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The igus Humanoid Open Platform

A Child-sized 3D Printed Open-Source Robot for Research

Philipp Allgeuer · Hafez Farazi · Grzegorz Ficht · Michael Schreiber · Sven Behnke

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Abstract The use of standard robotic platforms can accelerate research and lower the entry barrier for new research groups. There exist many affordable humanoid standard platforms in the lower size ranges of up to 60 cm, but larger humanoid robots quickly become less affordable and more difficult to operate, maintain and modify. The igus® Humanoid Open Platform is a new and affordable, fully open-source humanoid platform. At 92 cm in height, the robot is capable of interacting in an environment meant for humans, and is equipped with enough sensors, actuators and computing power to support researchers in many fields. The structure of the robot is entirely 3D printed, leading to a lightweight and visually appealing design. The main features of the platform are described in this article.

Keywords Humanoid Robot · Standard Platform · Open-Source

1 Introduction

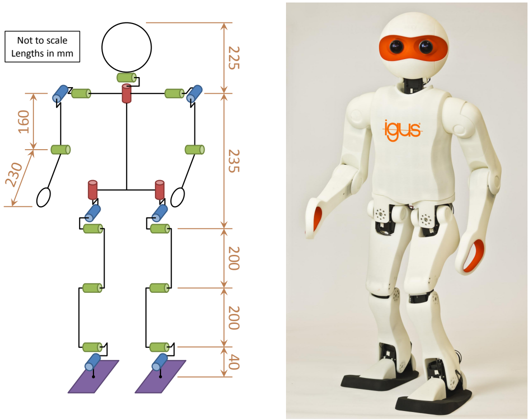

Fig. 1 The igus® Humanoid Open Platform.

The field of humanoid robotics is enjoying increasing popularity, with many research groups having developed platforms of all sizes and levels of complexity to investigate topics such as bipedal walking, environmental perception, object manipulation, and human-machine interaction. The initial effort to start humanoid robotics research on a real platform can be high though. Access to a standard robot platform can allow for greater focus on research, and facilitates greater collaboration and code exchange. The igus® Humanoid Open Platform, shown in Fig. 1, is a collaboration between researchers at the University of Bonn and igus® GmbH, a leading manufacturer of polymer bearings and energy chains. The igus® Humanoid Open Platform seeks to close the gap between small, albeit affordable, standard humanoid platforms, and larger significantly more expensive ones. We designed the platform to be as open, modular, maintainable and customisable as possible. The use of almost exclusively 3D printed plastic parts for the mechanical components of the robot is the result of this mindset, which also simplifies the manufacture

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All authors are at:
Rheinische Friedrich-Wilhelms-Universität Bonn
Friedrich-Ebert-Allee 144, 53113 Bonn
E-mail: pallgeuer@ais.uni-bonn.de

Table 1 igus® Humanoid Open Platform specifications

Type	Specification	Value
General	Height & Weight	92 cm, 6.6 kg
	Battery	4-cell LiPo (14.8 V, 3.8 Ah)
	Battery Life	15–30 min
	Material	Polyamide 12 (PA12)
PC	Product	Gigabyte Brix GB-BXi7-5500
	CPU	Intel i7-5500U, 2.4–3.0 GHz
	Memory	4 GB RAM, 120 GB SSD
	Network	Ethernet, Wi-Fi, Bluetooth
	Other	4 × USB 3.0, HDMI, MiniDP
CM730	Microcontroller	STM32F103RE (Cortex M3)
	Memory	512 KB Flash, 64 KB SRAM
	Other	3 × Buttons, 7 × LEDs
Actuators	Total	8 × MX-64, 12 × MX-106
	Head	2 × MX-64
	Each Arm	3 × MX-64
	Each Leg	6 × MX-106
Sensors	Encoders	4096 ticks/rev
	Gyroscope	3-axis (L3G4200D chip)
	Accelerometer	3-axis (LIS331DLH chip)
	Magnetometer	3-axis (HMC5883L chip)
	Camera	Logitech C905 (720p)
	Camera Lens	Wide-angle lens, 150° FOV

of the robots. This allows individual parts to be easily modified, reprinted and replaced to extend the capabilities of the robot. A demonstration video of the igus® Humanoid Open Platform is available.[1]

