Elements of Humanoid Robot Technology

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Abstract— **This paper introduces elemental approaches devised in our group to tackle both mathematical and technical key issues on the realization of sophisticated humanoid robots. Substantial difference of humanoids from industrial arms in terms of kinetics lies on a large number of degrees-of-freedom and discontinuity with collision and contact. Our innovations against them cover particular methods of body design, kinetics computation and motion control.**

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I. Introduction

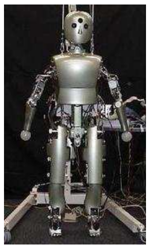
Humanoid robots, which are expected to support us as our alternative bodies, are still at the starting point of evolution. There lies both mathematical and technical difficulties to be overcome for the realization of sophisticated humanoid robots. Substantially different paradigm is required for any aspects – design, control, operation and so forth, while most of the latest humanoids don't depart from conventional one for industrial manipulators so that they are too vulnerable to cope with severity of the real world.

The main difficulties are summarized into the following two items; 1) A large number of degrees-of-freedom often causes not only kinetic complexity with redundancy and singularity but serious increase of computational cost, which realtime control suffers from. It also troubles joint assignment to keep sufficient motion range. 2) Discontinuous collision and contact with the environment, due to the lack of fixed base link, leads to hyperstatics, large perturbations and noises. Other key is the integration of components for comparatively high performance versus size. Table.I tabulates the above issues.

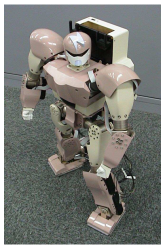
Our endeavors to tackle each aspect of them include robot body design, behavior observation of real human, kinetic computationand motion control theory. Each roman number in Table.I corresponds to the techniques introduced in the following sections.

TABLE I
Difficulties on humanoid robots

Difficulty	Mathematical issue	Technical issue
A large DOFs	(i) redundancy (ii) singularity	(iii) computation cost (iv) joint assignment
Collision & contact	(v) discontinuity (vi) underactuation (vii) hyperstatics	(viii) noise (ix) perturbation
Others		(x) integration of components

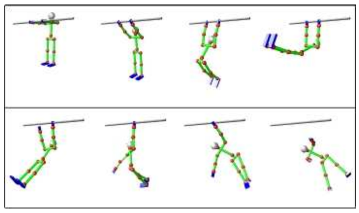


(A) UT-θ

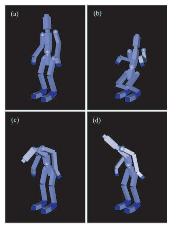


(B) UT-μ:mighty

(C) Behavior Capture Studio



(D) Structure-Varying Simulation



(E) UT-Poser

Fig. 1. Endeavors to realize humanoid robots

II. Humanoid body design

UT-θ[1] (Fig.1(A)) was the exploration of design possibilities with the fewest joints. It stands 150[cm], weighs 45[kg] (main structure is magnesium alloy), and consists of 23 joints, including some original mechanisms as follows.

Double spherical joint (Fig.2) is a combined couple of spherical joints with the shared center of rotation. It is at the hip and can also function as the waist joint without any extra actuators. Its advantage is particularly in the motion stabilization, in which the trunk is independently controlled from the leg motion. (iv)

Backlash clutch is adopted for the knee joint. In Fig.3, the movable part a unilaterally transmits torque to the fixed b when the gap d is controlled to be zero, while it is insulated by keeping d to be a certain d_0 for a natural-looking swing and a shock absorption at the collision. Utilizing the gravity gets rid of optional actuators. (v)(viii)(ix)

UT-μ:mighty(Fig.1(B)) also brought up a new design methodology. It consists of 10 orthogonal 2-axis units connected by casted exoskeletal parts as Fig.4 shows. And, careful joint assignment ensures wide motion ranges and singular posture avoidance. (ii)(iv)

III. Electric units for distributed control

Distributed motor controllers/sensor processing units back up the humanoid system which runs on heavy calculation. Fig.5 shows the units we developed on co-

