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# SHORT PAPER

## Development of open platform humanoid robot DARwIn-OP

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To develop an appropriate research platform, this paper presents the design method for a humanoid which has a network-based modular structure and a standard PC architecture. Based on the proposed method, we developed DARwIn-OP which meets the requirements for an open humanoid platform. DARwIn-OP has an expandable system structure, high performance, simple maintenance, familiar development environment and affordable prices. Not only hardware but also software aspects of open humanoid platform are discussed in this paper.

**Keywords:** open platform; humanoid; DARwIn-OP

### 1. Introduction

A humanoid robot is a robot that has a general structure of the human body, such as two legs, two arms, a torso, and a head. Although, some shapes of a humanoid robot may not be exactly the same as that of a human, a humanoid robot has a basic similar appearance and functions of a human. For its human-like features described above, a humanoid robot has a potential to conduct tasks in human environments. Furthermore, a humanoid robot may even use tools designed for a human without modification. The development purpose of a humanoid robot is to make a robot that thinks and acts like a human. At the end, the humanoid robot will do work on behalf of a human, and a human can concentrate on more productive activities. The other significant development purpose is to understand mental and physical fundamentals of a human. So, many researchers from different fields adopt humanoid robots for their research platform for its synthetic characteristics.

Recently, many kinds of full-size humanoid robots have been developed extensively during the past several decades. The first complete humanoid robot was the WABOT-1 which was created by Kato from Waseda University, Japan in 1973 [1]. The WABOT-1 had a walking control, a manipulating control, a vision and a conversation system. After that, in 1984, Sugano et al. developed the WABOT-2 known as the first personal robot and showed the performance of playing piano [2]. Inspired by these academic research activities on humanoid robots, companies and research institutes also undertook the development of humanoid robots. From 1993 to 1997, Honda created the humanoid robot P1–P3, an evolution from E series [3]. Then, they opened the first version of ASIMO which walked stably at 1.6 km/h to the public in 2000 [4]. A new ASIMO was introduced in 2005 and it could run and walk up and down stairs. Supported by the Ministry of Economics, Commerce and Industry, Japan, the HRP-2 was developed by National Institute of Advanced Industrial Science and Technology and Kawada Industries, Inc. from 1998 to 2002 [5]. The HRP-2 was the first humanoid robot which a research institute and a company were involved in. They also developed the HRP-3 in 2007 [6] and the HRP-4 [7] and the HRP-4C in 2009. Different from previous humanoid robots, the HRP-4C is a female humanoid robot which has realistic head, and a figure based on averages from the Japanese body dimension database.

On the other hand, small-size humanoid robots also have been developed. Although small-size humanoid robots are hard to be applied to a work for a human because of their limited size and performance, they can be appropriate research platforms for their manageability and affordability. Not only for research platforms but also for the entertainment, small-size humanoid robots have competitive features. Boosted by these merits, Sony introduced the biped entertainment robot SDR-3X [8] in 2000, and through the consisting development of SDR series, they showed the SDR-4X II [9] named as QRIO in 2003. The QRIO had a voice and a face recognition system, could run 23 cm/s and was known as the first running biped robot. Meanwhile, for the research platform, Fujitsu released the HOAP series, the HOAP-1 in 2001, the HOAP-2 in 2003, and the HOAP-3 in 2005 [10]. By adopting a standard personal computer as the

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Figure 1. Open platform humanoid robot DARwIn-OP.

main controller, the HOAP-3 showed the promise for the general research platform.

Based on these humanoids, various challenging robotics researches on motion planning, walking, manipulating, communication, vision processing, and artificial intelligence have been carried out and remarkable results also have been shown. From the overall point of view, it is no exaggeration to say that a humanoid is the most adequate platform for robotics research.

Although marvelous humanoid robots already exist, many researchers are still making their efforts and spending time to build new platforms. Of course, for some researchers, it can be an essential work to build a robot in itself because their design scheme is one of the most important research areas. But, for the others, it can be a burden to make a new robot, and furthermore, it also can be a major disincentive for research. Even those researchers who do not need to make a robot platform have no choice but to develop a robot because most humanoid robots in the current market do not satisfy requirements for research platform. For an appropriate research platform, a humanoid robot must be constructed considering expandable, modifiable system structure, high performance, simple maintenance, familiar development environment, and affordable prices.

Therefore, in this paper, we suggest the design method for humanoid platform which has a network-based modular structure and a standard PC architecture to meet above mentioned requirements, and develop the-small-size humanoid robot named as DARwIn-OP shown in Figure 1. A preliminary version of this article was delivered at the SICE Annual Conference in Tokyo, 2011.

## 2. System overview

DARwIn-OP has a network-based modular structure and a standard PC architecture, as shown in Figure 2. All devices, such as actuators, sensors, LEDs, buttons, and external I/Os, are connected to the sub-controller by a serial bus network which fully supports DYNAMIXEL protocol [11]. Each device has a memory-mapped operation structure with designated ID.

