or against. However, ViperRoos demonstrated their speed and accuracy during the penalty shoot out. The ViperRoos missed one goal in ten attempts and managed to block all shots on goal from the opponents.

4 Comparisons to Other Systems

There are a number of alternative approaches to building small, local vision robots. As with the Viper, most approaches rely on building custom hardware to achieve the desired performance characteristics within the compact size requirements. Probably the best amongst these are the Eyebots [1]. The Eyebot controller board is designed around a Motorola 68332 processor and uses a commercially available CCD camera with a parallel output. As the entire robot system is built around the same processor used for motor control on the Viper robot, the Eyebot is naturally more limited in terms of its processing capabilities.

Outside of the small-size scale there are a number of local vision robots that are either low cost or commercially available. The most notable of these is the Sony Aibo robot dog that is used as the base platform in the RoboCup legged league (e.g. [6]). These robots offer relatively cheap robot vision with the addition of legged motion. The mid-size league consists entirely of on-board vision robots, but these systems are neither cheap nor small. Typically these systems, due to the larger size specifications, use laptops or single board computers to process vision with simpler local processors to perform motor control (e.g. [4]). This is clearly a similar strategy to the Viper robot taken to a larger extreme.

5 Future Work

The heavy use of the Viper system for the RoboCup competition clearly demonstrated the versatile ability of the system. In particular, the choice of the dual processor architecture enabled a wider selection of processors more suited to the differing tasks of vision and motor control. The choice of CMOS imaging technology as opposed to CCDs reduced the complexity of the electrical interface and the power consumption of the camera overall.

At it is a prototype, there are always bugs or deficiencies that need to be improved. Firstly, the vision processor requires an upgrade to achieve the full possible 30fps. At this frame rate, the overall robot performance can be improved significantly. The data throughput rate of the RF link also requires upgrade to achieve efficient inter-robot communication. Using newer RF transceiver technologies such as BlueTooth^{TM} or the single chip transceivers that operate at higher frequencies offer an opportunity to greatly increase the transmission speed and throughput of the RF link.

6 Conclusions

This paper has described the Viper robot system and its performance as a robot platform in robot soccer competition and as a general research vehicle. We believe that the robust performance of the vehicle demonstrates both the virtue of investigating cheap autonomous robots with vision sensing, and our approach to doing so. Specifically, the dual processor architecture presented in this paper not only offers a way to make the most of processor technology that is currently available without breaking the budget but also providing a versatile upgrade path.

There is considerable remaining work to develop the Viper platform into a truly capable and versatile robot base for research and robot soccer purposes. Most of this work focuses on a redesign of the system to incorporate the latest technology that was not available during the initial design phase. Additionally, improvements to the software and development environment are required to make the developer's life easier and to aid in general productivity.

References

[1] Bräunl, T., Reinholdsen, P., Humble, S.: CIIPS Glory - Small Soccer Robots with Local Image Processing. submitted for RoboCup-2000: Robot Soccer World Cup IV, Springer-Verlag, (2001).

[2] Browning, B.: A Biologically Plausible Robot Navigation System. Phd. Dissertation, Dept. of Comp. Sci. & Elec. Eng., University of Queensland, (2000).

[3] Chang, M., Browning, B., Wyeth, G.: ViperRoos 2000. submitted for RoboCup-2000: Robot Soccer World Cup IV, Springer-Verlag, (2001).

[4] Emery, R., Balch, T., Bruce, J., Lenser, S.: CMU Hammerheads Team Description. submitted for RoboCup-2000: Robot Soccer World Cup IV, Springer-Verlag, (2001).

[5] Marchese, F., Sorrenti, D.: Omni-directional Vision with a Multi-part Mirror. Proceedings of The Fourth International Workshop on RoboCup, (2000), pp.289-298.
[6] Veloso, M., Winner, E., Lenser, S., Bruce, J., Balch, T.: Vision-servoed localization and behavior-based planning for an autonomous quadruped legged robot. Proceedings of AIPS-2000, Breckenridge, (2000).
[7] Wyeth, G., Tews, A., Browning, B.: RoboRoos: Kicking into 2000. submitted for RoboCup-2000: Robot Soccer World Cup IV, Springer-Verlag, (2001).