Architectural Design of Miniature Anthropomorphic Robots
Towards High-Mobility

Tomomichi Sugihara*  Kou Yamamoto*  Yoshihiko Nakamura*

*Department. of Mechano-Informatics, Univ. of Tokyo. 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8556, Japan.  
Email: sugihara@ynl.t.u-tokyo.ac.jp

Abstract
A design methodology to build miniature humanoid robots is discussed. Although light and small bodies would make aggressive types of motion experiments much safer and smoother, they would often cause self-collisions and even restrict the space to mount mechatronic components. In order to defeat some kinematic difficulties including the former issue, a technique to modularize and assign joints is proposed through our prototyped robot. And, as a solution against the latter issue, a portable core control unit which stores a stand-alone electronic system is also introduced through the second version of our humanoid, whose system centers around it.

1 Introduction
Greatly advanced technology in the field of robotics have aroused people’s expectation that robots will work in the human society. Some have begun to discuss the practical use of humanoid robots. In spite of that, those in the current stage disappointingly lack of mobility against the severity of real environment. Much deeper understand of motion control through experimental studies are required for their evolution to be our alternative bodies. At this starting stage, robots over one meter high [1, 2, 3] would be still threats for us if we shared the life-space with them. It’s preferable to begin with a light miniature body for the safety and smoothness of the experiments. A small body, however, causes some constraints on the assembly. Self-collision, for example, could happen so easily that careful joint assignment is required to keep wide motion range of each. And, the space to mount mechatronic components and to wire the cables is restricted.

There has been several attempts to build small lightweight humanoid robots. Remote-brained robot approach proposed by Inaba et al. [4] released the robot body from heavy computers. Their bodies consist of tens of small servo DC motor modules originally for radio-controlled toys, and have evolved to humanoid types[5]. Using those series, Nagasaka et al.[6] realized various whole-body motions. On the same technology, Nordin et al.[7], Furuta et al.[8] and Yamasaki et al.[9] also developed low-cost anthropomorphic robots. However, low precision on the control of those actuators prevents a reliable implementation of dynamic motion controller.

Kuroki et al.[10] developed SDR-4X. And, Fujitsu Automation[11, 12] produced HOAP-1/2 for the purpose of offering an open platform to researchers. They developed unique components including motors, gears, amplifiers, I/O interfaces and so forth to be integrated in them. A large part of those technology is not revealed. On the other hand, small types of mechatronic products with high specification to be embedded especially into robots have recently become commercially available. Common developers have gained the choice of them for their own systems. This paper discusses a design methodology of miniature humanoid robots to overcome the technical hurdles through two instances we developed with such public components. Kinematic issues including the motion range are firstly dealt with in the prototype, using modularized ortho-axis-coupled joint units. And then, the issue of integration and wiring is solved on the architecture which features AnimatoCore, which is applied to the second model.

2 UT-μ — prototyped robot

2.1 Specifications
Fig.1 shows UT-μ譬如, the prototype of our miniature humanoid robots. It is about 58cm tall, and weighs about 7kg including the battery and processor on the body. The total number of joints is 23; 3 for the neck are without actuation. 4 located at each arm, and 6 at each leg are actuated by coreless DC motors manufactured by maxon motor ag., and decelerated with harmonic drive gears by Harmonic Drive Systems. The gear ratios are all 100:1,
and the output of motors are 4.5W (for elbow rotational joints), 6.5W (for shoulder abduction joints, elbow flexional joints and knee rotational joints), and 11W (for the other joints), respectively. The choice of those high specifications mounted on the arms and legs encourages aggressive types of the whole body motion, and also promises feeling the results of experiments back to life-sized robots. Although it causes an increase of weight at each joint, the thin-shelled exoskeletal structure, made of magnesium alloy casting, is designed as curved surface for high stiffness versus weight, so that the total weight meets the standard weight-per-size ratio. In addition, the total number of parts is reduced, and much higher unit cost of magnesium alloy casting than milling and bending is balanced.

2.2 Ortho-axis-coupled joint unit

Each joint is modularized as a unit with coupled axes, named ortho-axis-coupled joint unit. The idea is basically in accordance with the fact that many of the couples of adjacent axes in anthropomorphic systems are mutually-perpendicular. The whole-body of the robot is assembled, connecting those units with magnesium exoskeletal structures. Fig.2(A) illustrates the unit and the structural connectivity around it. Each axis involves a pair of gear and motor. Fig.2(B) is the picture of the gear part. Adopting this technique, 1) the robot keeps maintainability, getting attachment-and-detachment of each joint to be easy, and 2) the production cycle is accelerated, sharing common parts.