For the main controller, we adopted the Intel's ATOM Z530 CPU, normally used for netbooks. The main controller communicates with the sub-controller by USB. The sub-controller works as a gateway to access devices, as shown in Figure 3. Therefore, all devices are encapsulated as an USB device, which means that the development environment is just like a standard PC.

## 3. Hardware structure

### 3.1. Mechanics

Figure 4 illustrates overall mechanical design scheme of DARwIn-OP. A basic configuration of DARwIn-OP has

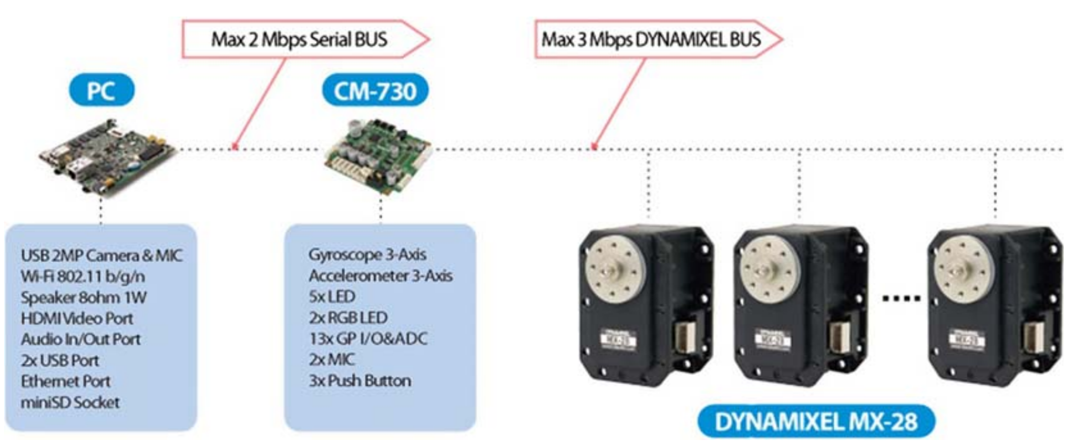


Figure 2. Modularized component of DARwIn-OP based on PC architecture.

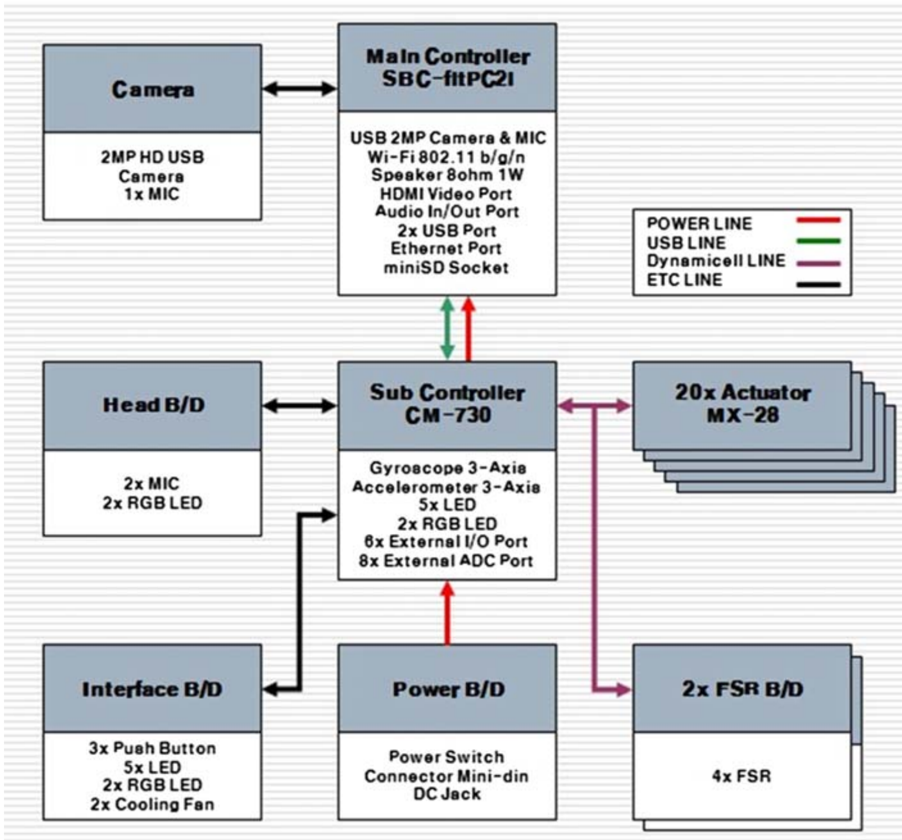


Figure 3. System block diagram.

