A Scalable Software Toolkit for Miniature Humanoids

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Abstract

Considering the cost and complexity, humanoid robots are typically isolated to academic or commercial environments. Rarely, these types of robot merge together on a common thread to be scaled to other real world applications. Very few of the most well-known humanoids become hands-on teaching tools for less expensive education approach to mechanical, electrical, and computer engineering. Many educational humanoid kits are available today to meet this demand, yet they lack creativity of design and manufacturing is treated as a product to produce mass qualities for cheap distribution.

This paper introduces a miniature, open- source, and low cost Humanoid robot: Mini-HUBO. To also allow for open nature of programming and the opportunity for sensor expansion, Mini-HUBO was coupled with a robust commercial visual programming language, LabVIEW. This humanoid later provided the motivation for the software developer, National Instruments, to set in motion the development of a new servo actuator API for the promotion of joint based robots within LabVIEW Robotics software.

1. Introduction

Robots have taken many roles in the human environment, undertaking jobs with clearly defined duties. Industrial robots, such as those used in automobile production, can reproduce complex motions accurately and precisely. The specialization that makes this possible, however, limits their versatility. Therefore a shared functional overlap between industrial robots and consumer robots remain small.

A natural choice for robot morphology would to mimic human motion and occupy human environment. The field of humanoid robotics heeds similar human mechanical design to allow the use of tools and interfaces designed for humans. The interaction of robot and human is approached as familiar and natural due to similarities emotion and appearance [1]. The example of an automotive robotic handler if transplanted to a human friendly environment will be clumsy in tight places and may not be aesthetically suitable in an office environment. Therefore there is a need for a robot that looks human, and can make natural human-like gestures. Today there is a divergence of technologies focused on creating a robot that can perform a wide range of functions that can adapt into humans' daily lives [2].

Humanoids mechanically are bipedal robots that are engineered to mimic human locomotion [3].These robots use actuators at key locations on the chassis to represent the human's range of motion. The mechanical and control system design for these robots are very challenging to create, due to their complexity. Modern humanoids have 22-42 DOF [2], which need to be coordinated in real-time to maintain stability. While feats such as navigation and human interaction are challenging for any robot, even basic position control of the limbs is significant hurdle.

Many methods are used to generate the robots motions. Inverse Kinematics (IK) is used to generate the legs trajectories or full body motions. Many large robots generate this in real time mixed with path planning to allow for adaptive gate control. Yet many smaller humanoids cannot close the loop, but rely solely on the stability of the mechanical design. Significant time can be consumed in simply designing the body; any changes to the arrangement or number of motors require scrutiny and testing to ensure stability.

Today many robots share the public spotlight like the ASIMO or HUBO humanoids. These robots both have in common that they are life-sized and mechanically complex. These research groups present these robots at public venues and produce many works to preserve and push the field to new heights. Also these groups do interact with education, but more on the visual representation of what can be done and theory. The robotic platform such as the Hitec Robonova-1 and the Robotis Bioloid humanoids (Figure 1) pursue the techniques of getting miniature humanoids into the hands of students.

Figure 1. The Robonova-1 / Robotis Bioloid are inexpensive “prosumer” level robots, powered by microcontrollers.

These robots are teaching tools but do not encompass the full process of producing a humanoid from mechanical design through expanding of programming. These frames also limit the use of processing units due to being designed for proprietary controllers. Each platform has tackled the problem of interaction by creating custom coding environments and interfaces that are only applicable to their product. Therefore, this paper will focus on the presentation of an open-source, low-cost miniature humanoid robot and development tools.

- The robot is a representation of a prominent Humanoid, HUBO, for public identification.
- Total fabrication of structural components to utilized teaching mechanics and manufacturing.
- It is anatomically designed to be a suitable representation of HUBO, to be used as a research platform or a stepping stone to learn the operation of the full scale HUBO.
- The processing architecture is not limited to one controller.

The one of the supported example platforms is an onboard PC with LabVIEW commercial visual programming language. It creates a more transparent programming environment with a strong API backed by the National Instruments LabVIEW Robotics. National Instruments released the Robotics module in January 2010 this module allows for high level abstraction of sensor communication, path planning, kinematics, and mobility.

