Hambot:
An Open Source Robot for RoboCup Soccer

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Abstract. *In this paper a new robot is presented which was designed especially for RoboCup soccer. It is an approach to evolve from the standard Darwin based skeleton towards a robot with more human motion capabilities. Many new features were added to the robot to adapt it for the special requirements of RoboCup Soccer. Therefore the interaction possibilities with the robot were improved and it has now more degrees of freedom to easier grip a ball and balance itself while walking. The design is open source, thus allowing other teams to easily use it and to encourage further development. Furthermore, nearly all parts can be produced with a standard 3D-Printer.*

Keywords: RoboCup; Humanoid; Open Source; Robot; Design; 3D printing; Rapid Prototyping

1 Introduction

Since the release of the Darwin-OP robot [7] for the IEEE Humanoids Conference in 2010 there was not much development of hardware in the humanoid league. Nearly all currently used platforms use the same structure as the Darwin-OP and are still expensive. Therefore we started developing our own robot platform, designed to be cheap, open source and usable in kid- and teen-size league. The first prototype was developed in 2014 and was presented at the RoboCup world championship in Brazil. An improved second prototype was build in early 2015 almost completely from 3D-printed parts. In this paper, we will present our robot and use the Darwin-OP as reference platform, due to its influence in the league. It will be used by the Hamburg Bit-Bots in the 2015 season of RoboCup tournaments.

2 Current Problems in the RoboCup Humanoid League

The existing specification limits for robots in the Humanoid league are quite open. However, nearly all teams in the kid- and teen-size league use a Darwin-OP or a robot with the same skeleton and DOF layout. It contains only the major joints of a human, e.g shoulder, hip or knee. Some teams made small modifications to the Darwin, e.g. changing the camera or mainboard. Other teams built a robot on their own, for example CIT Brains [5] and Hanuman KMUTT [13], but used the Darwin motor layout as well. The only team, which did a major change, are the FUmanoids [12]. They added one motor between the hip and the upper body, similar to the human lumbar spine, and used parallel kinematics in the robot's legs. Even newer platforms, e.g. the Nimbro-OP [11] or the robot of team Baset [3] have nearly the same layout. Most of the robots in the competition in 2014 were not especial designed for RoboCup. The battery layout is a good illustration for this problem. They must be changed during the game due to their limited capacity. Although this is time critical the batteries are located inside the robot and connected to the electronics by an extra cable. The robot is often difficult to handle during development, because most interaction is done via a connected laptop and not on the robot itself. Therefore the attention of the developer is divided between the laptop and robot.

The existing platforms are quite expensive, approx. 10,000 € [8] for the Darwin-OP and approx. 22,000 € [14] for the Nimbro-OP. The high costs make it difficult for a new team to start in the league, because they need at least 4 robots. Even the existing teams need to buy expensive parts and new robots as well, when the number of players increases, which is planned in the humanoid league proposed roadmap [2].

Some parts of the Darwin, e.g. boards and servo motors, are closed source. Therefore the robot is not completely open source, which limits further development.

3 Goals of the New Robot

After analyzing the current robots and analyzing their problems, we extracted the following goals for the new robot platform. Achieving these goal should improve the performance and the usability of the robot during competitions.

Costs Reducing the hardware cost lowers the barrier for new teams and enables established teams to upgrade their robots. The motors generate a major part of the price, therefore the costs can be reduced by reusing servos which are currently used in the league. The Dynamixel servos, especially the MX-28 [9], are very common. For the mechanical parts, simple aluminum sheet metal and 3D printed plastic parts are low cost alternatives to carbon parts, e.g. used in the Nimbro, which are expensive and harder to obtain.

Interaction The RoboCup competitions usually start with some set-up days for the teams to prepare their robots in the new environment. This is required because many algorithms, e.g. walking or vision, need to be adapted for the new environment. To simplify these tasks, the robot should be equipped with a direct human robot interface. This includes simple buttons as well as higher level controls to do frequent tasks, such as parameter adjustments without the need of a laptop. Good debug information is crucial to find bugs quickly and to accelerate the development. Besides the wireless network, additional audio and visual output is desired to simplify this task. A human understandable voice is very helpful for debugging purposes and potentially enables robot to robot communication with natural language as well.