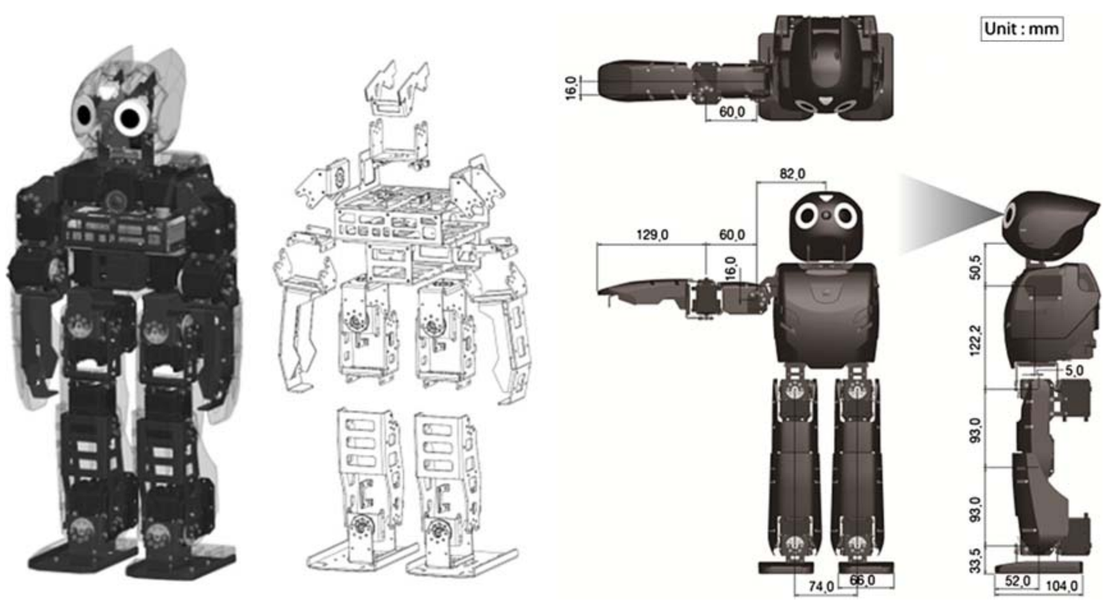


Figure 4. Mechanical design of DARwIn-OP.

20° of freedom. The center of mass is located at the center of its pelvis. Its location is optimal for proper balancing and proper distribution of inertia during gait, especially at the extremities. The modular network-based

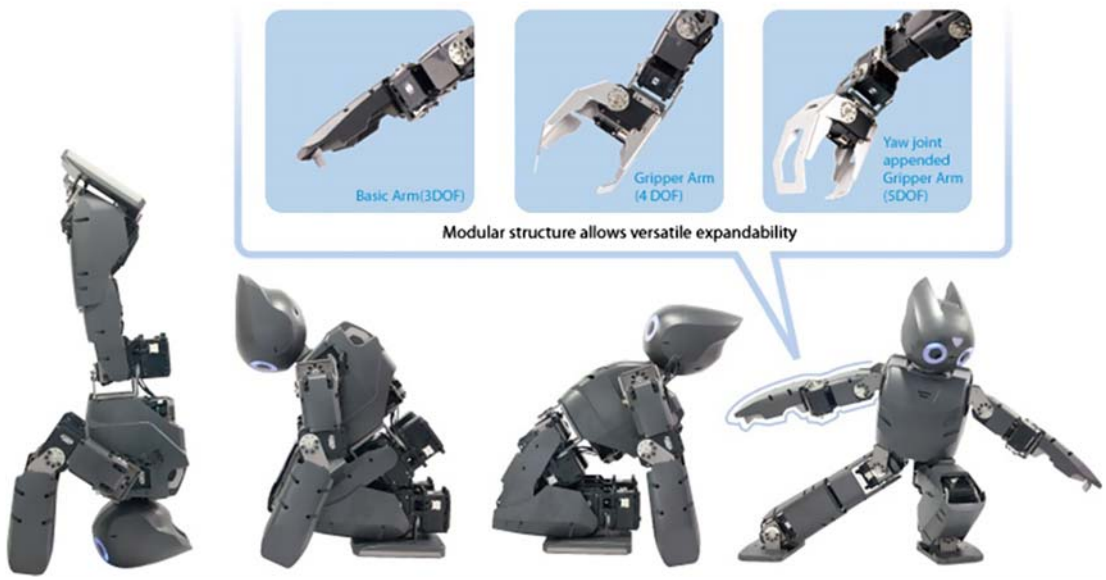


Figure 5. Different types of grippers for DARwIn-OP.

