Abarenbou - A Small Vision-Based Humanoid Robotic Research Platform

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Abstract

This paper describes our latest humanoid robot Abarenbou, a modification of the commercially available Kondo KHR-1 humanoid robotic kit. This kit provides a mechanically sound and affordable platform, but does not provide facilities for on-board computer vision and other sensors for active balancing. Thus, it is not suitable as a research platform for humanoid robotics. To overcome these limitations, we added a pan and tilt camera mount, and a small camera. Processing power is provided by a Sony Clie NR70V PDA which is responsible for computer vision and higher level reasoning. The PDA communicates with the robot kit via a serial line. We developed software to create, store, and play back motion sequences on the Kondo KHR-1. Abarenbou uses arbitrary lines in the image to localize itself within the environment. The agent architecture of Abarenbou is implemented as behaviour trees.

1 Introduction

Humanoid robots have always inspired the imagination of robotics researchers as well as the general public. Up until 2000, the design and construction of a humanoid robot was very expensive and limited to a few well funded research labs and companies (e.g., Honda Asimov, Fujitsu HOAP). Starting in about 2001 advances in material sciences, motors, batteries, sensors, and the continuing increase in processing power available to embedded systems developers has led to a new generation of affordable small humanoid robots (some examples include: Pino [7], Manus I [8], Tao-Pie-Pie [2], Roboerectus [9], and Hansa Ram [5]).

These robots cost in the range from $1000.00 to $20,000 USD. Many hobbyists have build their own humanoid robots, especially in Asia.

The creation of these humanoid robots also coincided with an increased interest in several high profile research oriented international robotics competitions (e.g., RoboCup [3] and FIRA [1]). The researchers chose robotic soccer as a challenge problem for the academic fields of artificial intelligence and robotics at it requires a large amount of intelligence at various levels of abstraction (e.g., offensive vs defensive strategy, role assignment, path planning, localization, computer vision, motion control). These competitions allowed researchers to compare their results to others in a real-world environment. It also meant that robustness, flexibility, and adaptability became more important since these robots had to perform for extended periods of time in variable conditions. This is in contrast to researchers that could previously fine tune their system to the specific conditions in their laboratory. The inaugural humanoid robotics competitions at RoboCup and at FIRA were held in 2002.

Furthermore, in 2002, hobbyists formed several popular robotics events which had less of a research emphasis. The most popular example are the televised Robot Wars (Battle Bots) events where remote controlled wheeled robots with weapons try to destroy each other. Several of these humanoid robots are now commercially available at a competitive price. Even though the robustness and cost make these remote controlled fighting robots attractive for humanoid robotics researchers, the robots are not immediately suitable as autonomous robot research platforms.

The main disadvantages are: (a) these fighting robots do not have sufficient processing power for onboard vision, and (b) they have few if any sensors (e.g., accelerometers, gyroscopes, force sensors) to support dynamic balancing and feedback control of the walking gait.

This paper describes our work in converting the Kondo KHR-1 humanoid robot kit from a remote controlled fighting robot into a fully autonomous soccer playing robot, Abarenbou. To keep the cost down, Abarenbou uses a commonly available personal digital assistant (PDA) with a built in camera as processing platform for vision and higher level reasoning. We used the Sony Clie NR70V PDA as the brain of our robot. The hope is that lower cost platforms such as this will help make humanoid robotics accessible to a larger population of researchers.

The following section describes the hardware of the Kondo KHR-1 robot and our modifications to the hardware. Section 3 describes the methodology we used for developing new motions (e.g., walk, turn, and kick). The vision processing part of our system is described in section 4. Section 5 describes our pragmatic Al method for localizing the robot in the playing field and mapping the environment around the robot. The agent architecture is described in section 6. The paper concludes with section 7, which also gives directions for future work.

2 Hardware Description

The Kondo KHR-1 robot is a humanoid robotics kit with 17 degrees of freedom (DOF) controlled by servo motors. These include two in each ankle for frontal and lateral movement of the foot, one in each knee, two at each hip for frontal and lateral movement of the leg, three in each arm, and one to pan the head. The KRS-784ICS servo provides 8.7kg/cm at 6.0 V of torque and a maximum speed of 0.17sec/60°. These servos are powerful given their cost and were the main reason that we decided on this robot kit.

