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A Self-Supporting Quadruped Walking-Robot

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A robot has been constructed which is capable of walking with four legs with neither external controller nor external power supply. The gait of the robot is a simulation of the gait of a real pony, data of which were collected from a videotape of a walking pony. A mechanism which may provide a light weight structure with high strength, is applied to all 9 joints on the body. Most of the ICs in the hardware are C-MOS versions effective for the reduction in electric consumption. Servo pulse motors to be controlled by CPUs are adopted on this robot to reduce the weight and increase the controllability of the robot.

1. Introduction

Recently, many processes of production are being automated by computers in factories. A great advance has been made in the speed and accuracy of the action of robots. Some robots which have recently been developed[1-3] can walk stably. Most robots cannot move for themselves without outer controllers or power supply, because they need not only heavy servo motors containing servo packs but also a large quantity of electric current[2,4,5]. We have been studying motors for the intelligent robot, and have recently developed some robots (e. g., a micro cat, i. e., a quadruped walking robot). We have developed a self-supporting quadruped walking-robot capable of walking without cables connected with external controllers and power supply. The features of this robot are as follows:

1. The mechanism of each joint is improved so that light structure may be provided with high strength.
2. Most ICs in the hardware are composed of C-MOS versions in order to reduce electric consumption.
3. Drivers of motors are light because they employ 8-bit processors.

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In this paper, the outline of the mechanism and control method is described in sections 2 and 3, respectively.

2. Mechanism

The self-supporting quadruped walking-robot is modeled after a real pony. The joints and degrees of freedom of this robot are shown in Fig. 1, where symbols "A" to "I" refer to the joints and those "1" to "10" to the motor. The robot has nine joints, the number of degrees of freedom of joints "F" and "H" is two, and that of the other joints is one. Joints "A" to "H" consist of a reduction gear and a motor system. Joint "I" has no motor, serving to absorb the strain of the robot.

Figure 2 shows the structure of the joints, Fig. 2-a) the structure of the legs, and Fig. 2-b) the structure of the front shoulders. The joints of each leg must support the dead load of the robot. Therefore, the joints have to be locked while the motors are out of action; the set of a worm wheel and a worm gear, which is used for the reduction of gear ratio and has the character of self-lock, is hard to rotate under external forces. For reducing the weight of the transport system of each joint, we use timing-belts and pulleys. The reduction ratio of motors 1 to 8 is 30 to 1, and that of motors 9 and 10 is 12 to 1.

The motor system was improved in that the interactive DC motor we had developed before[6] was provided. The motor system is featured by its high reliability in high speed rotation, and is capable of keeping correct positioning.

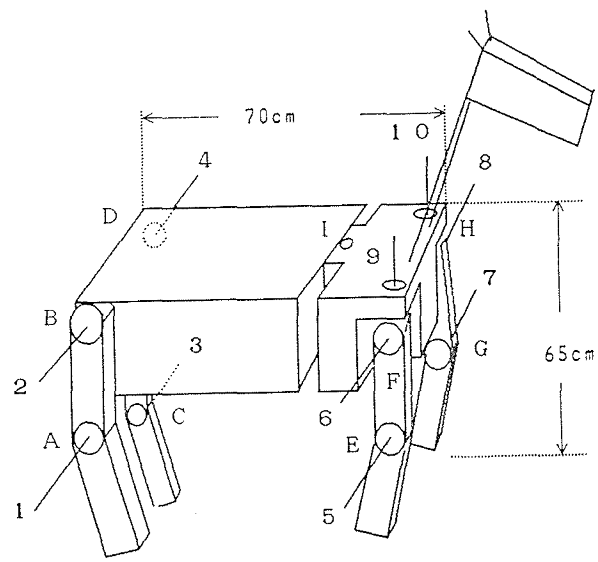

Fig. 1 Overview: the joints and the degrees of freedom.