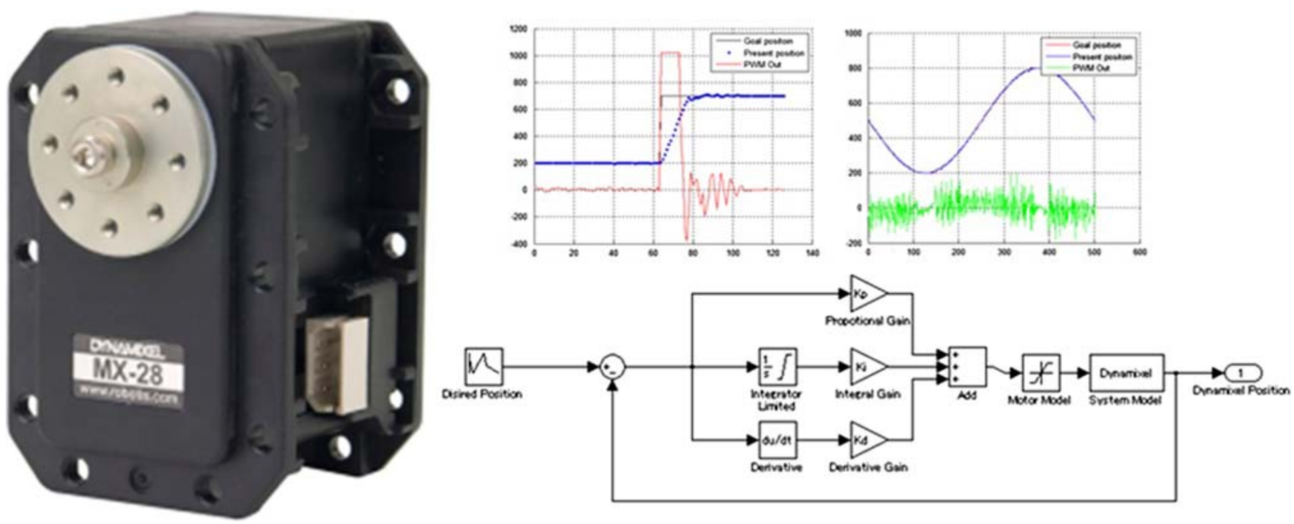


Figure 6. Developed MX-28 actuator for DARwIn-OP.



nature of the robot can help the researcher modify any extremities by isolating the desired limb from the rest of the body with virtually no overall performance compromise of DARwIn-OP.

The frames for DARwIn-OP were designed for robot sturdiness and durability. Hollowness of the frames allows the robot to maintain a fairly low overall weight. The hollow frames were also designed with the assumption that the user will include additional sensors to the robot. The frames were designed to accommodate such additional sensors and their respective wiring. The hollow design maintains the scope of a network-based modular structure and facilitates periodic robot maintenance.

Various optional frames for connecting actuators and other devices were also designed. Such frames are for optional gripper types for DARwIn-OP, as shown in Figure 5.

### 3.2. *Actuators*

We designed a new improved MX-28 actuator for DARwIn-OP, as shown in Figure 6, which has a higher resolution, faster communication speed, and a more sophisticated controller compared to the previous RX-28 [12]. The previous RX-28 featured a conventional potentiometer for position control. Over time, the contact required to give proper position measurement eventually wears the potentiometer out. The MX-28 implements an absolute contactless magnetic potentiometer; its contactless aspect of the encoder virtually eliminates any limited

