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Design and Development of the Biped Prototype ROBIAN

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Abstract

In order to study the human being locomotion system, a multi-degrees of freedom (DOFs) biped prototype equipped with flexible feet, which is named as ROBIAN, is developed. In this paper, the conceptual design of the biped prototype ROBIAN is discussed. The features of the ROBIAN are: (a) parallel mechanism at the hip and the ankle, (b) modular design and (c) 1-DOF active/passive joint between the heel and the toe. The ROBIAN will have 18-DOFs in total: 6-DOFs for each leg, 1-DOF passive or active joint for each foot and 4-DOFs for the upper limb. One of the major application of the ROBIAN will be the efficient development of a real testbed of active/passive prosthesis for the disabled.

1 Introduction

In the early 1970's, Kato and others developed a static walking of a biped robot [1]. Ever since, over the past few decades a considerable number of studies have been made on biped walking (e.g. [2]).

Despite the long history of the study, a practical biped humanoid robot had been considered as a dream because of the restrictions of hardware. However, the progress in the hardware design of humanoid robots has been notable in the recent few years, and many practical biped humanoid robots have been developed [3, 4, 5]. As humanoid robot becomes a hot topic in robotics, the study on the biped locomotion attracts attention again.

However, most of the bipeds developed so far has been designed with serial-actuated mechanism. Therefore, the ratio between power and weight has not been very good. In order to improve this ratio, a parallel-actuated mechanism is one of the solutions.

In order to study the human being locomotion system, a multi-degrees of freedom (DOFs) biped prototype equipped with parallel-actuated hip and ankle, which is named ROBIAN, is developed. The ROBIAN has a flexible joint between the heel and the toe. This feature will enable ROBIAN to simulate the human being locomotion. The ROBIAN will have 18-DOFs in total: 6-DOFs for each leg, 1-DOF between the heel and the toe for each foot, and 4-DOFs for the mass movement mechanism in the torso. This 4-DOFs mass movement mechanism simulates the dynamic effect exerted by the upper limb on the locomotion system.

In this paper, the conceptual design and the detailed design of the biped prototype ROBIAN is presented.

2 Conceptual Design

The ROBIAN is equipped with the legs, the feet and the torso. Since the objective of this work is to study the human being locomotion system, as described in the Introduction, the ROBIAN does not have an anthropomorphic upper limb, but have a 4-DOFs mass movement mechanism to simulate the dynamic effect exerted by the upper limb on the locomotion system. Four DOFs are necessary and sufficient to reproduce the dynamic effect [6].

The location of DOFs of ROBIAN is illustrated in Figure 1. Multi-DOFs circled by the dashed lines at the hips and the ankles are actuated by the parallel mechanisms.

The main features of the ROBIAN are:

- parallel-actuated mechanism at the hip and the ankle,
- modular design,
- 1-DOF active/passive joint between the heel and the toe.

The details of these features are described in the following subsections.

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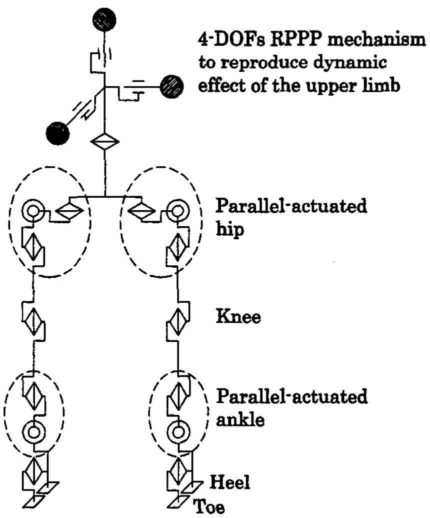

Figure 1: Location of DOFs.

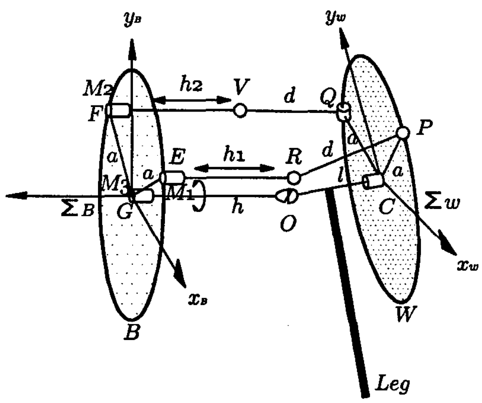

Figure 2: A kinematic model of the parallel actuated hip.