2. PIRE: Humanoids – Universally Accessible Infrastructure to Advanced Capabilities

The National Science Foundation (NSF) Partnership for International Research and Education (PIRE) was developed to catalyze international engagement in US Science and engineering collaborations [3]. A grant was awarded to pursue expanding the capabilities of humanoids by targeting Asia’s strength in mechatronics and merging it with US strength in sensor integration.

South Korea’s Korean Advanced Institute of Science and Technology (KAIST) supplied Drexel University with an adult sized humanoid robot, KHR-4 HUBO2. This humanoid is 1.2 meters tall and is 45 kilograms. It has 41 degrees of freedom and capable of running at 3.6km per hour. The full sized HUBO is shown in Figure 2.

Five collaborating Universities on the east coast will create tools to make this cutting edge robot available on many venues. These tools span the design process, from simulation, to prototyping with Mini-HUBO, to final implementation on HUBO itself. This combination allows the researcher to develop and debug in an accurate simulation with no initial cost.

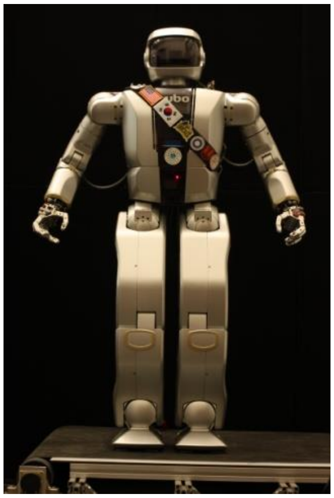


Figure 2. Jaemi HUBO Humanoid Robot at Drexel University

3. Mini-HUBO Humanoid Robot

3.1 Mini-HUBO Overview

Miniature humanoids are becoming more popular due to their low risk factor. Smaller robots can easily fall without damage and use low-cost off the shelf components. On the other hand large humanoids are used more conservatively when implementing new algorithms to avoid catastrophic damage that may thwart efforts for continuing research [4].

There is an evident gap between consumer humanoid robot kits and custom miniature humanoids. The mass-produced kits reduce development time for humanoid robots, but limit mechanical/electrical expansion. Custom humanoids give more development experience, but tend to be specialized and proprietary within high-level educational institutions. The ideal combination of advanced hardware and open architecture has few contenders.

Mini-HUBO addresses this gap by filling the void with a high-end custom surrogate [4] of a famous humanoid. In addition, allowing for a complete insight to the development and manufacturing process. In the hopes this openness will broaden the amount of researchers that can reproduce and interact with the platform.

3.2 Mini-HUBO Specifications

Mini-HUBO was designed by Prof. Dennis Hong’s research team, the Robotics and Mechanisms Lab (RoMeLa) at Virginia Tech. They are world-renowned for being the only United States Team to compete in humanoid RoboCup soccer competition. Mini-Hubo is the newest design in a long line of miniature humanoid platforms product of this lab since 2004.

The robot in figure 4 is constructed from 1.5mm 5052-Aluminum sheet. Many pieces are cut with a simple 2D process, then bent to form the 3D structure shapes.

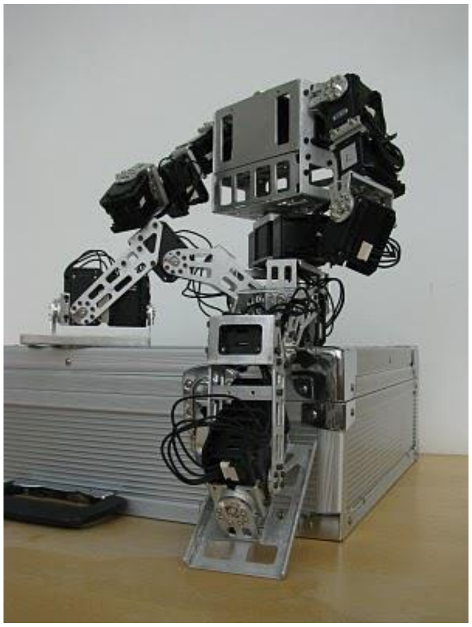


Figure 4. Mini-Hubo Humanoid Robot 1st manufactured copy at Drexel facility during Beta testing, showing a human-like pose.