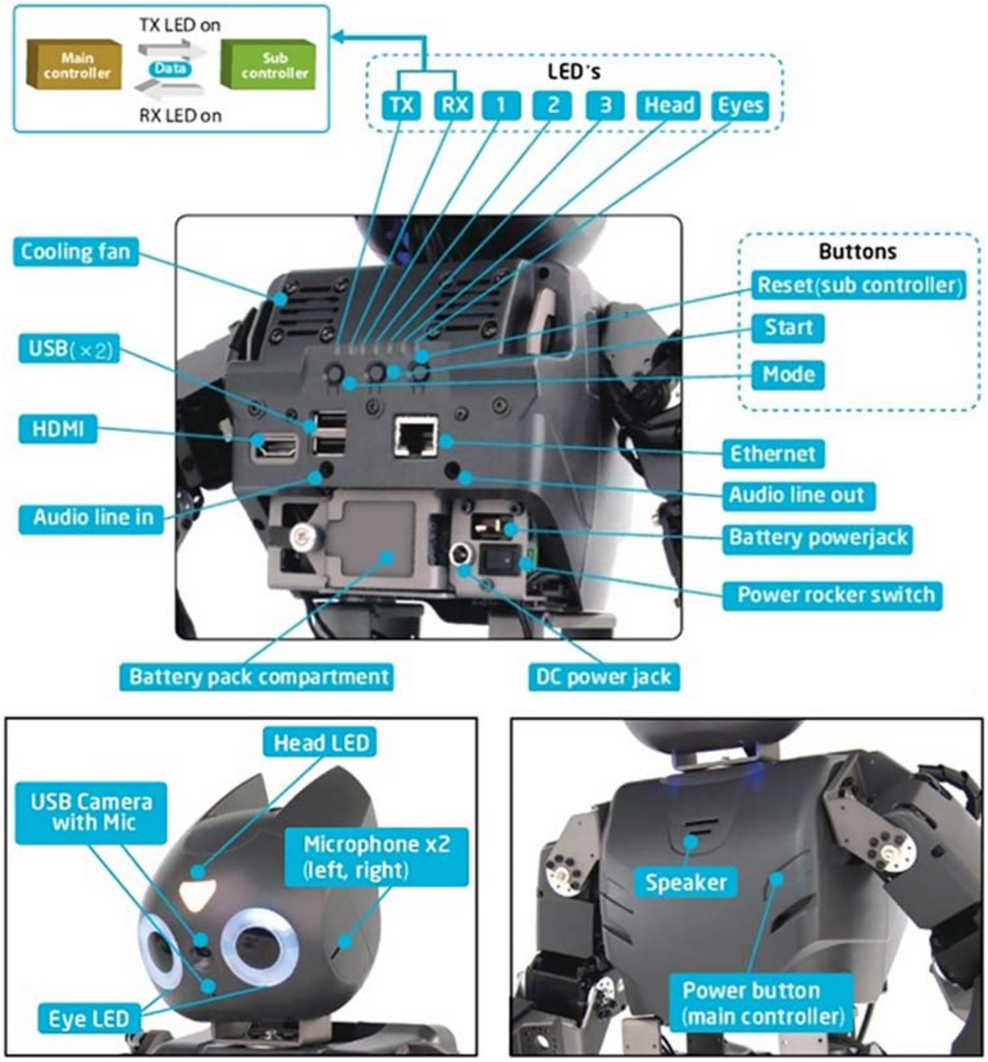


Figure 7. Device information of DARwIn-OP.

operation angle of the actuator. Another feature of the MX-28, not featured on the previous RX-28, is the increased 12-bit resolution for more precise position control all over 360° without any gaps or stops.

The MX-28 supports PID controller for position and speed control. The user can adjust not only position and speed profile but as well as PID gain parameter in real time. One of the purposes of the accessibility of PID controls of the MX-28 is to minimize or control actuator harmonic resonance-related aspects. As a result, from a holistic standpoint, PID controls provide DARwIn-OP with the highest performance for a humanoid of its type.

### *3.3. Sensors*

DARwIn-OP has pluralities of sensors, as illustrated in Figure 7, which maintains the scope of a network-based modular structure. Basic sensors are a three-axis gyroscope and a three-axis accelerometer for posture estimation and balancing are mounted in the upper body. A USB-based camera and a total of three microphones are located in the head. Optional sensors are Force Sensing Registers (FSR) modules, in which four FSR's are placed in each foot, for ground reaction force measurements. Additional sensors also can be attached via external I/O at the user's discretion.

DARwIn-OP makes full use of the provided three-axis accelerometer and gyroscope for balancing and posture estimation without compromising walking performance. In conjunction of proper implementation of closed-loop feedback control based on 'immediate performance history,' DARwIn-OP may be able to increase performance, such as faster walking or quicker recovery time after falling.

There is an USB-based camera for image processing placed inside the head. Unlike many other humanoids, the basic configuration of DARwIn-OP only requires a single camera. The camera is a high-definition camera

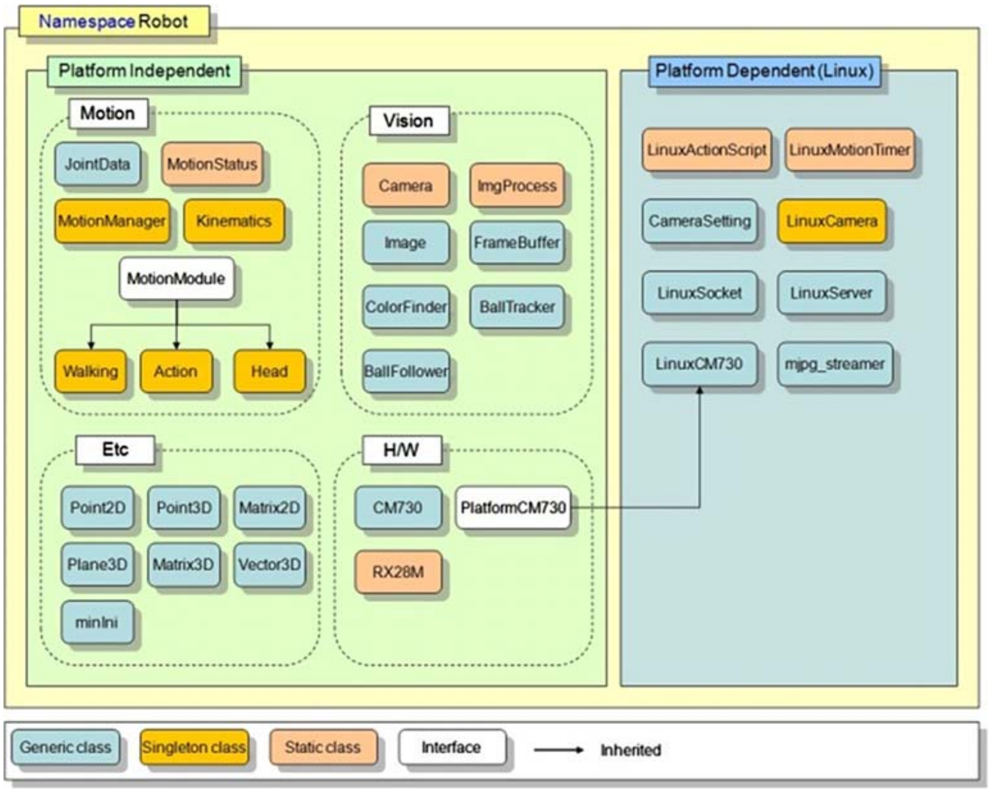


Figure 8. Software framework class diagram for DARwIn-OP.