2 Related Work

A number of standard humanoid robot platforms have been developed over the last decade, many of which have seen much success. The most prominent example of this is the Nao robot [6], developed by Aldebaran Robotics. The Nao comes with a rich set of features, such as a variety of available gaits, a programming SDK, and human-machine interaction modules. The robot however has a limited scope of use as it is only 58 cm tall. Also, as a proprietary product, there is not much space for own hardware repair and enhancements. Another example is the DARwIn-OP [7], and its successor the ROBOTIS OP2, distributed by Robotis. Both robots are quite similar in design and architecture, and stand at 45.5 cm tall, half the size of the igus® Humanoid Open Platform. The DARwIn-OP has the benefit of being an open platform, but its size remains a limiting factor for its range of applications.

Other significantly less widely disseminated robots include the Intel Jimmy robot, the Poppy robot from the Inria Flowers Laboratory [10], and the Jinn-Bot from Jinn-Bot Robotics & Design GmbH in Switzerland. All of these robots are at least in part 3D printed, and the first two are open source. The Jimmy robot is intended for social interactions and comes with software based on the DARwIn-OP framework. The Poppy robot is intended for non-autonomous use, and features a multi-articulated bio-inspired morphology. Jinn-Bot is built from over 90 plastic parts and 24 actuators, making for a complicated build, and is controlled by a Java application running on a smartphone mounted in its head. Larger standard platforms, such as the Asimo [8], HRP [9] and Atlas robots, are an order of magnitude more expensive and more troublesome to operate and maintain. Such large robots are less robust because of their complex hardware structure, and require a gantry in normal use. These factors limit the possibility of using such robots by most research groups.

3 Hardware Design

The igus® Humanoid Open Platform was developed with the assistance of a design bureau, to create a good overall aesthetic appearance. The main criteria for the design were the simplicity of manufacture, assembly, maintenance and customisation. To satisfy these criteria, a modular design approach was used. Due to the 3D printed nature of the robot, parts can be modified and replaced with great freedom. A summary of the hardware specifications of the robot is shown in Table 1.

Mechanical Structure The white plastic robot exoskeleton is meant not only for outward appearance, but also acts as a load-bearing frame. This makes the igus® Humanoid Open Platform very light in comparison to its size. Despite its low weight, the robot is still very durable and resistant to deformation and bending. This is achieved through wall thickness modulation in the areas more susceptible to damage, as well as through strategic distribution of ribs and other strengthening components, which are printed as part of the exoskeleton. Due to the versatile nature of 3D printing, if a weak spot is identified through practical experience, as indeed happened during early testing, the parts can be locally strengthened in the CAD design, without significantly impacting the design.

Robot Electronics and Sensors The electronics of the platform are built around an Intel i7-5500U processor, running a full 64-bit Ubuntu OS, and all of the

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[1] Video: `https://www.youtube.com/watch?v=RC7ZNXclWWY`

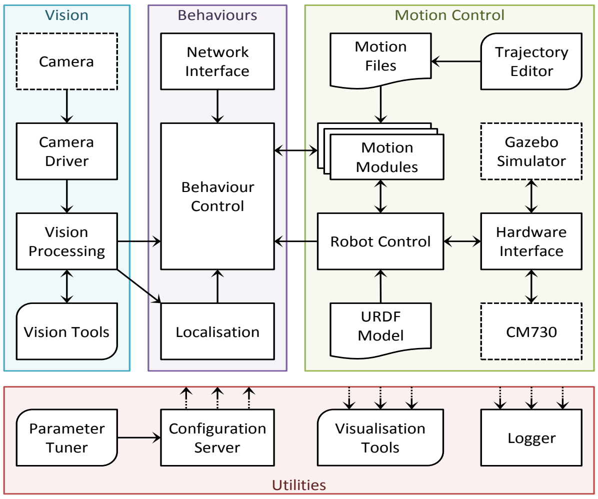

Fig. 2 Architecture of the ROS software.

robot control software. DC power is provided via a power board, where one or both DC power and a 4-cell Lithium Polymer (LiPo) battery can be connected, and the higher voltage of the two is used. The PC communicates with a Robotis CM730 subcontroller board, whose main purpose is to electrically interface the twelve MX-106 and eight MX-64 actuators, all connected on a single Dynamixel bus.