The driver circuit of each motor comprizes an 8-bit CPU, which secures high reliability in the state of overload. Figure 3 shows the range of degrees of freedom for each joint. The range of movement of motors 1, 3, 5, and 7 is from 0° to 96° and that of motors 2, 4, 6, and 8 is from −48° to 48°. These joints

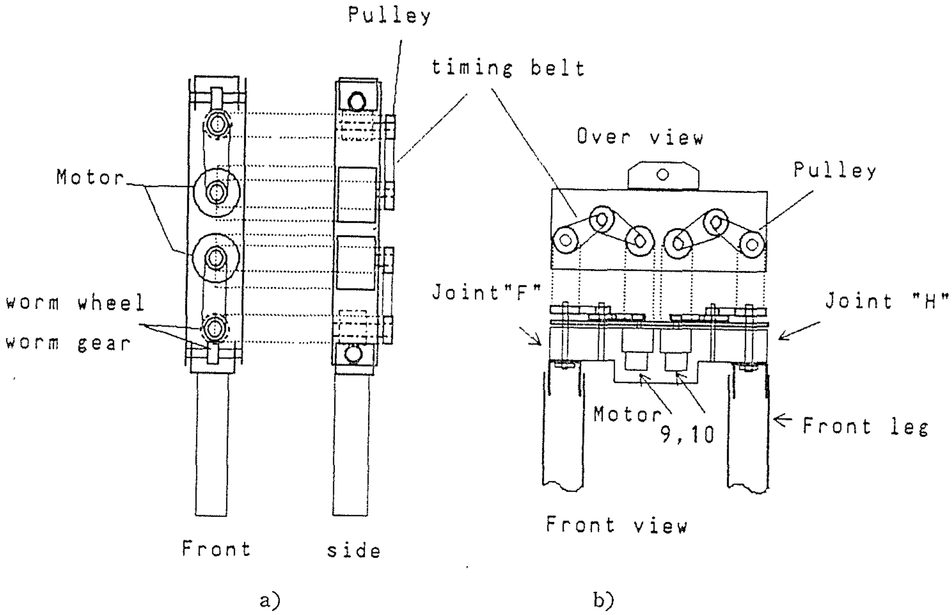

Fig. 2 Structure of the joints: a) shows one of the legs: b) shows the shoulder.

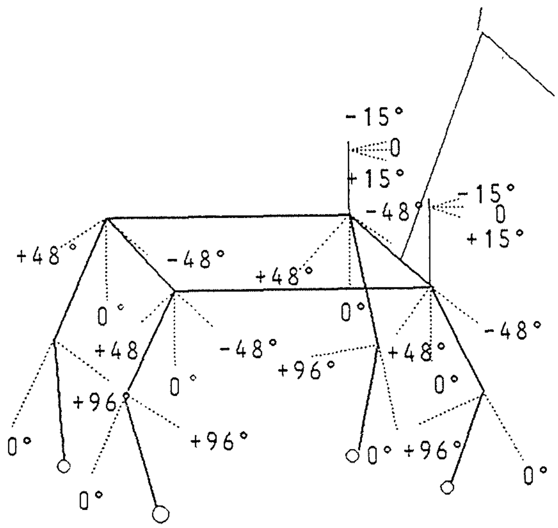

Fig. 3 Range of movement of the joints.

have absolute encoders. The range of movement of motors 9 and 10 is from −15° to 15°.

This robot is made of aluminum board, weighing about 70 kg. The control unit (comprizing CPU, I/O, I/F, and Driver) and power regulator are installed in the body of robot, and the batteries are attached on its back.

