Proposal of a Kit-Style Robot as the New Standard Platform for the Four-Legged League

S. K. Chalup[1], M. Dickinson[2], R. Fisher[1], R. H. Middleton[1], M. J. Quinlan[1], and P. Turner[1]

Newcastle Robotics Laboratory http://www.robots.newcastle.edu.au

(1) School of Electrical Engineering and Computer Science

(2) School of Design, Communication, and Information Technology

The University of Newcastle, Callaghan 2308, Australia

Abstract

In 2006 the Sony Corporation announced that production of the Aibo robot, which is the standard robot platform of the four-legged league of RoboCup, would be discontinued.

This paper describes a prototype robot kit which could lead to a new standard platform for the four-legged league. The aims for development of the new platform can be summarized as follows: 1.) Continue and improve the concepts behind the Sony Aibo robot. 2.) Allow research into sophisticated quadruped soccer skills. 3.) Build an open systems robot to advance low level features and to support high level strategy planning and learning. 4.) Achieve faster and more exciting soccer games. 5.) Contribute to progress of the four-legged league, which to date has been a very successful league. 6.) Determine kit style hardware for year to year upgrades of selected modules.

The robot kit allows for substantial new flexibility in hardware design in associated scientific challenges and research projects. The present paper addresses two possible versions of the proposed kit: terrier and bear.

1 Introduction

RoboCup has grown to be the largest and most important international event in intelligent robotic multi-agent systems. At its 10th anniversary in 2006 an estimated 2500 active participants from 35 countries attended (Table 1). RoboCup comprises a scientific symposium, an industrial robot exhibition, and a set of robot competitions in soccer, rescue, and household tasks [RoboCup, 2006]. Associated with RoboCup is the fast growing RoboCup Junior initiative for high school students. The central and largest component of RoboCup is the robot soccer world cup competition which consists of several leagues for different types of robots.

Research directions in the different leagues complement each other by emphasising different aspects of the complex task which is soccer. In the simulation and small size leagues a central server controls the soccer agents of each team. In the simulation leagues all 11 agents of each team are in software while in the (f-180) small size league physical wheeled robots with a diameter up to 18cm are controlled via an overhead camera installed above a real field. In the (f-2000) mid size league larger fully autonomous wheeled robots use a regular soccer ball to play on a 12m×8m field. While the simulated and wheeled agents can move quickly and are able to pass the ball, the latter task is much more difficult to achieve in the legged leagues. Research in the humanoid league is still focused on solving the challenge of robust stabilisation during bipedal walking.

Figure 1: Aibo models ERS-210a (left) and ERS-7W (right) with uniforms as used in the four-legged league.

The Sony four-legged league has operated since 1998 as a software focused league using the Sony Aibo robot [Sony, 2006] as the standard hardware platform. Of the two leagues which use 'biomimetic' (limb based) robots the four-legged league is the only league with both standardised hardware and has the most advanced play.

The Sony four-legged league has become one of the most popular leagues of RoboCup. Through develop-

Table 1: History of RoboCup in numbers

City, year	Countries	Teams	Jr. Teams	Participants	Visitors
Nagoya, 1997	11	40	-	-	5060
Paris, 1998	16	63	-	237	-
Stockholm, 1999	23	88	3	-	-
Melbourne, 2000	19	116	25	500	-
Seattle, 2001	22	141	25	700	18,300
Fukuoka, 2002	29	188	59	1004	117,300
Padova, 2003	35	135	67	1266	15,000
Lisbon, 2004	37	162	162	1627	-
Osaka, 2005	35	203	163	-	181,540
Bremen, 2006	35	200	240	2500	12,600

ment of a robust and fast quadruped walk and techniques for precise localisation of the autonomous robots, exciting soccer play has been achieved in recent years. The quickly developing capabilities of the robots and the high level of play have been astonishing for researchers and general audiences every year. Some of the top teams of the four-legged league in 2006 where able to demonstrated effective goalie behaviour, cooperative and adaptive team positioning, active perception, and occasionally successfully deliberate passing between players.