Due to a number of reliability and performance factors, we redesigned and rewrote the firmware of the CM730. This improved bus stability and error tolerance, and decreased the time required for the reading out of servo data, while still retaining compatibility with the standard Dynamixel protocol. The new firmware is compatible with both the CM730 and its successor CM740. The CM730 also connects to an interface board that has three buttons, five LEDs and two RGB LEDs, and internally incorporates a 3-axis gyroscope and accelerometer. An additional 3-axis magnetometer is connected via an I^2C interface on the onboard microcontroller which in total provides the user with a 9-axis IMU.

Further available external connections to the robot include USB, HDMI, Mini DisplayPort, Gigabit Ethernet, IEEE 802.11b/g/n Wi-Fi, and Bluetooth 4.0. The igus® Humanoid Open Platform is nominally equipped with a single 720p Logitech C905 camera behind its right eye, fitted with a wide-angle lens. A second camera can be optionally mounted behind the left eye for stereo vision.

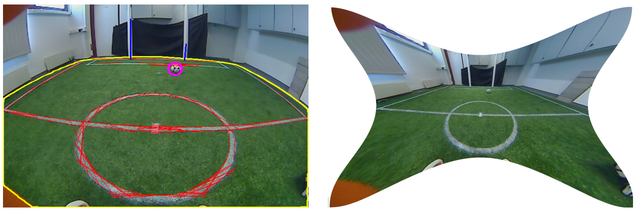

Fig. 3 Left: A captured image with ball (pink circle), field line (red lines), field boundary (yellow lines), and goal post (blue lines) detections annotated. Right: The raw captured image with undistortion applied.

4 Software

The ROS middleware was chosen as the basis of the software developed for the igus® Humanoid Open Platform. This fosters modularity, visibility, reusability, and to some degree also the platform independence. An overview of the software architecture is shown in Fig. 2. The software was developed with humanoid robot soccer in mind, but the platform can be used for virtually any other application. This is possible because of the strongly modular way in which the software was written, greatly supported by the natural modularity of ROS, and the use of plugin schemes.

Vision The nominally 640×480 images captured by the camera at 30 Hz are first converted into the HSV colour space. In our target application of soccer, the vision processing tasks include field, ball, goal, field line, centre circle and obstacle detection [5], as illustrated in Fig. 3. The wide-angle camera used in the platform introduces significant distortion, which must be compensated when projecting image coordinates into egocentric world coordinates. We undistort the image with a Newton-Raphson approach. This method is used to populate lookup tables that allow constant time distortion and undistortion at runtime. The effect of undistorting the image is shown in Fig. 3. We also compensate for remaining projection errors by calibrating the position and orientation of the camera frame using ground truth observations and the Nelder-Mead method. This calibration is essential for good performance of the projection operations.

State Estimation The 9-axis IMU on the CM730 is used to obtain the 3D orientation of the robot through the means of a nonlinear passive complementary filter [1]. This filter returns the estimated 3D orientation of the robot with the use of a novel way of representing orientations, namely the *fused angles* representation [2].

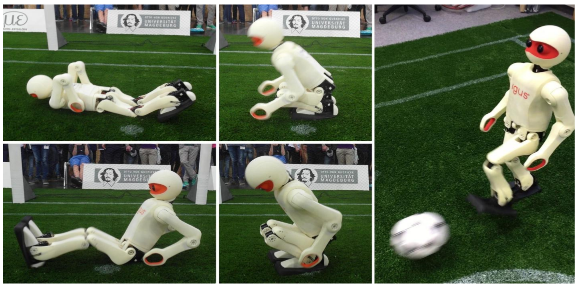

Fig. 4 Dynamic get-up motions of the igus® Humanoid Open Platform, from the prone (top row) and supine (bottom row) lying positions, and a still image of the dynamic kick motion.