2.1 Parallel-Actuated Mechanism

Agrawal and others proposed a novel 3-DOFs parallel-actuated mechanism for a robotic wrist [7]. This mechanism allows unlimited rotation about the pointing axis. This mechanism is applied to the hip and the ankle of the ROBIAN.

The design requirements are:

1. the design must be as small as possible,
2. the range of leg's motion in the sagittal plane must be large,
3. the ranges of leg's motion in other directions are not required to be very large.

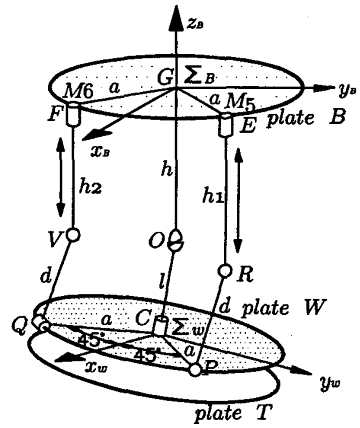

Figure 3: A kinematic model of the parallel actuated ankle.

The Agrawal's parallel-actuated mechanism satisfies the design requirements and is considered to be better than the other mechanism such as series-actuated mechanism.

Figures 2 and 3 are the conceptual sketches of the hip parallel mechanism and the ankle parallel mechanism, respectively.

The both mechanism consists of a base plate B and an intermediate plate W that free-wheels about OC, as shown in Figures 2 and 3. Coordinate systems Σ_B and Σ_W are attached to the plates B and W, respectively. The terminal plate T of the ankle is fixed at the shaft OC, and will be connected to the foot.

In the hip mechanism, three actuators, M_1, M_2, and M_3, are attached to the plate B. The ankle mechanism has a similar structure to the hip except for the actuator M_3. The shaft OG of the ankle is fixed on the plate B. In the hip mechanism, the leg is connected to the shaft OC so that its axis is perpendicular to the shaft. The actuator M_3 rotates the shaft OC via a universal joint at O. Consequently, the leg is driven by M_3 around the axis OC.

In both mechanism, M_1 and M_2 (M_5 and M_6) are connected to ball screw arrangements, and translate the spherical joints R and V, respectively. The spherical joint P and the pin joint Q are on the plate W. The axis of the pin joint is perpendicular to the line CQ. As the actuators M_1 and M_2 (M_5 and M_6) translate the spherical joints R and V, the plate W pivots about O.

The fixed parameters are: $GE = GF = CP = CQ = a$, $PR = QV = d$, $CO = l$, $GO = h$, and $\angle EGF$

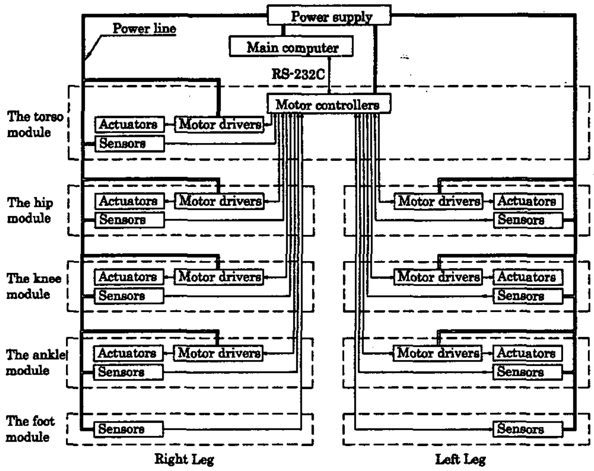

Figure 4: Control system of the first version of the ROBIAN.

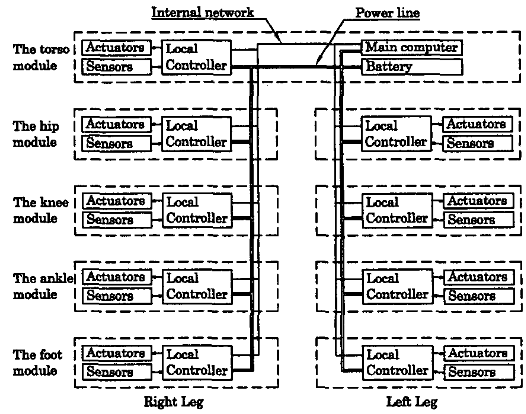

Figure 5: Control system of the second version of the ROBIAN.