The four-legged league is also a core motivator for many thousands of young students from over 22 countries who have joint the rapidly expanding RoboCup Junior initiative.

Despite the significant advances in the four-legged league, there is a great deal yet to be achieved. More specifically: (i) The gaits at present are limited to walking gaits. A revolution in hardware and software is needed to achieve the long term aims of running or galloping; (ii) The visual systems are largely constrained to colour coded constant illumination scenarios and have very limited team-mate versus opponent recognition capability; (iii) Localisation sensing and software remained weak, with even some of the top teams exhibiting disorientation and failure to remain on the field; and (iv) Highly reliable team play. These longer term aims of the four-legged league are difficult or impossible to achieve within the existing Aibo hardware due to sensing, computation, and actuation limitations.

Since Sony Corporation announced early in 2006 that production of the Aibo robot will be discontinued this proposal presents a prototype for a new kit based hardware system which addresses two general challenges:

(I) A new standard platform for the four-legged league should be designed to support the above longer term aims (i)-(iv) by evolving all aspects of the hardware design, in conjunction with software developments, until realistic quadruped robot soccer will be achieved.

(II) Aibo was an extremely popular and sophisticated robot [Fujita and Kageyama, 1997; Fujita and Kitano, 1998]. Its friendly and aesthetic design contributed significantly to the success and high popularity of the four-legged league and associated projects. Therefore a new robot for the four-legged league should have a similarly attractive design.

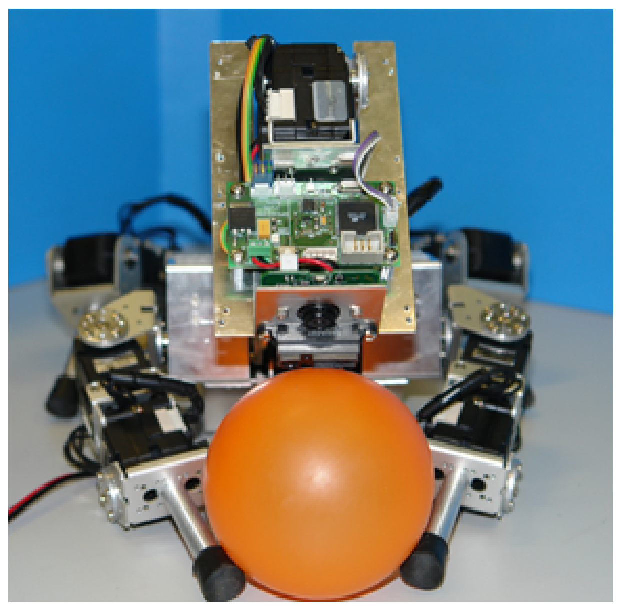

Figure 2: Proposed terrier robot prototype with official four-legged league ball.

The kit style robot concept proposed in this paper presents a new challenge for the technical committee of the league which would have to define the details of the standard platform and incremental hardware upgrades for each year. Stepping up to a new hardware platform provides the opportunity for significant advancements of skill standard and research achieved so far in the four-legged league.

Table 2: Specifications of the different models of the Sony AIBO robot as used in the four-legged league of RoboCup

Model	ERS-**110**	ERS-**210**	ERS-**210**A	ERS-**7**
years	2000	2001-2006	2003-2006	2004-2006
CPU	64-bit	64-bit	64-bit	64-bit
clock	-	192MHz	384MHz	576MHz
memory	8-16MB	32MB	32MB	64MB
camera	CCD	CMOS	CMOS	CMOS
pixels	176×120	176×144	176×144	208×160
$\frac{\text{frames}}{\text{second}}$	30	25	25	30
wireless	no	802.11b	802.11b	802.11b
size (mm^3)	-	154×266×274	154×266×274	180×278×310
weight	-	$1.4kg$	$1.4kg$	$1.7kg$

2 The Aibo Robot

In the four-legged league several different models of Sony Aibo robots have been in use over the years, namely the ERS-210, ERS-210A, and since 2004 the ERS-7 models (Figure 1). An overview about approximate specifications of the different Aibo models used at RoboCup during the years 2000-2006 is given in Table 2.