Actuator Control The ability of the actuators to track their set position are influenced by many factors, including battery voltage, joint friction, inertia and load. To minimise the impact of these factors, we apply feed-forward control to the commanded positions [11]. This allows the joints to be operated in higher ranges of compliance, reduces servo overheating and wear, increases battery life, and reduces the problems posed by impacts and disturbances. The vector of desired feed-forward output torques is computed from the commanded joint positions, velocities and accelerations using the full-body inverse dynamics of the robot. The torques are then converted into joint target offsets that are added to the setpoints of the position-controlled actuators.

Motions Often there is a need for a robot to play a particular pre-designed motion. This is the task of the *motion player*, which implements a nonlinear keyframe interpolator that connects robot poses, smoothly interpolates joint positions and velocities, and modulates the joint efforts and support coefficients. A PID feedback scheme is implemented on top of this, where joints can be controlled in response to the estimated robot orientation. To create and edit the motions, a trajectory editor was developed for the igus® Humanoid Open Platform. All motions can be edited in a user-friendly environment with a 3D preview of the robot poses. We have designed numerous motions including kicking, waving, balancing, get-up, and other motions, some of which are shown in Fig. 4.

Gait Generation The gait is formulated in three pose spaces: Joint space, abstract space, and inverse space. The *joint space* specifies all of the joint angles, while the *inverse space* specifies the Cartesian coordinates and quaternion orientations of each of the limb end effectors relative to the trunk link frame. The *abstract space*, however is a representation that was specifically developed for humanoid robots in the context of walking and balancing [4]. The walking gait is based on an open loop central pattern generated core that is calculated from a gait phase angle that increments at a rate proportional to the desired gait frequency. A number of simultaneously operating basic feedback mechanisms have been built around the open loop gait core to stabilise the walking, illustrated in Fig. 5. The feedback in each of these mechanisms derives from the fused pitch and fused roll state estimates, and adds corrective action components to the central pattern generated waveforms in both the abstract and inverse spaces [2].

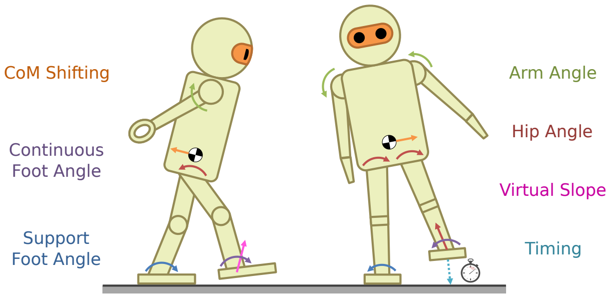

Fig. 5 Example fused angle feedback corrective actions, including arm, hip, foot and foot height components, in both the sagittal (left) and lateral (right) planes. Step timing is also considered based on the lateral motion.

5 Reception

To date, we have built five copies of the igus® Humanoid Open Platform in our lab, with the parts for a further two already printed, and have delivered a complete set of printed parts to the University of Newcastle's NUbots RoboCup team. We have demonstrated the robots at the RoboCup and various industrial trade fairs, including for example the Hannover Messe in Germany and the International Robot Exhibition in Tokyo, where the robots had the opportunity to show their interactive side. Demonstrations ranged from expressive and engaging looking, waving and idling motions, to visitor face tracking and hand shaking. The robots have been observed to spark interest and produce emotional responses in the audience.

Despite the recent design and creation of the platform, work groups have already taken inspiration from it, or even directly used the open-source hardware or software. A good example of this is the Humanoids Engineering & Intelligent Robotics team at Marquette

Fig. 6 Team NimbRo at RoboCup 2016 in Leipzig.