3. Control of the Robot

3.1 Control method

It seems that there are two kinds of control methods of robots, one of which is static and the other is dynamic. The dynamic control has been studied by many researchers.[7] Practically, these methods of robot control utilize feedback control. When these methods are handled by a CPU, decrease in processing speed (for reading the information from the sensor and controlling the motor) will raise a serious problem. For our robot, the control method adopted is dynamic, working in such a way that usual walk is executed by a hardware-

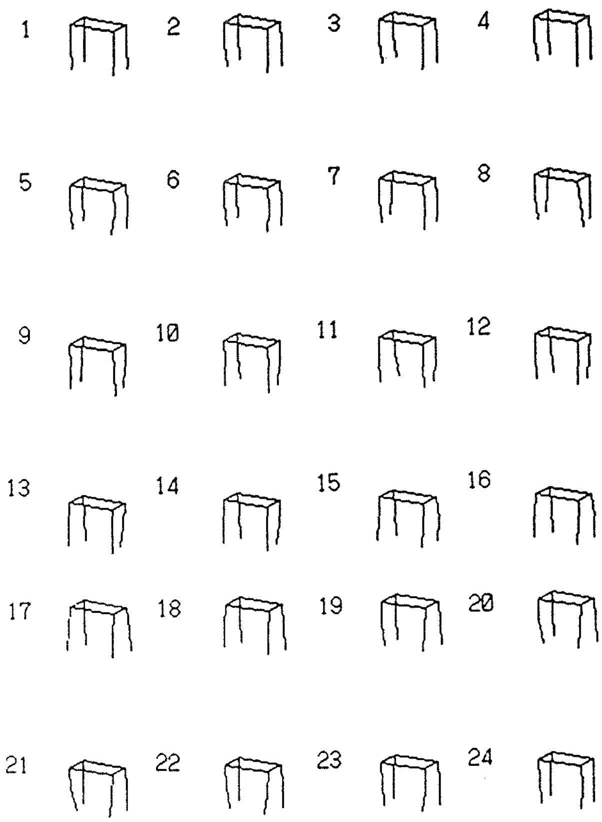

Fig. 4 Examlpe data obtained from pictures of a videotape recording a real pony

logic independent of the CPU, the hardware-logic produces pulses from written data in ROMs for each motor, and that the CPU reads information from the sensor and encoder and keeps checking the state of the robot.

The initial conditions of the robot and its handling (turning to the left or right) are controlled directly by a CPU, and the CPU processed handling for walking is controlled by hardware-logic.

Each motor is controlled by a CPU or hardware-logic, and the control method using hardware-logic is as follows. The hardware-logic reads a data written in ROMs by a clock different from the CPU clock, and each motor is rotated by this data. The frequency of this reading clock can be changed, and it is possible to control the walking speed of the robot by changing this frequency. The CPU gives the hardware-logic the initial address of ROMs and controls the hardware-logic.

Data in ROMs are produced from videotape pictures which have been taken with a walking pony. First, we got data on the correlation of every joints with a computer (data shown in Fig. 4). Next, the data were changed in form from

	ROM 1 Direction D7,D6,··,D2,D1,D0	ROM 2 Pulse D7,D6,··,D2,D1,D0	ROM 3 D7,D6,··,D2,D1,D0
0	0 1 0 1 0 1 0 1	1 0 1 0 1 0 1 0	1 1 1 0 0 0 0 0
1	1 1 0 1 0 1 0 1	1 0 1 1 1 1 1 1	0 0 0 0 0 0 0 0
2	0 0 1 1 0 1 1 1	1 1 1 0 0 1 1 0	1 1 1 0 0 0 0 0
3	1 1 0 1 1 1 1 1	1 0 1 1 1 0 1 1	0 0 0 0 0 0 0 0
·	· · · · · · · ·	· · · · · · · ·	· · · · · · · ·
·	· · · · · · · ·	· · · · · · · ·	· · · · · · · ·
·	· · · · · · · ·	· · · · · · · ·	· · · · · · · ·
	· · · · · · · ·	· · · · · · · ·	· · · · · · · ·
	0 1 0 1 0 1 0 1	1 0 1 0 1 0 1 0	1 1 1 0 0 0 0 0
	1 1 0 1 0 1 0 1	1 0 1 1 1 1 1 1	0 0 0 0 0 0 0 0

ROM1 & ROM2

D7 : Motor 8
D6 : Motor 7
D5 : Motor 6
D4 : Motor 5
D3 : Motor 4
D2 : Motor 3
D1 : Motor 2
D0 : Motor 1

ROM3

D7 : Motor 9(Pulse)
D6 : Motor10(Pulse)
D5 : Motor 9(Direction)
D4 : Motor10(Direction)
D0 : Endflag of data

Fig. 5 An example of a pattern of data of ROMs.