The open modular design leaves the chest cavity available for batteries and sensors. The rear provides space for a wide range of controllers. This back panel was purposely designed to be customizable to any controller that can fit in its 111X97X30 mm volume. This is a large enough space to still allow for an embedded PC or simple microcontroller, yet still allow for maximum travel for the arms to swing during full body motion. The head pan servo remains open for user defined adaption of path planning or visual sensors.

As a prototyping tool for HUBO, Mini-HUBO, was designed with similar features and kinematics (figure 5). The miniature robot has all the major axes of the full sized humanoid. Table 1 shows a direct comparison of Mini-Hubo specifications to the KAIST HUBO. The KAIST HUBO clearly costs 2 orders of magnitude more to own and operate. This shows that the Mini-HUBO alone seems expensive, but in comparison to the actual HUBO it's only the cost of the servos to obtain a fully working humanoid.

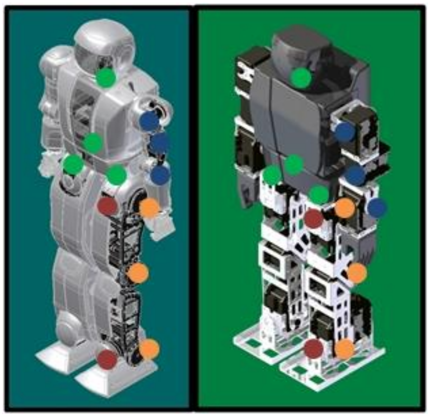


Figure 5. Color dots match the location of the major axes shared by Full sized HUBO and Mini-Hubo.

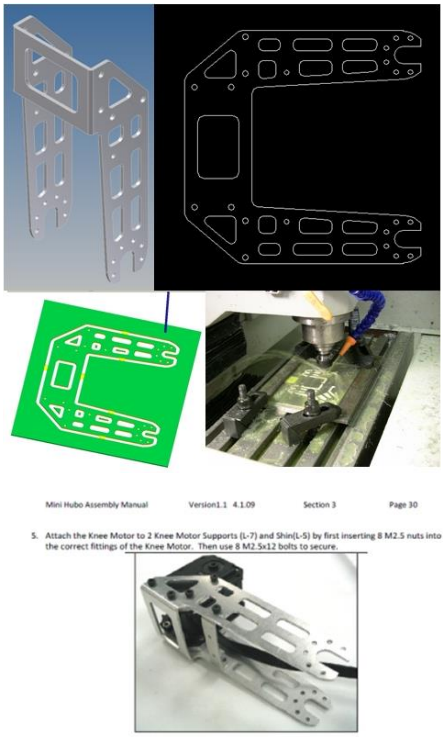
Table 1
A Comparison of Humanoid Robot Attributes

Category	Mini-HUBO	KAIST HUBO
Degrees of Freedom	22	41
Height	44.6cm	120cm
Weight	2.9kg	45kg
Fabrication./Assembly Time	40hrs	9+ Months
Total Cost	$5000	$500K +
Walking Speed	1.2cm/s	14-28cm/s
Controller	Open/FitPC2	2x 800MHz PC

The Robot is mechanically stable and is capable of walking open loop at speeds of 1.2cm/s. The robot's stock design does not come with any force or pressure sensors located in the feet. These features or other changes are promoted to tailor the user's mini-HUBO as needed before the manufacturing.

All plans and instructions to reproduce this robot are available for download. Three main manuals where written by RoMeLa on Mini-Hubo: Users, Fabrication, and Assembly Guides. The User's guide explains cost, material procurement, and time for completion. A Manufacturing tutorial and bending instructions are located in the Fabrication guide. Assembly guide uses pictorial images to walk through fasting of the robot pieces together.