University with their MU-L8 robot. A japanese robotics business owner, Tomio Sugiura, has also started printing parts of the igus® Humanoid Open Platform on an FDM-type 3D printer with great success. Naturally, the platform also inspired other humanoid soccer teams, like WF Wolves and Baset, to improve upon their own robots in certain respects. The NimbRo-OP, which was a prototype for the igus® Humanoid Open Platform, has also been successfully used in human-robot interaction research at the University of Hamburg [3].

In 2015, the igus® Humanoid Open Platform participated for the first time at RoboCup, and was awarded the first RoboCup Design Award, based on criteria such as performance, simplicity and ease of use. At RoboCup 2016, the platform was an integral part of the winning team NimbRo TeenSize (see Fig. 6), with a combined score of 29:0 over five games. The platform was also awarded the first International HARTING Open Source Prize.

6 Conclusions

The igus® Humanoid Open Platform represents a significant advancement over its predecessor, towards a robust, affordable, versatile and customisable open standard platform. It provides users with a rich set of features, while still maintaining modularity and flexiblity in the design. The main hardware and software components of the robot have been described in this article, and remain a continuous development effort. We have released the hardware in the form of print-ready 3D CAD files[2], and uploaded the software to GitHub[3]. We hope that it will benefit other research groups around the world, and encourage them to publish their results as a contribution to the open-source community.

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References

1. Allgeuer, P., Behnke, S.: Robust sensor fusion for biped robot attitude estimation. In: Proceedings of 14th Int. Conf. on Humanoid Robotics (Humanoids). Spain (2014)
2. Allgeuer, P., Behnke, S.: Fused Angles: A representation of body orientation for balance. In: Int. Conf. on Intelligent Robots and Systems (IROS). Germany (2015)
3. Barros, P., Parisi, G.I., Jirak, D., Wermter, S.: Real-time gesture recognition using a humanoid robot with a deep neural architecture. In: Proceedings of 14th Int. Conf. on Humanoid Robotics (Humanoids) (2014)
4. Behnke, S.: Online trajectory generation for omnidirectional biped walking. In: Proceedings of Int. Conf. on Robotics and Automation. Orlando, USA (2006)
5. Farazi, H., Allgeuer, P., Behnke, S.: A monocular vision system for playing soccer in low color information environments. In: Proceedings of 10th Workshop on Humanoid Soccer Robots, IEEE-RAS Int. Conference on Humanoid Robots. Seoul, Korea (2015)
6. Gouaillier, D., Hugel, V., Blazevic, P., Kilner, C., Monceaux, J., Lafourcade, P., Marnier, B., Serre, J., Maisonnier, B.: Mechatronic design of NAO humanoid. In: Int. Conf. on Robotics and Automation (2009)
7. Ha, I., Tamura, Y., Asama, H., Han, J., Hong, D.: Development of open humanoid platform DARwIn-OP. In: SICE Annual Conf. (2011)
8. Hirai, K., Hirose, M., Haikawa, Y., Takenaka, T.: The development of Honda humanoid robot. In: Int. Conf. on Rob. and Autom. (1998)
9. Kaneko, K., Kanehiro, F., Morisawa, M., Miura, K., Nakaoka, S., Kajita, S.: Cybernetic human HRP-4C. In: Proceedings of 9th IEEE-RAS Int. Conf. on Humanoid Robotics (Humanoids), pp. 7–14 (2009)
10. Lapeyre, M., Rouanet, P., Grizou, J., Nguyen, S., Depraetre, F., Le Falher, A., Oudeyer, P.Y.: Poppy Project: Open-Source Fabrication of 3D Printed Humanoid Robot for Science, Education and Art. In: Dig. Intell. (2014)
11. Schwarz, M., Behnke, S.: Compliant robot behavior using servo actuator models identified by iterative learning control. In: Robot Soccer World Cup. Springer (2013)

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[2] `https://github.com/igusGmbH/HumanoidOpenPlatform`

[3] `https://github.com/AIS-Bonn/humanoid_op_ros`