The servos are controlled by two simple embedded PIC based micro-controller systems. Each board can control a maximum of 12 different servos; this means that in theory the Kondo KHR-1 kit can control up to 24 different servos. However, in practice the number of servos is limited by the maximum current that can be driven by the controller boards. To reduce the maximum current for the two boards, the 17 servos of the KHR-1 are distributed equally across the two boards. The first controller board is responsible for the legs, whereas the upper torso, arms, and head are controlled by the second controller board.

The two embedded systems are controlled via a shared serial line. The controller boards accept commands at 115200 baud. Commands include setting the position (i.e., set point for all 17 servos), writing a motion (i.e., a sequence of positions), as well as reading back positions and motions.

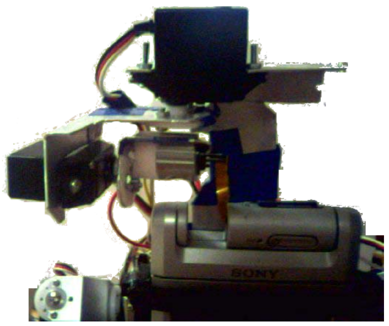


Figure 1: The Pan and Tilt Unit of Abarenbou. The servos are mounted upside down to prevent stress on the thin ribbon cable.

Several additions were made to the standard kit. A pan and tilt camera unit was constructed using two servo motors and the camera from a Sony Clie NR70V PDA 1. First, we removed the camera from the Sony Clie NR70V casing. The camera is connected to the main board via a fragile short ribbon cable and therefore has only a small range of motion. A pan and tilt unit was constructed out of two micro RC servos in such a way that the link joint is as close as possible to the original position of the camera. The pan and tilt assembly allows the camera to tilt by +/- 45 degrees and to pan by +/- 70 degrees. The Clie itself was mounted in a bracket attached to the front of the robot. The PDA uses a 66 MHz Dragonball CPU for processing and captures images with a 320x240 resolution. While the PDA does not have as much processing power as other alternatives, it does have a serial port for communication with Abarenbou's control boards.

In order to control the robot using the Sony Clie we intended to connect the robot and the Sony Clie PDA via the serial port. The Sony Clie NR70V PDAs provide a serial port which is intended to connect the PDA via the hot sync cradle to a standard PC. Unfortunately, like many other new PDAs, the NR70V only generates +5V and GND instead of the RS 232 standard voltages of +/- 12V. To overcome this problem, we built a level changer circuit using the Maxim MAX232 level changer IC, which is a popular chip specifically designed for this task. After generating the correct voltage, we were able to send data to the robot, but were unable to read data from the robot successfully. Upon further investigation, we discovered that the control circuitry on the robot did not generate 12V. Instead the client software was expected to drive the DTR pin low, and this pin was connected via a pull down resistor to the transmit pin on the robot.

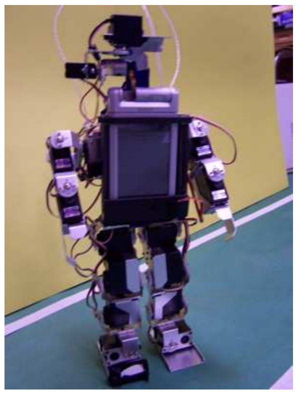
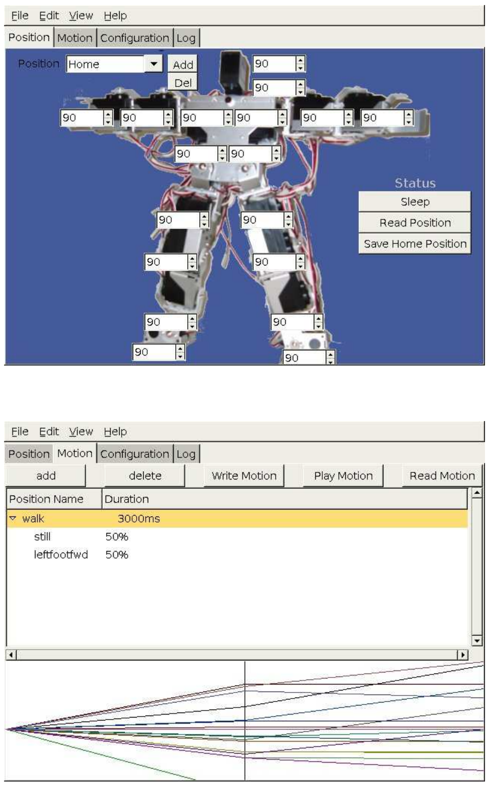