In addition all engineering drawings are available (figure 5). This includes all flat and 3D Computer Aided Design (CAD) files of structural frames and assemblies. Also available are the posted Numeric Control (NC) text files for operation of standard three axes vertical Mills. Structure pieces can be easy outsourced to be batch cut with a laser cutter if a facility cannot offer automated manufacturing machinery.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5. Attach the Knee Motor to 2 Knee Motor Supports (L-7) and Shin(L-5) by first inserting 8 M2.5 nuts into the correct fittings of the Knee Motor. Then use 8 M2.5x12 bolts to secure.

Figure 5. Key steps in manufacturing of a thigh bracket, from the CAD model and manufacturing to final assembly. [5]

4. Open Controller Hardware Selection

4.1 Dynamixel Platform Generalizations

The Dynamixel offers expandability in comparison to a typical Pulse Width Modulated (PWM) servo. The mini-HUBO uses the Dynamixel servo actuator. These actuators are classified as “smart” actuators due to their communication style. These motors can send serial instructions and return feedback or alarms. Table 3 offers some data on the capabilities of the Dynamixel actuator in comparison with a Robonova-1 servo. It is shown that this motor is more diverse in use when assuming precise control and feed back over a robotic platform. These motors are based on an addressable multi-drop bus to allow for expandability to add additional motors or sensors on same communication line.

Table 3
Dynamixel Comparison

	Dynamixel RX-28	Hitec Robonova-1 Servo
Voltage	12-16vDC	4.8-6vDC
Torque	12V 393oz/in 16V 523oz/in	425 oz/in
Position Sensing	Digital Encoder	Analog Potentiometer
Range of Motion	0-300 degrees or Continuous	0 to 90 degrees
Controls	Position, Velocity, Torque, Temperature, Identification	Position
Indicators	Temperature Alarm, Over Torque Alarm, Feedback on all Controls	None

4.2 FitPC2 Target

Mini-Hubo’s design permits many types of microprocessors. There is a few metrics that should be looked at before the selection. The size of the controller cannot exceed the back foot print of chest. It should be under 10 watts of power consumption for longer battery life. Finally, the controller should run on a similar voltage to the motors’ operating voltage.

The author chose to describe a possible controller that is most general and easily accessible. The FitPC2 by Compulab is a low cost but powerful alternative to many small form factor PCs available. This platform is available on most online computer stores and can run most OS’s. Windows XP was chosen due to it being common and has many software development tools. Also, LabVIEW runs best on windows based machines. The Computer has an x86 1.6GHz Atom Processor, chosen due to LabVIEW performance benchmarks higher with 1 GHz or better. It has 1 GB of onboard RAM along with a 32 GB Solid-State Hard drive (SSD). The SSD hard drive is very important for humanoids for data storage, due to the frequency of falls.

Figure 6. FitPC2

5. National Instruments Joint based Dynamixel API

5.1 LabVIEW

LabVIEW is a graphical programming environment developed for instrumentation and control systems. Graphical icons and wires form the programming structure, resembling a flow chart [6]. The expandability of

LabVIEW is a key feature: the Robotics library (2010) offers many tools to rapidly design sophisticated robotics systems while being embedded into the LabVIEW engine.

5.2 Robotics Dynamixel Motor API

The January 2010 release of the LabVIEW Robotics the software was based on the most common robotic application, unmanned group vehicles (UGV) and Industrial robotics. The USG's were split into cognitive categories, sensing, path planning, obstacle avoidance, and steering. Industrial robotics encompassed kinematics, dynamics, and transforms. The adoption of Mini-Hubo created a new challenge; this robot does not fit into the one category, but shares attributes from both categories.

To address these broader needs, an Application Programming Interface (API) was designed to control the smart actuators. The structure that existed started with high level abstraction of a sensor that intern matches with a motor class to retrieve motor specific commands. This started the development of a library to meet the need of communicating with the Dynamixel and the motor class. Figure 6 shows the flow of the typical operation that this API would carry out. To minimize programming effort, a good API simplifies communication from the control code to the servos.