$= \angle PCQ = \pi/2$. The variable parameters h_1 and h_2 are the length between E and R, and between F and V, respectively. Same notations are used for the hip and ankle, however, the hip and ankle take different values for the notations.

Unlike the Agrawal's parallel-actuated mechanism, F, E, Q and P are not placed on the x and y axes but placed at an angle of 45 [°] with x and y axes in order to produce coupled force for each direction. This coupling mechanism have a big advantage, since the hip and ankle are required to produce an important force in lateral direction in a walking gait to balance.

2.2 Modular Design

The ROBIAN consists of the torso module, the hip modules, the knee modules, the ankle modules, and the foot modules. Each module is designed so as to easily attach to and detach from each other.

The first version of the ROBIAN has the motor controller cards inside its torso. They are connected to a backplane and communicate with the main computer via RS232C serial bus. Each motor controller reads a rotary encoder signal and produces an analogue control input for a motor. A motor driver mounted inside each module translates this analogue control input into a PWM motor drive signal. Consequently, a lot of wires are required to connect each module (Figure 4).

Such complicated cabling decreases the system reliability. Therefore, a network-based local motor controller is under development. The new local controllers will communicate with the main computer via an internal network (Figure 5). The new local controller decreases the number of cables, consequently, increases the system reliability. The new local controller will be applied to the second version of the ROBIAN.

2.3 1-DOF joint of the Feet

Let's examine the phases of a human being gait cycle. The first phase of the gait cycle is the heel contact. The next phase is called as mid-stance. In the propulsive phase, the leg passes over the foot and the heel takes off. The last phase is known as the swing phase.

The flexibility of the foot plays a crucial role in the propulsive phase of the human being locomotion system. Since the objective of this work is to study the human being locomotion system, the flexibility of the feet is necessary for the ROBIAN.

The ROBIAN has 1-DOF joint between the heel and the toe. In the first version of the ROBIAN, a joint that has passive elasticity is studied. If necessary, the passive joint will be replaced by an active joint in the second version of the ROBIAN.

3 Detailed Design of Each Part

A CAD model of the legs of the ROBIAN is illustrated in Figure 6. The length between the hip axis and the ankle axis is 0.5 [m]. The total length of the

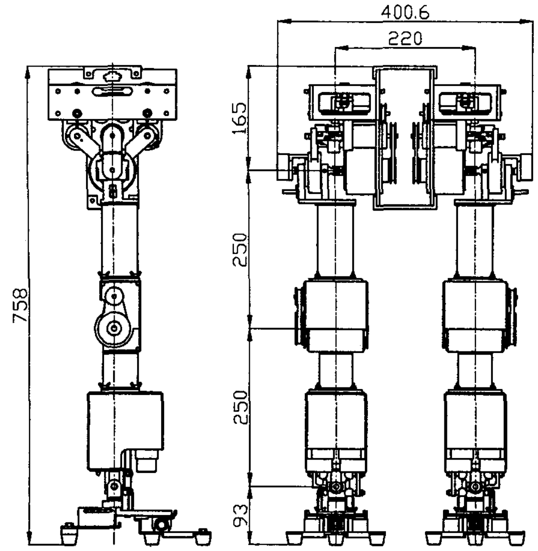

Figure 6: CAD model of the legs of the ROBIAN.

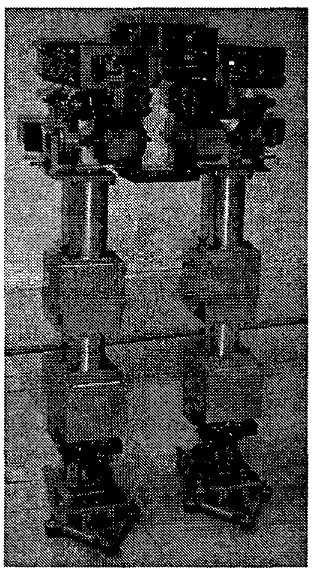

Figure 7: Photograph of the ROBIAN.

leg is about 0.76 [m]. The total weight of the leg is about 14 [kg]. A photograph of the ROBIAN is presented in Figure 7.

The details of the design of each part is presented in the following subsections.