Figure 2: Abarenbou



Position Name	Duration
walk	3000ms
still	50%
leftfootfwd	50%

Figure 3: Interface of our motion development system. The top window shows the development of a position, the bottom window shows the combination of these positions into motions.

We generated a 12V signal using the Maxim MAX232 level changer IC in a similar manner. After this modification, we were able to send and receive data from the robot reliably.

3 Motion Development

The serial interface to the embedded control boards allows setting the position of the robot, reading the current servo setting, saving a sequence of positions with timings, and playback of those sequences.

Figure 3 shows the interface of the motion control software that we developed to control the Kondo KHR-1. The interface allows one to move the robot into a specific position and save this position. The interface also allows one to set the trim (i.e., offset) for all joints as well as the home position.

A separate window tab is used to combine positions into motions. Each motion has a cycle time associated with it and each part of a motion has a arrival time associated with it. Thus, the interface allows the user to easily adjust the speed of a whole motion or individual parts of the motion. The trajectory of all joints is shown in the window.

All positions and motions are saved in an XML file. This allows one to easily check the syntax of the file. Positions and motions can be loaded from an XML file and saved on the robot. Multiple movements were programmed onto the robot. These included the start walking, take step with right foot, take step with left foot, stop from left walk, stop from right walk, sideways step left, sideways step right, and kick with right foot.

These movements are then available to be played back as required by any of our programs running on the Clie.

4 Vision Processing

Abarenbou uses a CMOS camera as the main sensor. The camera is used to approach objects in the field of view of the robot as well as for localization and mapping.

First, objects are extracted from the image. It is possible to calibrate the object recognition for the colours that we are looking for in balls, goals, etc. We perform a colour-gradient guided flood fill which terminates at a certain threshold. This gives a set of potential objects, each with an average colour and size (number of pixels). If the region meets certain criteria, like matching a colour from the calibration and being a minimum size, it is labeled as the appropriate object, otherwise it is ignored. It is in this manner that we track the ball and goals in soccer, and the obstacles in an obstacle run.

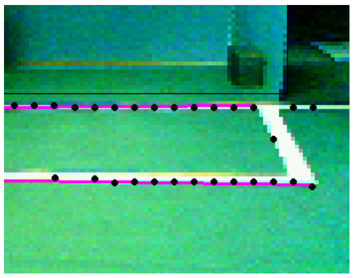


Figure 4: The dots are centred on the pixels that are detected as transition pixels from field to line colour.

To determine the relative location of the objects and to help the feature based localization method described in the following section, we use a complex camera calibration based on the Tsai camera calibration algorithm [6]. This calibration is only done once for each robot. Given this calibration information, we are able to map points in the image accurately to their real world coordinates. This is essential since it allows us to determine the distance and orientation of the robot to a feature point (ball, goal post, line). Since Abarenbou has a camera that can tilt, we needed multiple calibrations. Instead of calibrating for each possible tilt position, we calibrate for three tilt positions and interpolate between these.

Before localization can occur, features must be extracted from the image. The relevant features for localization on the soccer field are lines, goals, and the centre circle. We use the lines and the goals to achieve localization.

Every 5th column, the system scans from the bottom of the image towards the top. If there is a transition from a green pixel to a white pixel, the pixel p is remembered in a list. The scan continues upward, so there may be more than one transition pixel in a column. Figure 4 shows debugging output sent back from the PDA highlighting these transition pixels. Next, lines are found by running a gradient guided Hough transform [4]. For each point p_i, a set of adjacent points is determined. Triplets are formed from these by including one point to the left of the point p_i, and one point to the right of p_i. There are several triplets that can be formed this way out of the neighborhood of adjacent points. Each triplet votes for an unbounded line in the image. This vote is fuzzified by voting for a small range of slopes through the point p_i. Figure 5 shows an example of triplet formation and the corresponding votes. The peaks in the Hough accumulator space determine the equations of possible lines. For each peak in the accumulator space, we search along the pixels determined by the line equation to find start and end points of the lines. This results in a set of line segments.