Please note that the details collected from different team reports, Sony's webpages [Sony, 2006], and our own experience, did not always coincide. Information regarding the robot hardware used in the early years of the league is not readily available, and teams seem to interpret hardware parameters in different ways. We also have not included specifications about any prototype robots (for example the DRX-720 or MUTANT) which were used before 2000 [Fujita and Kitano, 1998; Fujita, 2001; Fujita, 2004].

All four Aibo models used in the league had 64-bit MIPS processors. The ERS-210 and ERS-210A were identical apart from their processors. The robots were programmed in languages such as `C++` or Python using Sony's OPEN-R software development kit (see `openr.aibo.com` [Fujita and Kageyama, 1997; Kitano *et al.*, 1998]). The robots were fully autonomous. Since 2002 they could communicate through wireless LAN (IEEE 802.11b) with the other robots on their team.

The Sony Aibo robot [Sony, 2006] was a very good robot and through its development and production Sony has made a great contribution to robotics research.

3 Design of the Terrier Robot Prototype

The design of the proposed robot kit aims at matching or surpasing the computational, electrical, mechanical, and visual features of Aibo. The kit-style system consists of high quality exchangeable parts which make the robot robust and allow for economical maintenance. One of the goals is to be able to reuse significant amounts of the computational concepts and software which has been developed in the four-legged league so far. The proposed terrier style robot has similar dimensions and price as Aibo. However, it has a much better camera, intelligent motors with metal gears and the option to use a more powerful processor. In section 4 the bear is proposed as an alternative design. It can still reuse significant parts of the quadruped code but would otherwise be a completely new robot concept with extended functionality and features for the four-legged league.

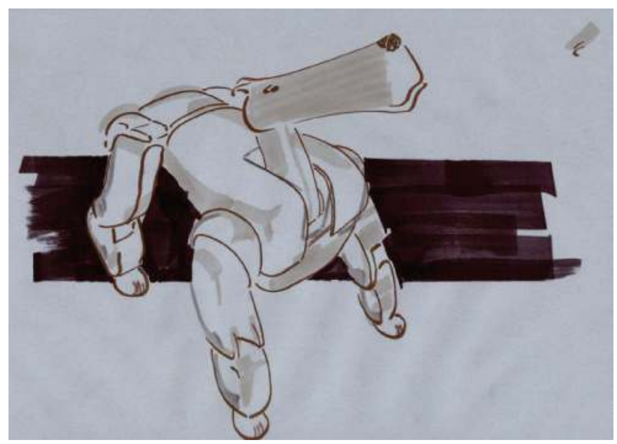

Figure 3: Visual design proposal for the terrier robot.

3.1 Visual Design of the Terrier

The visual design of Aibo has a cute element which has been a part of the success of the four-legged league competition to date. This should be captured by the new proposal as well. In Figure 3 a preliminary concept drawing is provided which displays the general form of a terrier. This type of dog has exhibited a wide and enduring public appeal in the classic Tin Tin cartoon series by Georges Rémi (Hergé). Specific aspects of the proposed design, which are affected by pursuing this aesthetic direction, are the leg placement and the head configuration. One characteristic feature for a terrier is that the distance between the hip joints is much closer than