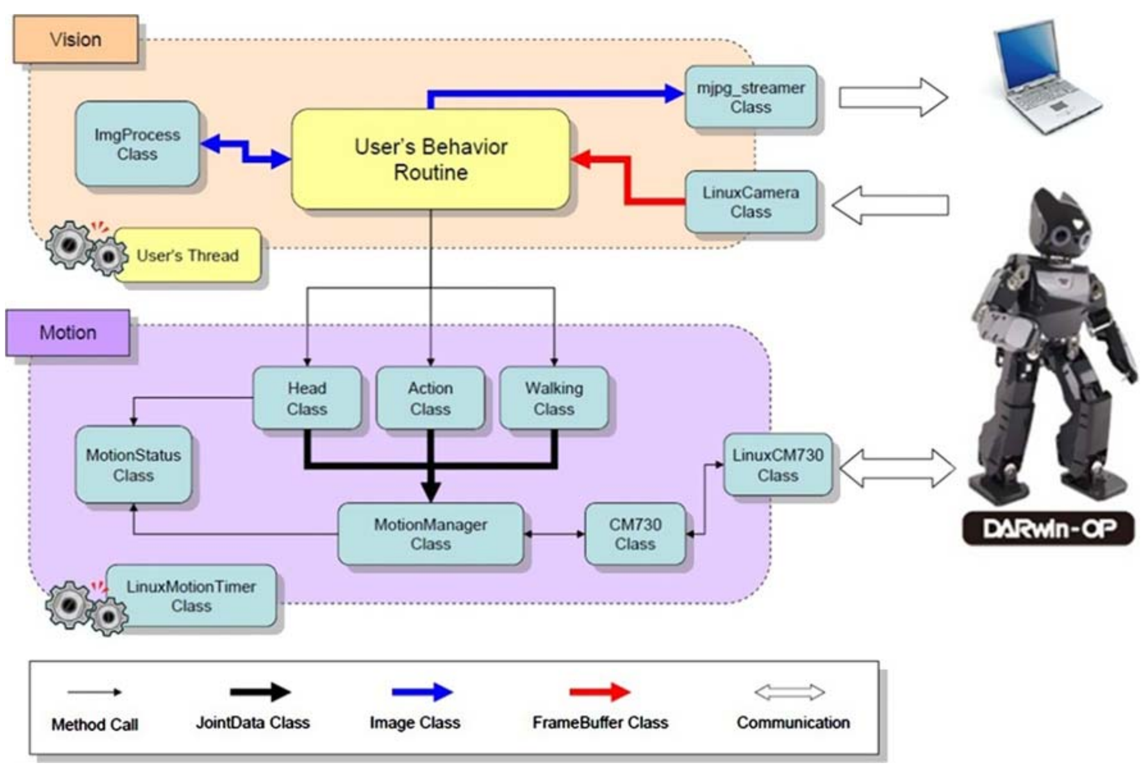


Figure 9. Software framework pipeline for DARwIn-OP.


Figure 10. Application software for DARwIn-OP.