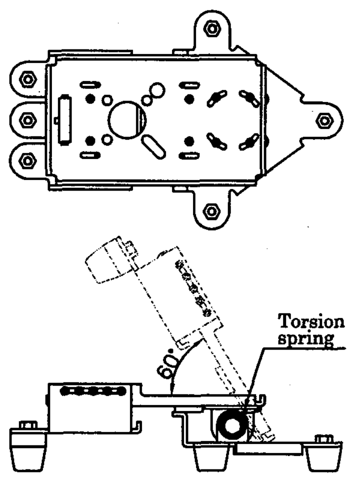

Figure 8: Foot of the ROBIAN.

3.1 Foot

In order to add an elasticity for the passive joint between the toe and the heel, torsion springs are used as shown in Figure 8. The movable limit of the passive joint is 60 degrees.

There are four/five contact points: three for the toe and one/two for the heel. The number of contact points of the heel is configurable. Rubber cushions are used at the contact points. The lateral position of the heel and the angle of the toe are adjustable. Strain gauges are used to measure the reaction force from the ground at each contact point.

3.2 Ankle

In order to get a big propulsive force, a large movable region is required for the ankle. Therefore, movable limit is studied to determine the kinematic parameters. The parameters are finally decided as follows:

$a = 0.03$ [m], $d = 0.03$ [m], $l = 0.01$ [m],
$h_1, h_2 = 0.05$ [m], $h_{1max}, h_{2max} = 0.06$ [m],
$h_{1min}, h_{2min} = 0$ [m].

The posture of the terminal plate T (Figure 3) is given by a set of two parameters α_1 and α_2 which are rotations about $\boldsymbol{x}_B$ and $\boldsymbol{y}_B$, respectively. The possible postures (α_1, α_2) of the plate W with the above parameters are illustrated in Figure 9.

There are four possible configurations (see Figure 3 for the kinematic parameters):

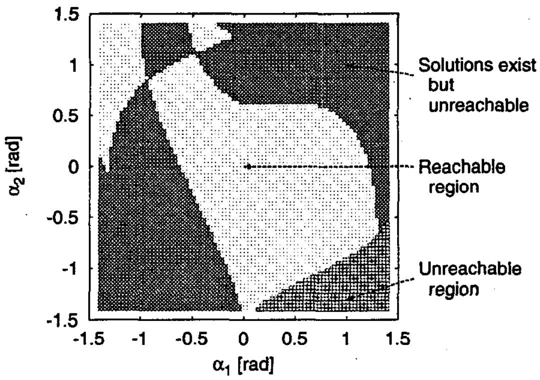

Figure 9: Movable region of the ankle.

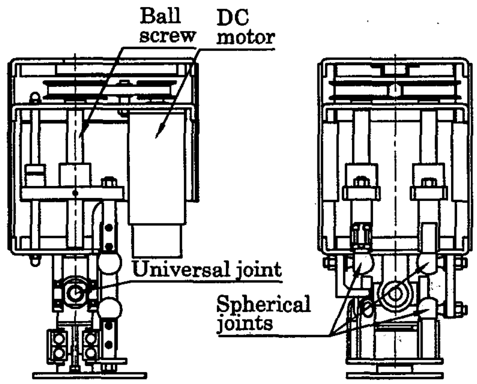

Figure 10: Ankle module of the ROBIAN.

(a) $\angle ERP \geq \pi/2$, $\angle FVQ \geq \pi/2$,
(b) $\angle ERP < \pi/2$, $\angle FVQ \geq \pi/2$,
(c) $\angle ERP \geq \pi/2$, $\angle FVQ < \pi/2$,
(d) $\angle ERP < \pi/2$. $\angle FVQ < \pi/2$,

The initial posture of the plate T $(\alpha_1, \alpha_2) = (0,0)$ is in the configuration (a). In order to move from configuration (a) into other configurations, it needs to cross over the singular configuration. Consequently, the configuration (a) specifies the actual movable limit.

Note that the domain illustrated in Figure 9 is given by solving the inverse kinematics, and thus, it does not always correspond to the movable limit of the real mechanism. In most of the parallel mechanisms, the movable limits of spherical joints specify the movable limits of the end point.

The final design of the ankle is illustrated in Figure 10.