Open Source Established platforms like the Darwin or Nimbro are not entirely open source due to the restrictions on third party standard parts (e.g. CM-730 motor controller board). This leads to difficulties concerning replacement, repairs and changes in the firmware. It also limits development of the hardware. This is one reason why there are so few modifications of the Darwin platform. Most of the extensions are limited to the replacement of cameras, batteries or motor controller boards. Another difficulty is changing the plastic parts of the Darwin-OP because these are made by injection molding. Thus the production method has to be simple to enable other teams to produce their own parts.

Designed for RoboCup Soccer Competition There are no robots available which are designed exclusively for RoboCup soccer, because the market is too small for it. Even the NAO robot, which has a league on its own, is only used in RoboCup because it is common in other research fields. Standard robots are missing helpful features and have functions which are not necessary. For example a fast battery change as well a handle to pick up the robot is required during a RoboCup game but not necessary for many other research activities. Therefore we wanted to design the robot from scratch for RoboCup. Features such as fast repair possibilities and a anatomy made especially for soccer playing are major concerns.

Progress in Relation to the Darwin-OP As mentioned in section 2, most of the currently used robots in humanoid soccer have a very similar body composition to the Darwin-OP. With more degrees of freedom (DOF) in the torso of the robot, it is possible to bend the upper body in pitch and roll direction independently from the legs. This is useful for walking stabilization and for standing up. A third DOF in the shoulder would enable the robot to move the arms more freely. This is practical for standing up, but it is mainly important to do throw-ins.

4 "GOAL"

The first prototype GOAL was made out of aluminum sheets in 2014. Only three additional MX-64 [9] and two additional MX-28 motors were used to upgrade one Darwin to a 87 cm tall robot with 24 DOF. The robot was able to stand and walk, but was unable to get up, because the motors were not able to lift the weight of the upper body.
Besides the problem of getting up, we experienced high lead times for the production of the sheet metal parts, significantly delaying the development. The

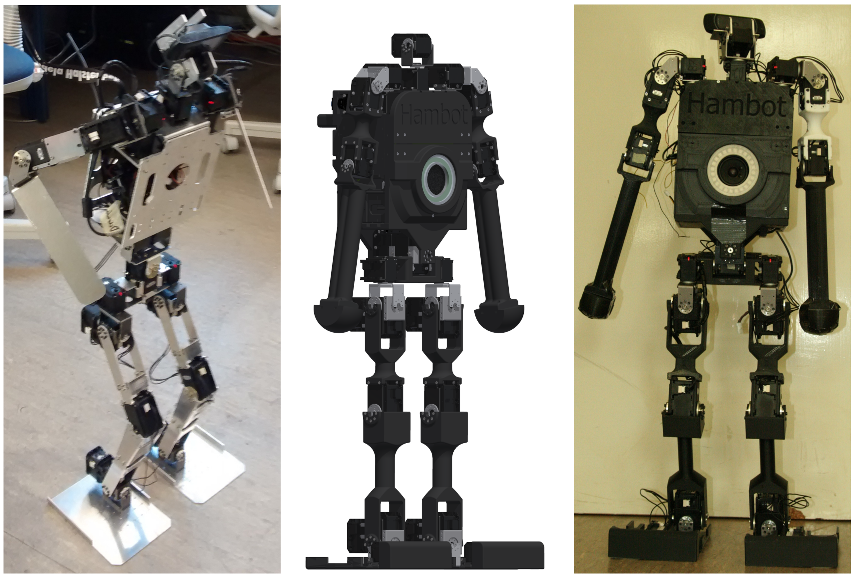

Fig. 1: Prototypes of GOAL (**left**) and Hambot (**right**). CAD model of Hambot (**center**).

production method considerably constrains the design of complex parts, which are required especially in the torso, where parts have to be connected in all three dimensions. This particularly affects the cable routing. Changing existing parts later is complicated due to these constrains and the high production time. Another problem which is already known from the Darwin-OP is loosening nuts and screws, resulting in instable part connections.