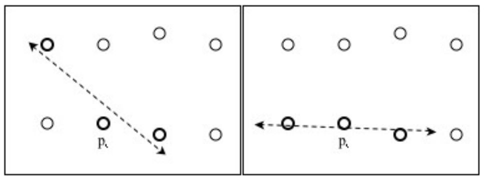


Figure 5: Two possible triplets surrounding a pixel, and their corresponding votes.

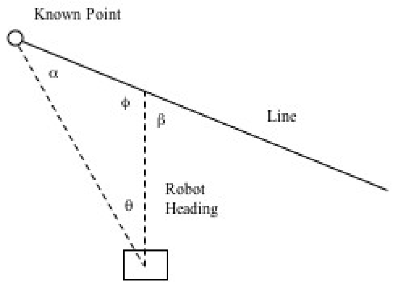


Figure 6: Localizing using a known point, its relative position, and relative orientation of a line

The line segments are ordered based on their size. The longest line segment is assumed to represent the edge of the playing field. Given the distance and gradient of the line segment, the position and direction of the robot can be computed.

5 Localization and Mapping

Knowing the position of the ball is important. Its relative position from the robot is easily determined from an image. However, without knowing the world position of the ball, the robot would often kick the ball out of bounds or even into its own goal. Actions can not be taken toward kicking the ball until its world position is known. If the ball's relative position to the robot is known, localization of the robot will give localization of the ball. This localization can be achieved as long as a point is viewed with a known world coordinate, and knowing the robot's world bearing from it. One instance of this is when a goal post is seen. Once this is accomplished, dead reckoning can be used

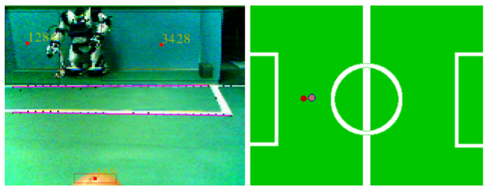


Figure 7: An example of a captured image and associated localization result.

with some accuracy for a short time afterward. Figure 7 shows a captured image and the localization of the robot and ball using that image.

6 Agent Architecture

This section will give a brief introduction to the behaviour tree based agent architecture used in Abarenbou. The discussion will focus on the state transitions. More complex features of the agent architecture (e.g., behaviour trees and state references) are outside of the scope of this paper.

Designing an architecture that is flexible, versatile, and intuitive enough for an intelligent mobile robot is a difficult problem. This is especially true in the case of autonomous robots with limited processing capabilities.

Abarenbou uses a behaviour tree to balance the need for deliberate planning and reactive behaviours. The behaviours themselves are implemented as finite state machines. As the complexity of the task increases, the implementation of the state machine becomes more error prone.

We therefore developed a meta language to describe the behaviors in XML. The specification of the behaviors includes preconditions (enter functions) and post conditions (exit functions) of the behaviours. An slightly simplified example of a simple behaviour that scans for a target with increasing sweeps is shown in Table 1. The XML schemas include additional markup to refer to states by name (`%%State("Random Walk")` access variables (`%%v`) and to trigger transitions to other states (`%%Transition`).

Behaviours are organized into behaviour trees. Higher level behaviours can override or enable other lower level behaviours. For example, a "Perception" behaviour may disable the scan for target behaviour and enable the state "Target In Front" if it recognizes the target.