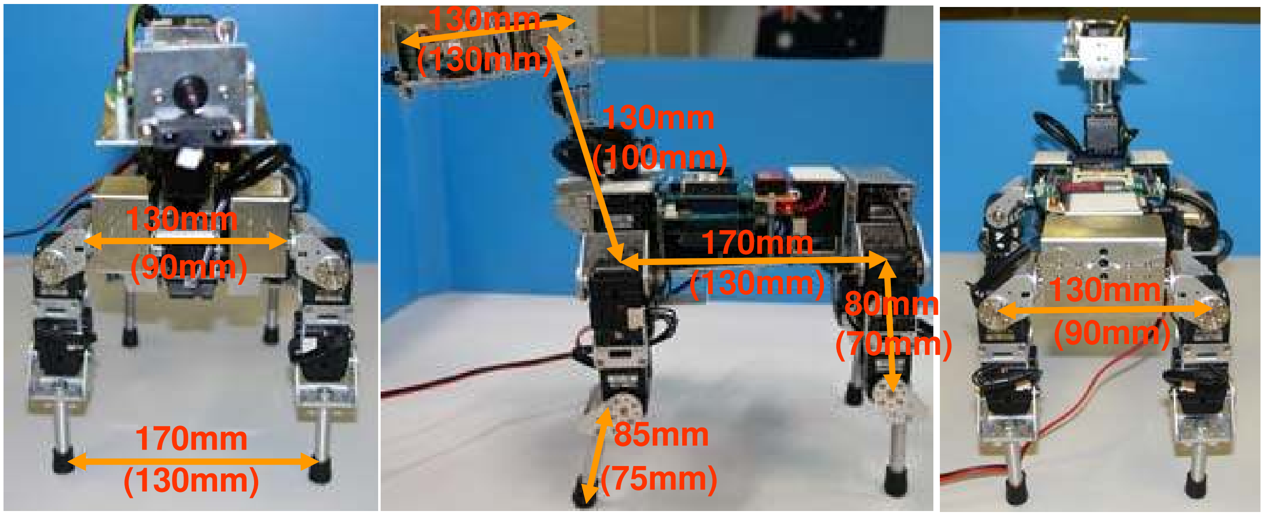

Figure 4: Dimensions of the terrier robot (and the Aibo robot for comparison).

the distance between the shoulder joints. While presenting visual clues to the terrier dog type (Figure 3), over-exaggeration of this feature may lead to an aggressive appearance. The balancing of the visual details will be part of the continuing proposal development.

Of great importance is the design of the visual details of the head. The head is a key element in determining the character of the robot and how the dog will be perceived and accepted by humans. The mechanical and electrical design of the robot does not impose severe constraints on determining the shape of the head so that a large variety of different designs are possible. At this stage a final decision for a particular head design for the prototype has not yet been made. Some example drawings of possible head designs are displayed in Figure 5.

3.2 Mechanical Design

The principal dimensions and functionality of the terrier (Figure 4) were designed to facilitate reuse of essential motor behaviors which were previously implemented by the four-legged league teams for the Aibo robot. The new robot would be able to grab and kick the official ball of the four-legged league (Figure 2).

Alternatively it could use other balls such as tennis or small size soccer balls. An additional degree of freedom was integrated into the terrier by a servo above its hips to allow twists along the backbone. The intended effect is that shoulder and hip axes can rotate against each other to improve the quadruped walk.

The first prototype, as shown in Figure 4, has stick-like lower legs resembling the slender legs of a terrier. The foot and lower leg combination can easily be modified in future prototypes.