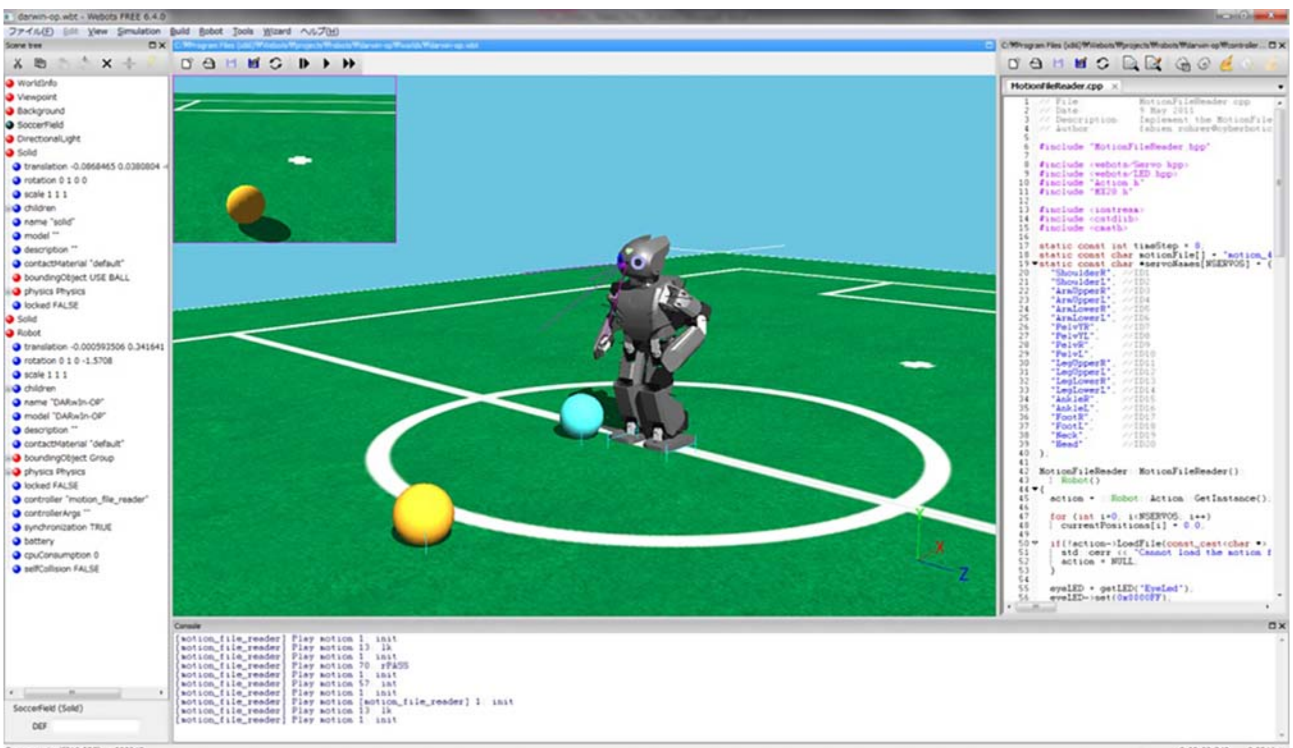

Figure 11. Dynamics simulation environment for DARwIn-OP.

that interfaces with the robot via the USB standard. The high-definition aspect of the camera provides much detailed information. Another result of implementing a high-definition camera is that a single camera device can help maintain a fairly robot simple configuration, therefore, eliminating the need for a dedicated camera actuator. The flexibility of the USB standard allows implementation of any desired type of camera or multiple cameras for 'stereo' vision. Last but not least, the USB-based camera eliminates the need of a dedicated camera power source, therefore, keeping the scope of the architecture simple.

The microphone allows DARwIn-OP to receive voice commands. A simple API can be installed in DARwIn-OP for voice recognition followed by any programmed sequential behavior from the voice command. Two additional microphones are also placed inside the head as well for the purposes of sound localization. Audio signals given by each microphone may be differentiated from each other by simple differential margin; where the

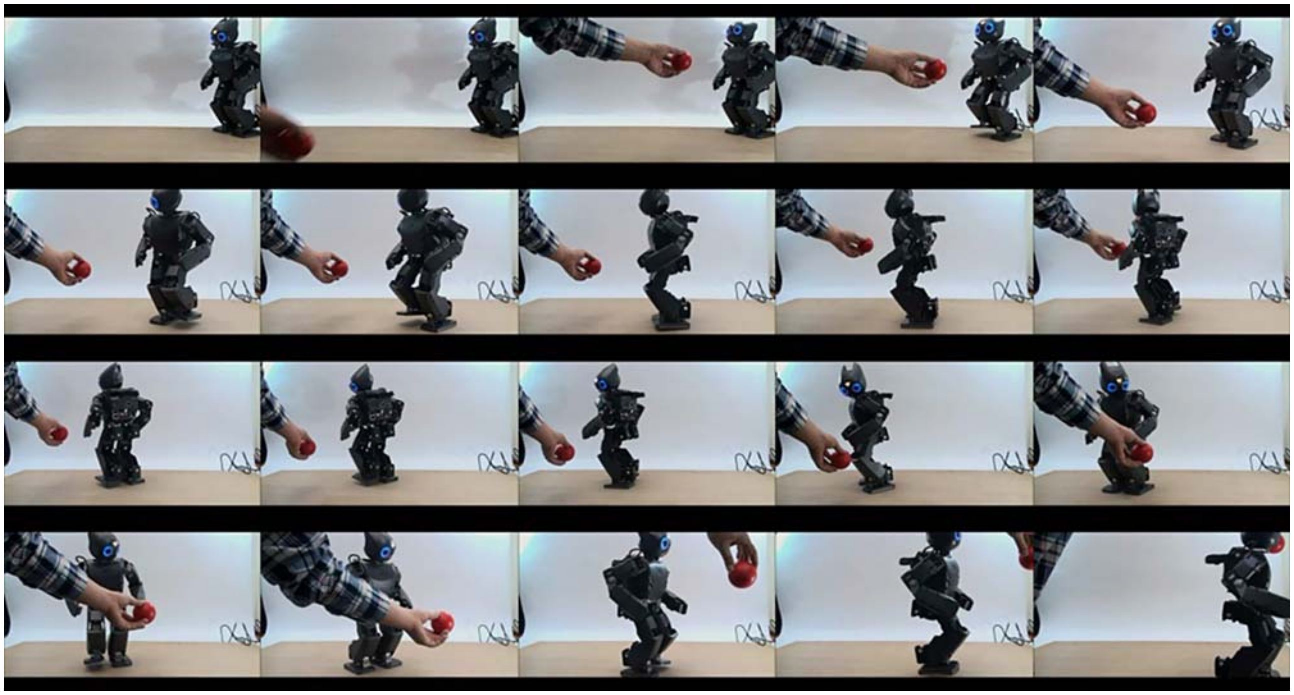

Figure 12. Movie captures of walking test of DARwIn-OP.

