KENSEI-chan: Design of a Humanoid for Running

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Abstract. This paper presents the design of the humanoid robot KENSEI-chan for RoboCup Humanoid League. Many humanoids have been developed, but no humanoids have a capability of running. Because running needs huge torque, shock tolerance, and weight reduction. KENSEI-chan was designed with these things. KENSEI-chan is planed to have 12 degrees of freedom (DOFs) in two legs, 4 DOFs in two arms, 2 DOFs in the neck, and 1 DOFs in the trunk. Totally KENSEI-chan has 19 DOFs. 2DOFs in the knees and the ankles are Rotary Elastic Joints, which provide shock tolerance and force control.

1 Introduction

The RoboCup Federation will start Humanoid League from RoboCup-2002 Fukuoka Japan. The success of the humanoid league is very important key for the future of RoboCup, and it will have a tremendous impact on robotics research and industries.

Many humanoids have been developed, for example, P3 [1], ASIMO [2] from Honda company, WL-10RV1, WABIAN [3] from Waseda university, H5, H6 [4] from university of Tokyo, Saika-3 [5] from Tohoku university, PINO [6] from JST and so on. However, those humanoids lack the capability of running what soccer needs. Thus, we have begun to develop the humanoid robot named KENSEI-chan that has a capability of running, and following points dominated the design of it.

– **Running Mechanism** Rotary Elastic Joints are used for knee joints. Rotary Elastic Joints are composed of encoders, motors, reduction gears, torsion springs, and leg links. Those joints transform kinetic energy to elastic energy, transform elastic energy to kinetic energy, and provide shock tolerance as well.
– **Infant Proportion** The size of the humanoid is restricted to have the ability of running using motors sold on the market. The height of the humanoid is about 110cm, the approximate size of a 5 year old child.
– **Pretty Exterior Design** The importance of exterior design is addressed by PINO. The design of KENSEI-chan would be pretty like an infant, the audience in the RoboCup games will watch it attentively and affectionately.

A. Birk, S. Coradeschi, and S. Tadokoro (Eds.): RoboCup 2001, LNAI 2377, pp. 331–336, 2002.

This paper describes the design concept of KENSEI-chan and its running mechanism. KENSEI-chan is under developing, and the lower part of the body is almost finished.

2 Running

2.1 Running Mechanism

In this paper, running is defined by periods of ballistic flight with all feet leaving the ground. Running is very similar to the bouncing ball [7]. That is , during the flight phase, a leg is swung forward in preparation for the heel touches ground. After the heel touches ground, heel and toe contact, then toe contact, and flight phase again. During the transitions, kinetic energy is transformed to elastic energy in the elastic elements, such as muscle, ligament and bone tissue in the body and stored. Then elastic energy is reused. The knee acts as a passive spring to store the kinetic energy. The use of elastic energy is up to from 25 % to 50% [8]. Human has a high efficiency running mechanism.

In RoboCup, humanoid robots have to play soccer during half time without replacement batteries. The humanoid which we have developed introduces the mechanism of human running.

2.2 Condition of Running

Let us consider the condition of running to design the humanoids. When a runner runs with an speed of 3.6m/s, vertical ground reaction forces reach 2.1 times body weight and horizontal ground reaction forces reach 0.4 times body weight.

Thus, running humanoids have to have the shock tolerance mechanism and huge torque for the touchdown, moreover angular velocity of each joints would be enough for running.

Table 1 shows the condition of running for KENSEI-chan. Angular velocity data are from a 178cm and 63kg runner runs at 2.8m/s. Necessary Torque T_n are calculated as follows

$$T_n = T_{peak} \times weight\ ratio \times size\ ratio.$$

Where, the weight ration is 0.63, and the size ratio is 0.62.

	Angular Velocity [rad/s]	Peak Torque [Nm]	Necessary Torque for KENSEI-chan [Nm]
Hip (pitch)	5.8	300.0	117.2
Knee (pitch)	11.0	245.0	95.6
Ankle (pitch)	5.4	220.5	86.1

Table 1. The Condition of Running. Torque and angular velocity are given for maximum value in teh sagital plane.

3 Architecture

3.1 Overview

Fig.1 shows the DOFs configuration of the lower part of KENSEI-chan which we had developed. It has 12 DOFs, and Table 2 shows the specification of each joint. We adopted Maxon DC motor RE40 (power:150W, maximum torque 2.3Nm, weight 480g) for the hip pitch, the hip roll, and the knee pitch joints, RE35 (90W, 0.78Nm, 340g) for the hip roll and ankle pitch joints, and RE25 (20W, 0.24Nm, 130g) for the hip yaw and ankle roll joints.

All motors for the pitch are connected to Harmonic Drive (HD) gears. The types of the Harmonic Drive gears are CSF-25-100-2A-GR and CSF-20-160-2A-GR [9]. Harmonic Drive gears are zero-backlash speed reduction system, light and compact in relation to the large torque. The other motors are connected to high ratio hipoid (MHP) gears . The hipoid gears are also high reducation ratio, precise and high performance. We adopted MHP1-0601R, MHP1-1060L from Kohara gear industrial company [10].

Table 2 shows that the maximum torque of each joints are bigger than the torque condition of Table 1. Thus, KENSEI-chan has a capability of running at the speed of 2.5m/s.