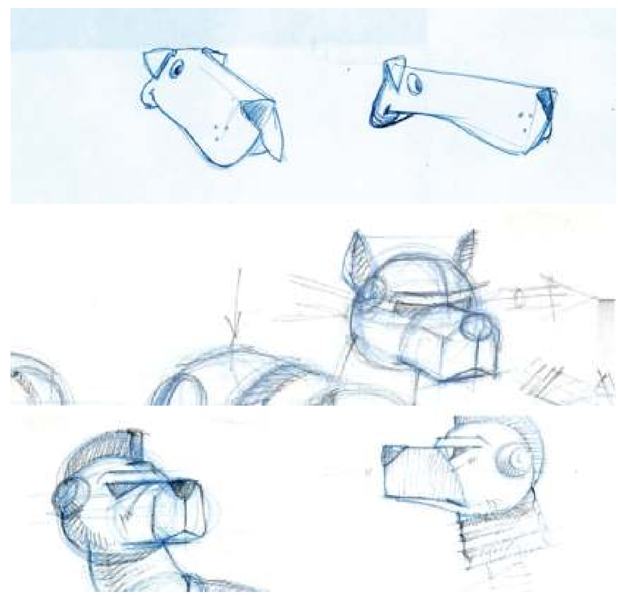

Figure 5: Visual design studies for the terrier head (Courtesy of Roger Quinn and Chris Lawrence).

3.3 Electronical/Electrical Design

The prototype electronical/electrical design for the terrier robot has two 400MHz ARM mcu's located on two KoreBot boards which can be connected to a customised motherboard as shown in Figure 6. One board would be reserved for vision processing and the other one for processing of behaviour, localisation, locomotion, and WLAN, etc.. The current prototype uses Dynamixel's DX-113 [alternatively DX-117] serially controlled servo motors which have been used, for example, by teams in the humanoid league of RoboCup before. Further the terrier robot prototype includes a 3 axis tilt compensated