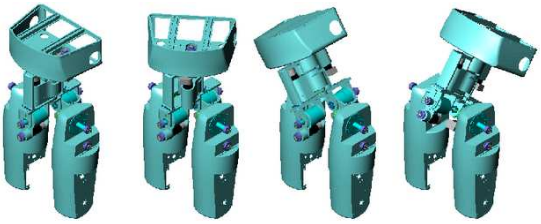
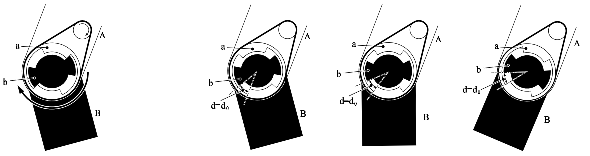


Fig. 2. Double spherical joint



(A) Transmission mode (B) Torque Insulation mode

Fig. 3. Backlash clutch

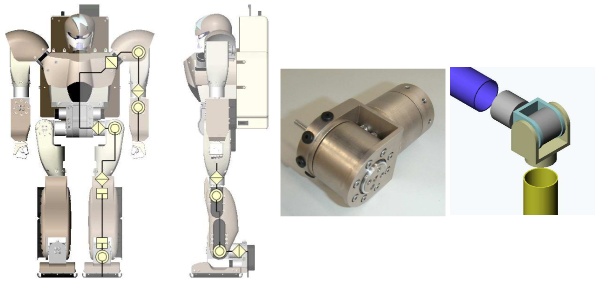


Fig. 4. Joint assignment and orthogonal 2-axis unit

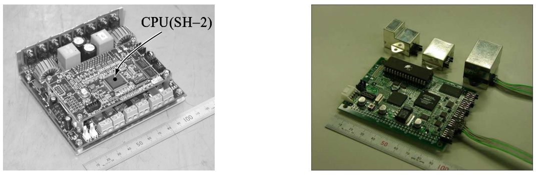


Fig. 5. High power motor driver and sensor unit

operation with 3TEC Corp. The size and weight are $110 \times 98 \times 35$[mm^3] and 0.3[kg]. They have CPUs(SH-2, Renesas Technology Corp.) on them and communicate with a host PC via RS-232C. The motor driver simultaneously controls two motors at most (position, velocity and torque control are available). The input voltage and maximum current are 36[V] and 20[A]/ch(total 30[A]), respectively, so that both a large amount of torque output and high rotational velocity are achieved. The sensor unit can fuse the information from up to four sensors. (viii)(x)

IV. Software for kinematics/dynamics

Efficient computation algorithms for simulation and motion design were developed. Some of them have been incorporated into packages for CG as well as humanoids.

Behavior Capture Studio is a system to capture not only human *motion* but *behavior* with multiple sensors including an optical motion capture system, force plates, electromyograph(EMG) and an eye-mark recorder. The realtime motion capturing software system developed by ourselves provides full access to the internal data. (i)

Forward Dynamics of Structure-Varying Kinematic Chains [2] has the time complexity is $O(N)$ and $O(\log N)$ for serial and parallel computations, respectively. OpenHRP[1] (freely available for non-commercial use) adopts our algorithm for the engine. (iii)(v)

UT-Poser[3] is an inverse kinematics solver which enables intuitive motion creation by adding kinematic constraints (link positions, joint motion ranges and so forth) by avoiding the singularity problem. It serves as the main engine of SEGA|Animanium™, a software package for keyframe animation in CG. (i)(ii)(iii)

Dynamics Filter[4] is an online filter that modifies a physically inconsistent motion (e.g. motion capture data) to a consistent one, namely, feasible for a choice of joint torques and contact forces. (i)(v)(vi)

V. Control theory

The absence of directly actuated base link necessitates skillful indirect manipulation of the reaction force from the environment through the interaction with it for responsive acceleration of the body. The controlling theory we developed[5] converts the desired external force to the equivalent whole body motion in accordance with a simple relationship between the center of gravity(COG) and Zero Moment Point(ZMP) with COG Jacobian, which maps the whole joint movement to COG motion, rather in a small computational cost. It enables to apply simple controllers to dynamically complex humanoids. (i)(iii)(vi)(vii)(ix)

VI. Conclusion

Our contributions to sophisticated humanoid robots cover 1) body design of humanoid robots to simplify the joint configuration and to exploit the best function of them, 2) electric components which reduce load of the main processor by distributed control, 3) efficient computation algorithms including behavior capture of real human, simulation and motion creation, and 4) responsive realtime motion control. All of them can be fundamental solutions for the essential problems of a large number of degrees-of-freedom and discontinuous collision and contact.

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