5 "Hambot"

The second prototype version is designed to be fabricated using 3D-printers. Almost all parts have been designed again from scratch and refined by several steps of evolution in a rapid prototyping and testing process. All required motors, except for five MX-64 and one MX-28, can be taken from a Darwin to minimize the costs of production.

5.1 Body Composition

Feet The capability to control the toes extends the feet by a second DOF, potentially improving both walking stability and standing up movements. This first design is simple but it can be exchanged to one which is more useful for high kick. The toes can be bend up to 90° (Fig. 5.1).

Legs The legs are designed in a pipe-like shape. This has different advantages to the U-profile composition, which is often used with sheet metals. Cables are routed directly through these pipes, preventing abrasion of the wires. Besides, it looks more human and is more comfortable to touch and hold (Fig. 5.1).

Waist An additional 2 DOF joint has been added at the waist, which allows the robot to move the upper body independently from the legs. The joint should be similar to the lumbar spine and the lower thoracic spine of humans, but only in two directions. This flexibility is necessary for human walking because the upper body moves and rotates during every step [6]. By doing so, human walking is very energy efficient [10]. With the roll axis of the new waist joint this movement is possible. The pitch axis allows a better control of the center of mass. With this joint we can move the upper body about 45° to left and right, 35° to the front and 12° to the back.

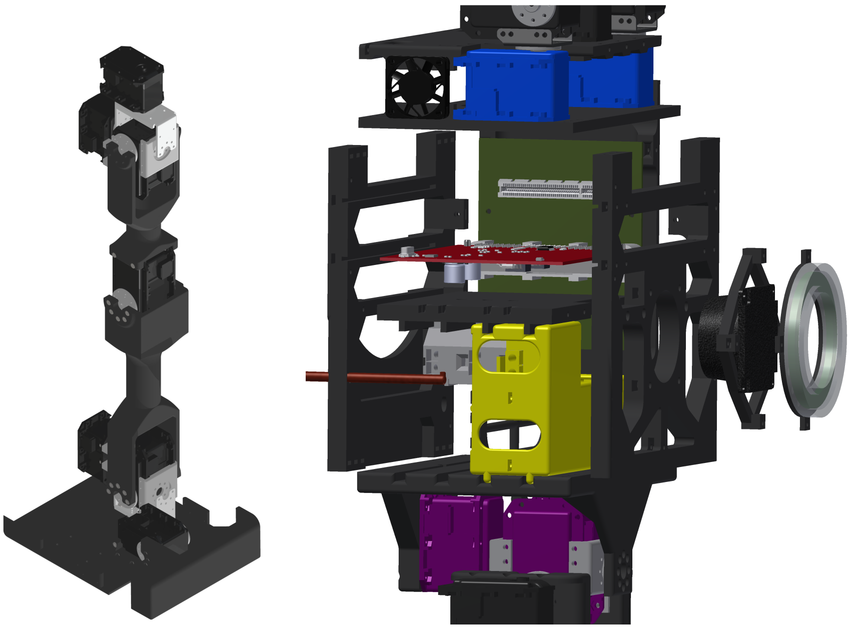

Fig. 2: CAD model of the leg (**left**) and explosion view of the torso (**right**). Note the additional shoulder servos (blue) and the new waist joint (purple). The two batteries (yellow, only one shown) are inserted from left and locked by a bolt (brown) which fits into a bayonet socket. The powerboard (red) and motor controller board (not shown) are directly plugged into the backbone board (green) and locked by a side plate (not shown).