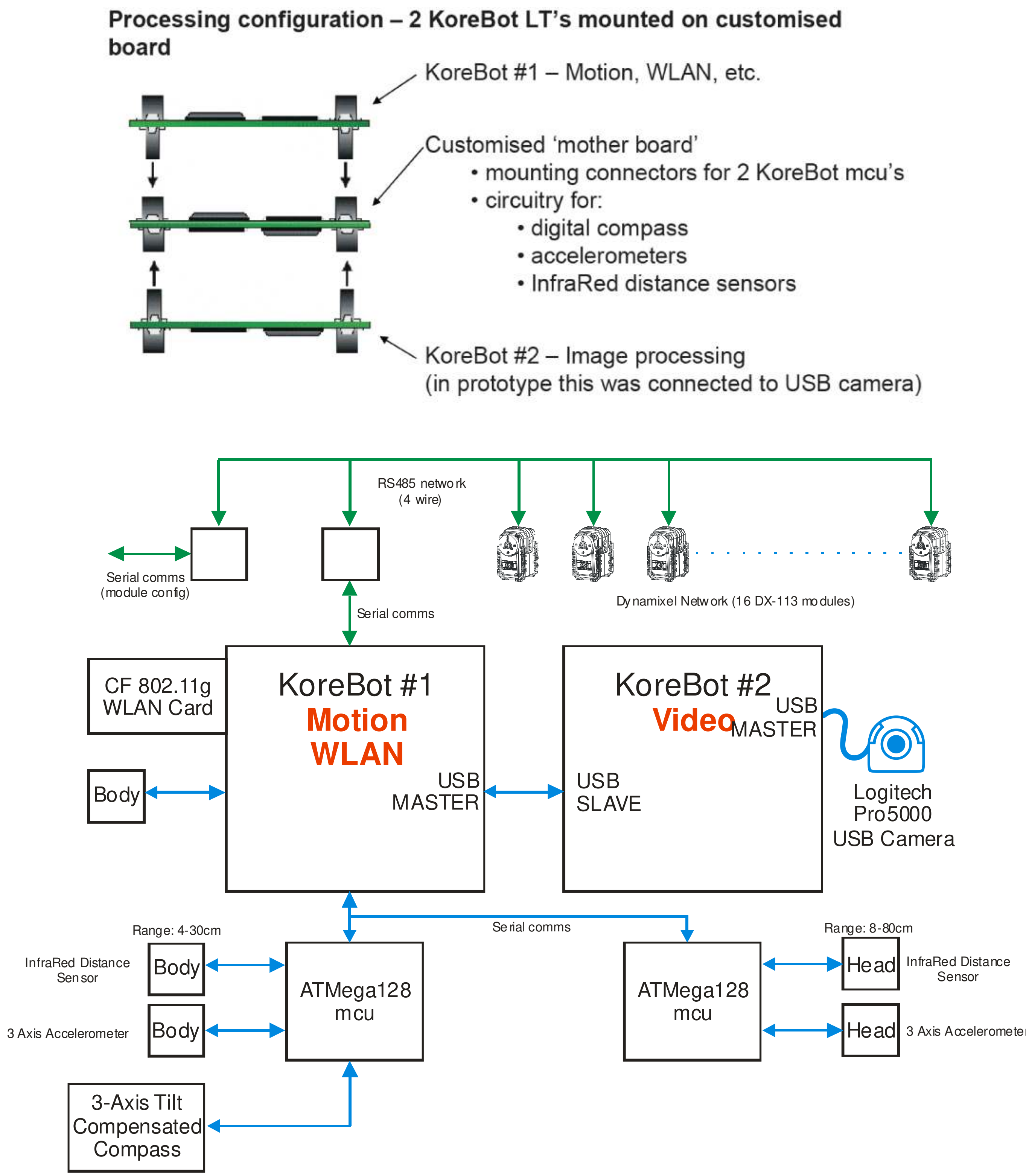

Figure 6: Example electronic design with two KoreBot boards.

digital compass, 802.11g WLAN, a high resolution camera (640×480 pixels, 60fps), and two 3 axis accelerometers: One for the body and one for the head.

Features of the Robotis Dynamixel DX-113 [DX-117] Modules

- Strong, durable motors with reasonable holding torque.
- An inbuilt mcu which allows:
  - Distributed control (no CPU load for low level control)
  - Change operational parameters, e.g. compliance.
  - Get sensor information, e.g. current → torque
- Fault detection & max, min angles
- Turn motor torque on/off
- Send angle ($0 - 300^o$; 0.35^o steps) and K speed ($\pm 400^o/sec$ range; $0.4^o/sec$ steps)
- Holding torque at 14.4V: 10.2 kg·cm [33 kg·cm]
- Speed $0.150 sec/60^o$ [$0.167 - 0.126 sec/60^o$]
- Current 800mA [1200mA]
- Gear reduction ratio 1/192.6
- RS 485 multi drop, serial communication
- Half duplex asynchronous serial communication (8 bit, 1 stop, no parity)
- Speed 7343bps ∼ 1 Mbps

3.4 Software Design

To provide the maximum flexibility in software design the prototype uses a derivative of the debian linux operating system. Linux provides efficient and open source control to the hardware installed within the robot. This allows programmers to quickly adapt to the task of software design and to also write software in a language of their choosing. Currently the robot has been programmed in C/C++ however the addition of other languages such as Python are planned.

Using linux as a base operating system allows the addition of thirdparty robotic languages such as Pyro, Player/Stage etc. This means that while the low level drivers for the hardware are written in C/C++, and are provided with the operating system, higher level languages can be used to develop the robot's tasks, such as behaviour routines and localisation.

Most four-legged league teams should be able to reuse (with modifications) significant parts of their software system which was initially developed for the Aibo robots.

4 The Bear Proposal

As a possible alternative to the terrier dog design we propose the concept of a bear robot. It introduces several new features and is significantly different from the dog concept of the terrier and Aibo. The bear robot still aims at being a sophisticated kit-style quadruped robot for soccer-like games and it will allow transfer and reuse of most essential software concepts and modules from the previous four-legged league code.

Most quadruped robot designs such as Aibo or the above proposed terrier use servo motors which results in a relatively heavy and strong robot. This type of robot can much better represent the proportions and dynamic functionality of a bear than that of a dog or cat which typically should have very slender and light legs. In contrast to cats and dogs a bear walks plantigrade, that is, heels-down with flat feet like a human (Figure 7).