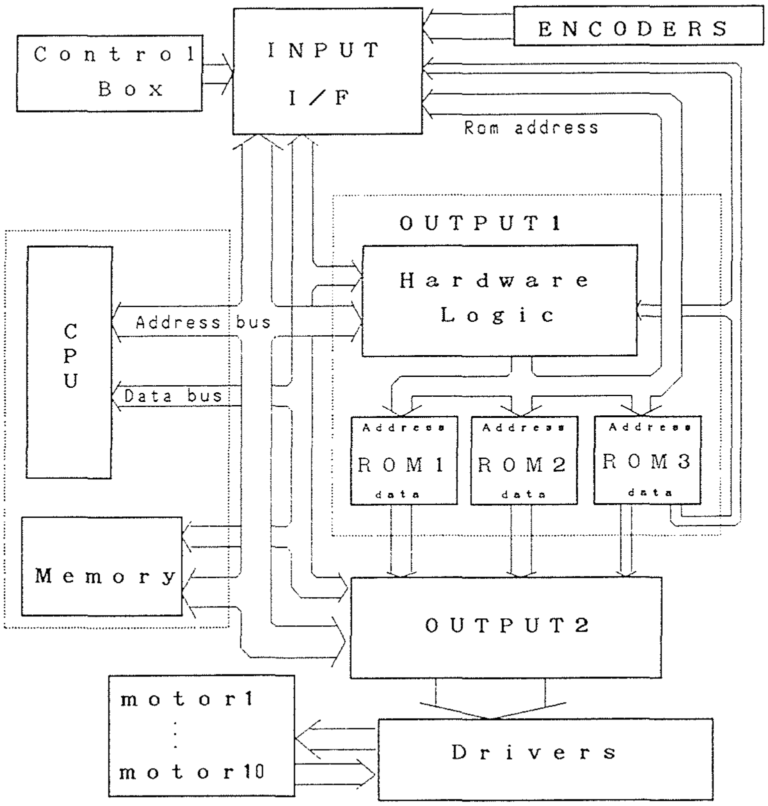

Fig. 6 Overview: a block diagram of the hardware-logic.

graphic information to data of the degrees of joint, and further to a row of direction angles and also to a sequence of pulses. In Fig. 5, a format of ROMs are shown. Direction data of motors 1 to 8 are stored in ROM1, and pulse data in ROM2. Data D4 to D7 are for motors 9 and 10, and data D0 in ROM3 indicates an end of moving cycle.

3.2 Control hardware

The structure of the control hardware is shown in Fig. 6. The hardware consists of blocks such as 10 drivers for the motor, an input-interface, an output-interface, and a control-box. The control hardware uses no servo packs for the reduction of weight of robot. Most of the ICs in this logic are C-MOS versions for the decrease in electric consumption, and absolute encoders are installed on the working points of motors 1 to 8. In OUTPUT 1, three ROMs and a hardware-logic to read ROM are arranged, by which the read address and read clock are formed. OUTPUT 2 chooses data from OUTPUT 1 or the CPU and sends them to the driver circuits. It changes the data format for the

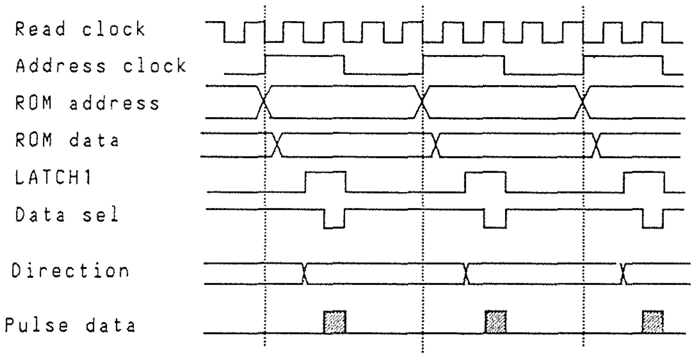

Fig. 7 Timing diagram of the hardware-logic.

drivers of the motor and sends data to the driver circuits. I/F is an input interface, which has 10 input ports to read data of each encoder, controlling data, and addresses to read ROM.