Fig.3 shows the total joint assignment of the robot. All the units are located to avoid easy self-collision. Some unique features in it are as follows.

i) Hip joint (Fig.4(A))

Two axes of the hip joints are assigned so as to enlarge the motion range of flexion-extension and abduction. The distance between the two hip joints is counteracted by inward offset of knee rotation joints to prevent the sideward perturbation of the trunk.

ii) Flexional joint at the leg (Fig.4(B))

The ankle flexional joint is assigned with 5[mm] offset backward to the hip and knee in order to exclude singular posture out of the motion range. And, the mechanical stopper at the knee flexional joint saves kinematic energy in the stretched-knee posture.

iii) Shoulder joint (Fig.4(C))

The root axis of each shoulder is slanted from the perpendicular axis to 45 degrees, aiming at a natural flavor on its mixed motion of extension and abduction in a simple way.
four corners to calculate the resultant linear force and moment applied to each foot from the ground.

2.4 Experimental operations

Fig.7 shows some motion examples of UT-μ.

(A) is a rock’n’roll motion realized on the basis of Sugihara et al.[13], in which the projection of the center of gravity (COG) onto the ground is controlled through manipulation of Zero Moment Point (ZMP[14]). Each transportation of the COG projection from one sole to the other took about 0.6[sec].

(B) is a knee-bend motion. From the upright posture to the bent posture was taken about 0.6[sec]. COG stayed right upon the midpoint of the feet during the motion.

(C) is a walking motion generated by an online gait planner [15]. Each step took 0.5[sec], and the step length was about 20[mm].

Through these experiments, we found some immature parts on UT-μ in terms of both mechanics and electronics. They have been fixed to the second version explained in the following section.

3 UT-μ2 – animatronic humanoid robot

3.1 Specification

Fig.9 shows UT-μ2: magnum, our second version. Size, weight and joint assignment of the robot are almost the same with those of the prototype. It has some mechanical improvements that 1) thickness of the exoskeletal shell is controlled, 2) the hip flexional joint is reinforced to two-point-support bearings while that of the prototype is supported by one-point bearing as Fig.10 shows, and 3) 22W motor was chosen at the hip abductor joint. The 3-axis accelerometer and gyro sensor are replaced with GSX010011T(Matsushita Co.,Ltd.) and CRS-03(Silicon Sensing Systems Ltd.), respectively.
3.2 AnimatoCore

The electronic components only except actuators, rotary encoders and force sensors are integrated to be a core control unit, independently from the robot body. We named it AnimatoCore. Fig.11 is its illustration and the outer view. On this technique, cable wiring in the limited space is simplified so that 1) fragile electric circuits are excluded from the extremities, which frequently suffer from vibration and perturbation during the motion (robustness), 2) the risk of self-destruction around mechanically complex parts such as wire-breaking is reduced (suppression of interference), 3) unmount-and-remount operation of components, especially in the early stage of the development, is less troublesome (maintainability), and 4) system modification with increase/decrease of actuators or sensors is easy (extensibility). In addition, it could function as a stand-alone portable controller of various space-saving robotic systems such as mobile robots, multi-legged robots, surgical robots and so forth. One constraint is that this architecture conditions mechanical design to have sizable space to mount the unit.

Fig.12 is a diagram of the electronics system of UT-µ2 centering around AnimatoCore. The processor board is EKit-1100(Device Drivers) featuring Au-1100 400MHz(AMD), 128MB RAM and two CF slots, one of which is for wireless LAN(terreg) and the other for storage. In the course of the development of UT-µ, we found that USB has some drawbacks for realtime communication, mainly due to the procedural complexity. Then, we chose...
CUnet (StepTechnica), which realizes widely-ranged multi-CPU network on shared memory, and constructed the internal communication network between the main processor and distributed motor/sensor controllers. We also developed a small device controller board with H8 processor (Renuesa Technology Corp.), two-channel DC motor drivers and eight-channel A/D converters on the cooperation with 3TEC Corp. Fig.13 shows the external view of the board.

3.3 Experiments

Fig.14 shows a sequence of bowing, shadow-boxing and walking motions. All motions were navigated by pre-designed trajectories generated by [15].

4 Conclusion

Technical difficulties in the design of miniature humanoid robots range from kinematical ones to those in the integration. Our developments proposed 1) joint unit modularization and easy construction of the robot body with them, and 2) an electronic system architecture centering around the core control unit to ease the troubles with integration and wiring in the limited space, and we innovated *ortho-axis-coupled joint unit* and AnimatoCore. Those products are practically included in two small humanoids, which encourage more aggressive types of motion and the evolution of motor control.

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References


Figure 12: Electronics system of UTα2

Figure 14: Bowing, shadow-boxing and walking motion experiments

Figure 13: Device controller board