One of the design goals of the meta language was to be highly efficient. Therefore, instead of adding a

```
<State id="Scan For Target" >
<Enter>
%%v(angle) = 0;
if ( previousState == %%State("Target Right Forward") )
    {
      %%v(newAngle) = 20; /* Turn 20 degrees first */
      %%v(angleAdjust) = +10;
    }
 else
    {
      %%v(newAngle) = - 20; /* Turn 20 degrees first */
      %%v(angleAdjust) = -10;
    }
</Enter>
<Process>
  if ( ( %%v(newAngle) >= -190 ) &&
       ( %%v(newAngle) <= 190 ) )
    {
      if  (%%v(angle) != %%v(newAngle) )
        {
          turn( (%%v(angleAdjust) * TEN_DEGREE) / 10 );
          %%v(angle) = %%v(angle) + %%v(angleAdjust);
        }
      else
        {
          %%v(newAngle) = - %%v(newAngle) - 40;
          %%v(angleAdjust) = - %%v(angleAdjust);
        }
    }
  else
    {
      %%Transition("Random Walk");
    }
</Process>
</State>
```

Table 1: An XML schema for a behaviour that scans for a target by turning right/left with increasing sweeps

XML parser and interpreter to the agent, the meta language is parsed and interpreted offline and converted into highly efficient C code. This code is then compiled and executed on the PDA. For example, the example above shows that the programmer uses state names (e.g., "Random Walk," and "Scan For Target"). However, the states names are converted to integers in the C code. There is some loss of the interactive aspects of XML by requiring off-board interpreting, but this is unavoidable due to the limited processing power available on the PDA.

An additional advantage of using a formalized state representation language with markup in the code is that it is possible to generate other representations. For example, our state compiler automatically generates a state transition graph. Figure 8 shows the state transition graph for a simple approach task. The robot first approaches a target and then walks away from it.

7 Conclusion

This paper describes the modifications and additions that we made to convert the Kondo KHR-1 humanoid fighting robot kit into a platform for humanoid robotic soccer.

The addition of a Sony Clie PDA NR-70V with a pan and tilt assembly provides visual feedback for the robot. The original embedded controllers of the Kondo

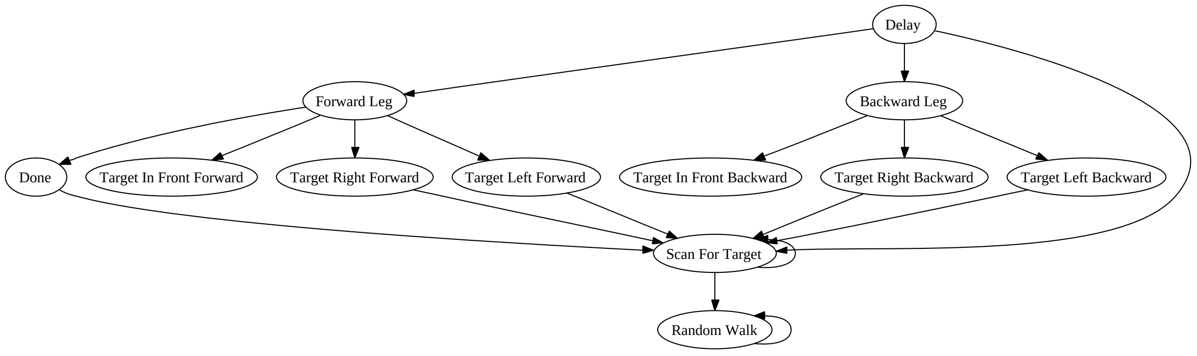


Figure 8: Automatically generated state transition graph for a simple approach and avoid task. Solid lines are state transitions.

KHR-1 robot are used to control the motion. The PDA communicates via a serial line with the robot and is able to start/stop the motions of the robot.

We use a vision-based approach to determine the behaviour of the robot. The robot uses lines on the playing field to localize itself on the playing field and to map objects into the robot's environment.

The development of the complex architecture necessary for an intelligent soccer player is simplified through the use of an XML based meta language for behaviour trees. This meta language makes the pre-conditions, process stack, and state transitions explicit. The XML representation is converted into C code, which can be compiled into efficient code and thus does not introduce computational overhead through its use.

We are currently investigating methods for adding sensors (e.g., accelerometers, gyroscopes, and force feedback) that provide feedback about the balance of the robot. Even though active balancing is not necessary for a robot playing soccer on an even surface, it is at the heart of humanoid robotics research and is necessary to build robots that are able to move over uneven surfaces. This requires a reprogramming of the PIC micro-controllers used in the Kondo KHR-1 controller boards.

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