Timing diagrams for reading data from ROMs, changing data, etc. are shown in Fig. 7. The binary counter in OUTPUT 1 produces a ROM address, and the initial address is set by the CPU. The clock to count up addresses is controlled by a CPU or by a flip-flop changed by bit 1 (=D0) in ROM 3.

The direction data read from ROM is latched by LATCH1, and pulse

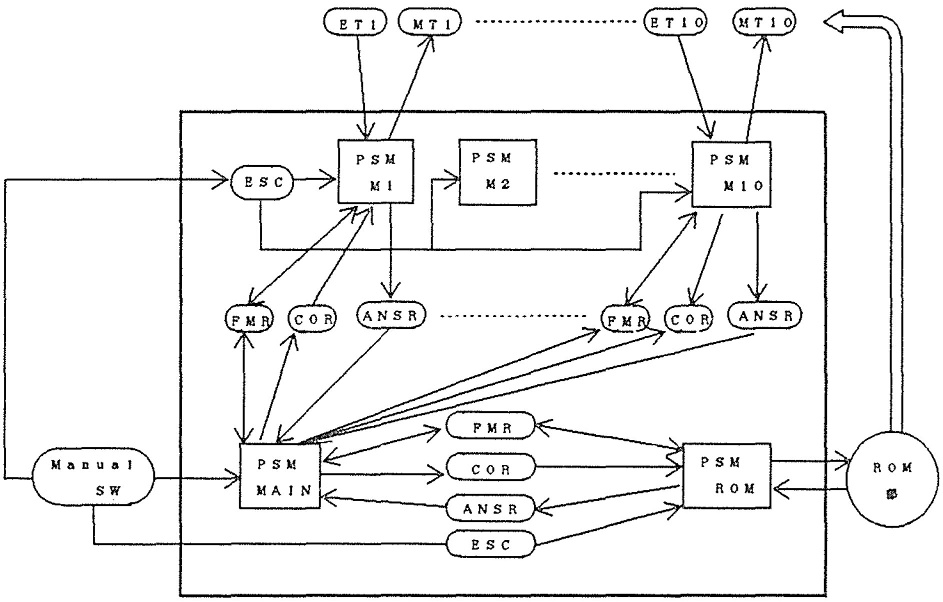

Fig. 8 A block diagram of the control software.

data are sent to the driver while a Data Sel line is low. The data which are pointed by the ROM address are read simultaneously from ROMs 1 and 2. The motor rotates one step (1.8°) during the rising phase of the wave form produced from the pulse data.

Three 12V batteries are used for operation, one being used for the control unit and the others for the motors. The 5V voltage for the control unit is produced by the switching regulator from 12V voltage; the service duration of the battery was about 20 minutes in our system.

3.3 Software to control the robot

The software is written by the PSM method[8] so that concurrent processing may be effected. Figure 8 shows the block diagram[8] of this software, which is composed of 12 PSMs, PSM-MAIN, PSM-M1, ……, PSM-M10, and PSM-ROM. All the PSMs move concurrently; PSM-MAIN serves to control the whole robot, PSM-Mn (n=1 to 10) serve to control each motor directly, and PSM-ROM serves to control the hardware-logic for reading data in the ROM.

4. Conclusions

This robot can walk as fast as about two meters per minute. It can reproduce continual walks without conducting any calculation for maintaining equilibrium. Parallel processings of hardware and software have enabled the robot to walk smoothly and at high speed. We are planning to prolong the duration and increase the speed of walk.

5. Acknowledgment

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