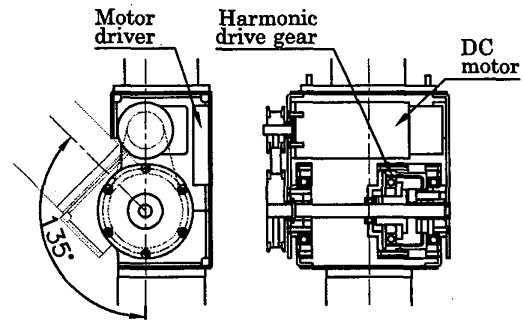

Figure 11: Knee module of the ROBIAN.

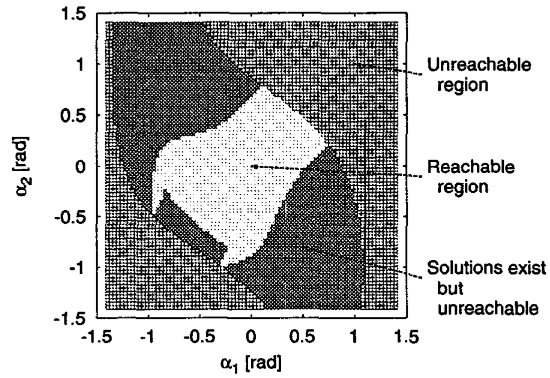

Figure 12: Movable region of the hip.

3.3 Knee

A belt-pulleys and harmonic drive gear mechanism is applied to the knee joint. The reduction gear ratio of the mechanism is 1/240. Considering the movable limit of the human knee, the extension limit at knee is set at zero. The flexion limit becomes 135 degrees as shown in Figure 11.

3.4 Hip

In the hip design, the rigidity is rather required than the large movable region. The parameters illustrated in Figure 2 are determined as follows:

$a = 0.055\sqrt{2}$ [m], $d = 0.03$ [m], $l = 0.01$ [m],
$h_1, h_2 = 0.045$ [m], $h_{1max}, h_{2max} = 0.05$ [m],
$h_{1min}, h_{2min} = 0$ [m].

As the parameter a becomes small the movable region of the plate W becomes large. However, on the contrary, as a becomes small the rigidity becomes small. Therefore, the determined parameters are points of

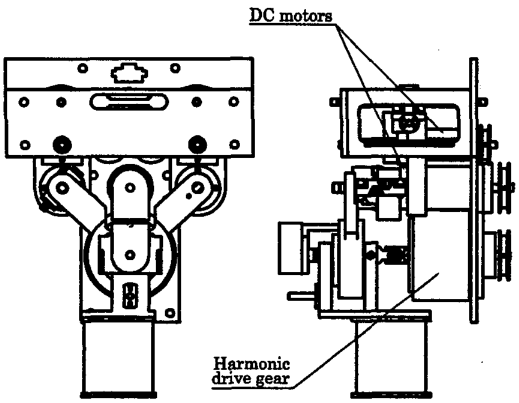

Figure 13: Hip module of the ROBIAN.

compromise between the movable region and rigidity. The movable region with the above parameters is illustrated in Figure 12.

Three DC motors are installed inside the module. The linear motions of h_1 and h_2 illustrated in Figure 2 are realized by a belt-pulleys and ball screw mechanism. The final design of the hip is illustrated in Figure 13.

3.5 Connection between Modules

To make maintenance easy, the ROBIAN has a modular construction. The connections between modules consist of mechanical fixation and electrical connectors. The connection between the hip and the knee is illustrated in Figure 14. Four wing nuts are used for mechanical fixation.

Since the first version of the ROBIAN has a centralized control system, a lot of cables are required. Consequently, big electrical connectors are needed for the connection. As illustrated in Figure 5, the second version of the ROBIAN will have a distributed control system, and thus, the cables needed are just power and 10Base-T.

4 Conclusion

The conceptual design of the ROBIAN is presented in this paper. Adopting parallel mechanism at hip and ankle is a maiden attempt. The parallel mechanism increases the rigidity of the leg. Also the flexible feet of the ROBIAN will play a great roll to study the human locomotion system.

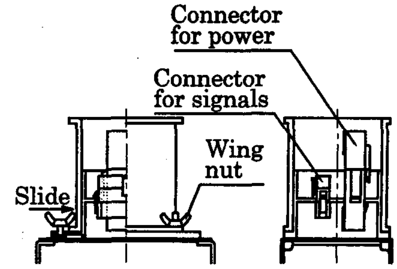

Figure 14: Mechanical and electrical connection.

The ROBIAN is expected to be a good testbed for the efficient development of active/passive prosthesis for disabled people.

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