Table 1. Overall specification of developed DARwIn-OP.

| Category | Description | Data |
|---|---|---|
| Dimension | Height | 0.455 m |
| | Weight | 2.8 kg |
| DOF | Head | 2 DOF |
| | Arm | 2 × 3 DOF |
| | Leg | 2 × 6 DOF |
| Main controller | CPU | Intel atom Z530 @ 1.6 GHz |
| | RAM | DDR2 1 GB |
| | Disk | Flash disk 4 GB |
| | Network | Ethernet/WiFi |
| | USB port | 2 × USB2.0 |
| Sub controller | CPU | ARM 32-bit cortex-M3 |
| | Frequency | 72 MHz |
| | Flash memory | 512 KB |
| | SRAM | 64 KB |
| Actuator RX-28 M | Holding torque | 24 kgf·cm @ 12 V |
| | Speed | 45 RPM @ No Load |
| | Position sensor | Magnetic potentiometer |
| | Resolution | 0.072° |
| | Command Interface | Serial 3 MBPS |
| Sensor | Gyroscope | 3-axis |
| | Accelerometer | 3-axis |
| | Pressure-meter | 2 × 4 FSR |

robot can accurately localize the sound source by said differential margin. The additional microphones, in conjunction with the voice recognition microphone, can also be tools for improving sound localization for a more accurate source detection.

Additional FSR are implemented on each foot for more accurate ground reaction force. These sensors interface with DARwIn-OP with the same communication and power line shared by the actuators, while maintaining the daisy chain configuration. This common line eliminates the need to add a dedicated line for the FSR's helping keep architecture simple. Placing four sensors per foot allows for more precise information the specific amount of force in a specific area of the foot at a specific pose of DARwIn-OP during its walk. A closed-loop feedback control augmented with data from the FSR can allow the researcher to refine DARwIn-OP's gait. Such data can also be implemented to improve gait during unexpected changes on walking surface.

### 3.4. *Display and Interfaces*

DARwIn-OP comes equipped with full-color range RGB LED's in the eyes and forehead. The researcher can program specific colors of each LED. The colors can help or alert the researcher visually in real time with the status of DARwIn-OP. There are also status LEDs and buttons in the back panel.

For purposes of direct development environment, DARwIn-OP is also equipped with external ports such as HDMI, USB, flash memory port, and Ethernet port. These external ports facilitate interfacing, communications, data storage, and software implementation with the robot due to the standardized nature of said external ports in their PC implementation. The external ports from the standard PC also maintain scope of the open architecture nature of DARwIn-OP.

## 4. Software architecture

### *4.1. Software framework*

The software aspect of DARwIn-OP has been built with a hierarchical framework considering modularity and independency. The framework consists of device communication module, motion module, walking module, sensing module, behavior module, vision module, and diagnostics module, as shown in Figures 8 and 9. The framework has been developed with C++ programming language where the code is operating system independent. The operating system independent aspect of the framework is essential so that the code can be ported to any existing or future computer operating system.

The user may simply write a behavioral code for DARwIn-OP without the need to develop a separate framework set. In such case, software simulator is the most practical method of writing the program and testing said program for DArwIn-OP, given that such simulator makes use of the provided framework. Due to the open-source nature of DARwIn-OP, the user is encouraged to share the developed program with other users. However, users may not be limited to open-DARwIn-SDK.

There is currently another independently developed software that does not implement open-DARwIn-SDK. There are some examples where software has been developed at 'levels.' For instance, low-level programming can take care of the robot's sub-routines, such as camera refresh times or read the actuator's position. The high-level programming can take care of the more abstract aspects of the robots. The different levels are practical so that recompiling of the entire code is unnecessary on simple changes in subroutine behaviors or parameters.

### *4.2. Application tools*

We also designed application tools such as action editor, firmware updater, device monitor, walking tuner, and offset tuner based on software framework above, as shown in Figure 10. We also prepared dynamics simulation environment by Webots [13] which is well known as a development environment for modeling, programming, and dynamics simulating, as shown in Figure 11. Physical properties of DARwIn-OP are used in Webots for model data. We also ported software framework for the simulation.

We also built demonstration program with framework open-DARwIn-SDK for evaluating the performance of DARwIn-OP. Simple walking algorithm based on gait pattern generator and walk stabilizer are implemented on the robot, as shown in Figure 12.

## 5. Conclusion

In this paper, we suggested the design method for humanoid which has a network-based modular structure and a standard PC architecture to meet the requirements for an open humanoid platform. We surveyed the requirements for the humanoid robot research platform and defined considerable matters for the development of the robot. Also, we explained the software aspect of the DARwIn-OP and proposed the hierarchical framework which has modularity and independency for the humanoid robot research platform. DARwIn-OP's key features are illustrated in Table 1.

All resources of DARwIn-OP including source codes, circuit diagrams, mechanical CAD files, and parts information are open to the public. We hope that DARwIn-OP will contribute to robotics research.

## Notes on contributors

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