Biological bears can temporarily stand up on their back legs and walk for short distances. We propose that a bear-like robot would be capable of sophisticated agile quadruped walking. It also could stand up and walk for short distances on his back legs. The upright position would give the robot advantages in vision and localisation. In contrast to typical biped robots the bear would never fall but perform transitions between biped and quadruped mode.

The visual design of the bear robot can follow that of a teddy bear which is a classic and well-accepted design for a cute toy and would be, similar as Aibo, well-positioned outside the uncanny valley [Mori, 1970; MacDorman, 2005].

Figure 7: Sun bear at Taronga Zoo.

5 Summary

This paper presented the proposal to employ a kit based robot as standard platform for the four-legged league. We believe the following general aims for the development of the new robot are appropriate:

1. Continue and improve the fundamental concepts behind the Aibo (i.e. a sophisticated legged robot with extremely high acceptance by humans).
2. Allow research into sophisticated quadruped soccer skills.
3. Achieve faster and more exciting soccer games.
4. Contribute to progress of the four-legged league which has been a very successful league.
5. Build an open systems robot to advance low level features and to support high level strategy, planning, and learning.
6. Employ a standard kit style hardware platform for year to year upgrades of selected modules. The technical advantages of the proposed robot kit can be described in more detail:
   - Mechanically the robots will be more reliable using the Dynamixel (or similar) modules and allow much more sophisticated control.
   - Powerful processors can be employed to allow more complex algorithms. The presented prototype uses two 400MHz MCUs which will be replaced as higher power economically viable alternatives become available. The option to use Pentium M based processors is currently investigated.
   - Since the MCUs use an open source operating system (Linux) software previously developed for Aibo can easily be transferred to the new robot.
   - The MCUs are plugged into a motherboard/backplane – this will allow easy transitions to new hardware such as, for example, a FPGA board for image processing, ethernet, memory upgrades, and so on.
   - An optional digital compass could easily be incorporated which could help with localisation.

At the time of writing of this article the first prototype (the terrier) was assembled as shown in Figures 2 and 4 and a simple walk was implemented. However, work on some parts of the control software and improvements of the hardware were still in progress. The second prototype (the bear) was still in the planning phase and not assembled yet. Details about availability and updated specifications of the described prototype robot kits can be obtained from Tribotix [Tribotix, 2006].

References

[Fujita and Kageyama, 1997] Masahiro Fujita and Koji Kageyama. An open architecture for robot entertainment. pages 435–442. ACM Press, 1997.

[Fujita and Kitano, 1998] Masahiro Fujita and Hiroaki Kitano. Development of an autonomous quadruped robot for robot entertainment. *Autonomous Robots*, 5(1):7–18, 1998.

[Fujita, 2001] Masahiro Fujita. AIBO: Toward the era of digital creatures. *The International Journal of Robotics Research*, 20:781–794, 2001.

[Fujita, 2004] Masahiro Fujita. On activating human communications with pet-type robot AIBO. *Proceedings of the IEEE*, 92(11):1804–1813, 2004.

[Kitano *et al.*, 1998] H. Kitano, M. Fujita, S. Zrehen, and K. Kageyama. Sony legged robot for RoboCup challenge. In *Proceedings of the 1998 IEEE International Conference on Robotics and Automation.*, volume 3, pages 2605–2612, 16-20 May 1998.

[MacDorman, 2005] Karl F. MacDorman. Androids as an experimental apparatus: Why is there an uncanny valley and can we exploit it? In *CogSci-2005 Workshop: Toward Social Mechanisms of Android Science*, pages 106–118, 2005.

[Mori, 1970] Masahiro Mori. Bukimi no tani ("the uncanny valley"). *Energy*, 7(4):33–35, 1970. in Japanese.

[RoboCup, 2006] RoboCup. www.robocup2006.org. webpage, 2006. RoboCup Federation.

[Sony, 2006] Sony. www.sony.net. webpage, 2006. Sony's Global Home Page.

[Tribotix, 2006] Tribotix. www.tribotix.com. webpage, 2006. sales@tribotix.com.