Torso The torso consists of a cage-like structure with detachable side plates for easy access. 3D printing allows the production of complex parts that exactly fit into each other or are slidable to one side. The electronics consist of the main computer board (Odroid XU3 lite [4]), the powerboard and a subboard. The powerboard manages the power sources and the voltage conversions. The subboard controls the servos and other peripheral electronics, such as the LEDs and the audio output. These two boards are directly plugged into a backbone board, which is located at the side of the robot and replaces the cables, which would normally run through the torso. Therefore no cables are necessary inside the torso, which simplifies maintenance. All boards except the Odroid XU3 lite are open source and developed by ourself. The two batteries in the robot can be hot swapped. Each has an own printed case which can be slid into the robot and locked with a bolt, thus enabling a fast change. LEDs on the side are showing the current battery charge levels and which battery is currently used.

Shoulders The human shoulder is a joint with three DOF, whereas the shoulder of the Darwin-OP has only two DOF. For many tasks this is sufficient, but not for a good throw-in. An additional motor was added to the robots shoulder to enable a movement in yaw direction. This third DOF allows the robot to hold the ball behind his head like a human, while his elbows point to the sides.

5.2 Interaction

The Hambot has five free programmable buttons on the back, which are equipped with LEDs to indicate their state. There is a LCD touch display in the back for laptop free interaction (sec. 3). A ring of RGB LEDs is embedded into the front. Every LED can be individually controlled. This is handy to express the robots current beliefs, e.g. the position of the ball, from the border of the field. The audio output is used for debug. Therefore a dedicated text-to-speech chip and a speaker with a human resonance frequency is installed to ensure good speech quality.

5.3 3D Printing

All parts were designed to be smaller than 20x20x10 cm and therefore printable with a low cost fused deposition modeling (FDM) consumer printer. The two most used plastic print materials are acrylonitrile butadiene styrene(ABS) and polylactic acid (PLA) which can be printed by almost all consumer printers. While it is possible to build the robot with both materials, ABS is preferred due to its better strength and heat resistance [1]. The printing direction is important for the stability of prints. Therefore all parts are printed in a direction that maximizes the plane between two layers and improves the adhesion. Standard socket cap screws (ISO 4762 12.9) and nuts (ISO 4032) were used to connect the parts. Screwing directly into the plastic would be possible, but threads in plastic tend to wear of very fast. Multiple disassembles due to repairs would destroy the parts. Therefore steel nuts were used for tightening. They are inserted into prepared holes, which clamp them into their position. Thus all screws can be tightened without a wrench and the parts can be assembled multiple times. The estimated print time for a whole Hambot is two weeks with a standard FDM printer. Parallel printing can reduce this time.

5.4 Costs

The estimated hardware costs for the parts to build a whole Hambot are listed in table 1. By reusing the parts of the Darwin, it is possible to reduce them significantly, because only one additional MX-28 and five MX-64 servo motors are needed. Therefore the cost for upgrading a Darwin reduces to approximately 2,380 €. Expenses for maintaining the 3D-Printers are not included in this calculation.

Filament	100 €	100 €
Odroid XU3 lite	120 €	120 €
Logitech C910	60 €	60 €
Other electronics	550 €	550 €
Dynamixl servos	6000 €	1550 €
Metal parts from Darwin	200 €	0 €
Total	6730 €	2380 €

Table 1: Estimated hardware costs for one Hambot (**left**) and for an upgrade from a Darwin (**right**).

6 Conclusion and Further Work

This work introduces an open source humanoid robot, which enables teams to switch from Darwin-like robots with approximately 45 cm height over to a 87 cm robot platform. The costs are significantly lower than buying new robots that are currently available on the market. This becomes even more important, when the robot size and the number of players increase in the next years [2]. Due to its size, Hambot is currently allowed to play in the Kid- and Teen-size league. The increased interaction possibilities enable a faster development as well as a better handling during the game. First tests in real environment will be done at the IranOpen and GermanOpen in April 2015. This will show whether further improvements are necessary, especially concerning the strength of the 3D printed parts and the size of the motors. These results will be incorporated into version 1.1, which will be used by the Hamburg Bit-Bots in the world championship in July 2015. Next steps include the development of new hands which can grip and throw a ball, more human feet and a better camera system.

We encourage other teams to use the projects source code which is available at: **https://github.com/bit-bots**

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