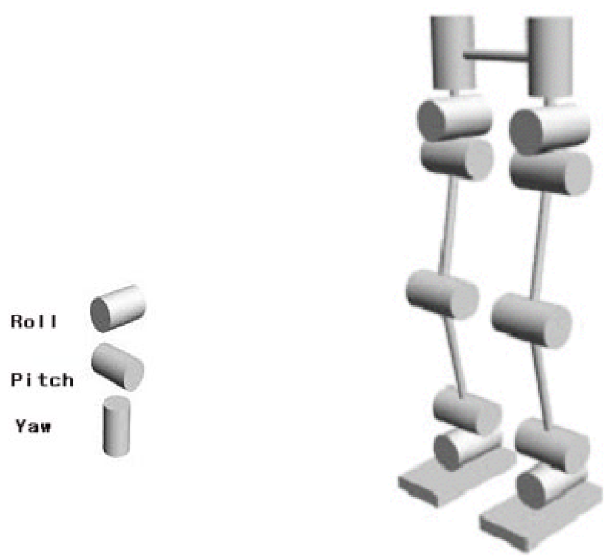

Fig. 1. DOFs configuration

		Motor Power [W]	Gear		Max. Angular Velocity [rad/s]	Max. Torque [Nm]
			Type	Ratio		
Hip	Pitch	150	HD	100	8.4	230.0
	Yow	20	MHP	60	12.0	14.0
	Roll	90	HD	100	8.1	78.0
Knee	Pitch	150	HD	100	11.3	170.0
Ankle	Pitch	90	HD	160	6.0	127.0
	Roll	20	MHP	60	6.0	28.0

Table 2. Robot Joint Specifications

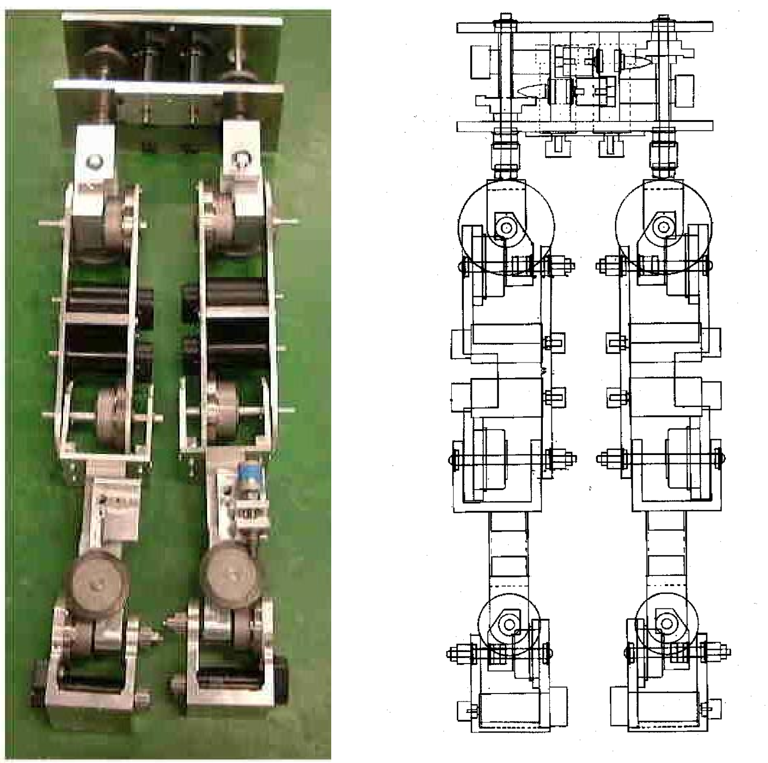

Fig. 2. The mechanical design and a photo of the lower part of KENSEI-chan

3.2 Mechanism for Running

To realize the efficiency running like human, we have developed REJs (Rotary Elastic Joints) for knee joints shown in Fig.3. In REJ, the output of reduction gear is connected to a torsion spring directly, and the torsion spring is connected to the lower leg of KENSEI-chan directly. Thus, the output of gear and the lower leg is connected indirectly via the torsion spring.

The shock of touchdown is stored as the elastic energy of the spring, and the elastic energy is used for the flight phase.

Besides, REJ can measure the torque of the knee joints by a potentio meter which measures the spring deflection.

The basic idea of using the spring for dynamic locomotion is not new. For example, Marc Raibert developed Series Elastic Actuators (SEAs) [11]. They are composed of a spring in series with the output of the actuator, after the gear reduction (ball screw).

However, they are reciprocating motion. About a motor and the combination of the Harmonic drive, the REJs are suitable compared with SEAs. By using the Harmonic drives, the mechanism of the humanoid can be simplified.

4 Conclusions

This paper introduced the mechanism of KENSEI-chan under development for the RoboCup Humanoid League. The lower part of KENSEI-chan has almost completed, the upper part equipped a processing system (Pentium III 1GHz) and various sensors (FSR, CCD camera, gyro, encoders) will be completed by the end of this year.

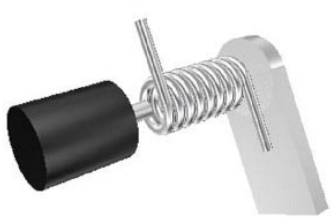

Fig. 3. Image of Rotary Elastic Joint

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