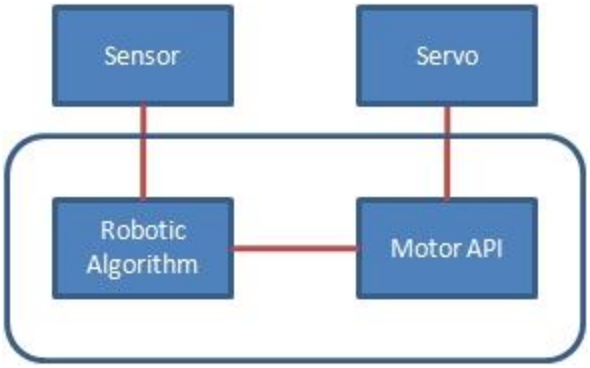

Figure 7. LabVIEW communication flow chart

This API need to have a strong back bone to be able to be flexible for detecting number of actuators present and to dynamically adapt to changing input conditions. A changing input condition may include commanding a Dynamixel to change from position to velocity control. This platform also needed to be open to different body structures to allow humanoids as well as leg based robots, such as hex-a-pods. This would allow a new level of control to work with many types of joint based robots. This new functionally also needed to support and nest with the LabVIEW legacy components to be an effective counterpart.

6. Results

The Dynamixel API is in alpha testing working with within the LabVIEW Robotics engine. Initial work shows that the API can detect changes in the number of motors and reorient the programming for new conditions, as well as changing on the fly the majority of the control table.

To test with an application the Dynamixel API is receiving input from a Hokuyo Laser Scanner. The data is parsed by a robotics sub-program called a vector field histogram to find the best trajectory to a clear path. The Dynamixel is using the UGV steering parameters to create target steering angle. The Dynamixel can move an actuator arm in the range of 0-300 degrees in accordance with the optimal path from the sensor. Figure 8 shows the user interface; the graph shows the best path in green and the dial below it is displaying the associative angle.

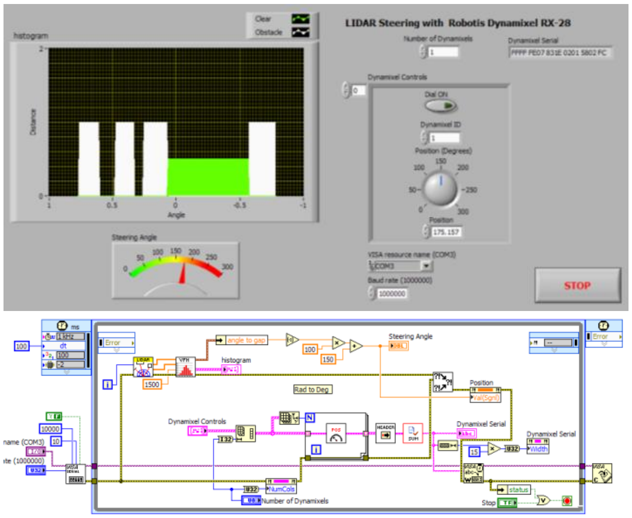

Figure 8. Laser Scanner Data finding open heading and using Dynamixel API to adjust steering angle.

The API was also applied to Mini-Hubo, which successfully interfaced all 22 servos. A simple open loop control with a trajectory look up table sufficed for gate generation. During this operation position control was chosen along with a sync write to gain speed with transmission. The sync write addresses the selected ID's all at once, eliminating the status message and associated overhead. The API could control position of each joint individually while looking up a new frame to move into.

7. Conclusions and Future Work

The Mini-HUBO research platform has inspired a new Dynamixel API within National Instruments LabVIEW. The interface designed for these servos allows seamless integration with current NI Robotics functions. Currently implemented features such as on-the-fly reconfiguration of robot servos are an important step. Without the low level development burden of current robotic systems, humanoid robotics research will be able to flourish.

A large portion of the humanoid dependent development still lies ahead. Many of these techniques exist currently in the robotics package such as inverse kinematics, sensor interfaces, and standard controllers. These functions need to be ported to humanoid platforms, to make available a standard and scalable tool kit for rapid development. The building blocks of humanoid robotics, these tools must be robust and reliable to realize time and effort savings.

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