INTERNATIONAL CENTRE FOR MECHANICAL SCIENCES

COURSES AND LECTURES No. 201

Ro. man. sy. '73

FIRST CISM - IFToMM SYMPOSIUM
5 - 8 September 1973

ON THEORY AND PRACTICE OF ROBOTS AND MANIPULATORS

VOLUME I

UDINE 1974

SPRINGER - VERLAG WIEN - NEW YORK

INFORMATION–POWER MACHINE WITH SENSES AND LIMBS (Wabot 1)

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Summary

The WABOT project is aimed at developing an information-power machine to introduce external and internal informations, judge the same by itself and perform a given action autonomously. The WABOT-1 consists of a human-type biped walking machine provided with artificial ears and mouth to receive a vocal command from the operator and make a vocal response, artificial eyes to recognize the position, distance and direction of an object and human-type bilateral hands. Under the control of a mini-computer as the artificial brain and on the basis of external informations received from the visual, auditory and dermal senses, etc., the WABOT-1 performs a given work in linked motions of hands and feet in on-line real time.

Zusammenfassung

Theoretische Untersuchung zweibeiniges Gehens is notwendig für Erkentnisse von menschlichen Gehen und für Konstruktion von künstlichen Beinen und von Gangmaschinen. Dynamische Stabilität ist eine Hauptfrage in diesem Gebiet.

Eine Methode zur Stabilitätsregelung einer Gangmaschine wird vom dynamischen Gesichtspunkt aus behandelt. Unter der Voraussetzung, dass die Maschine mit einem festen Körper und zwei Beinen ohne Masse ausgerüstet ist, wird ihre Bewegung im Hinblick auf die Reibungskraft zwischen dem Fuss und dem Boden untersucht. Die Regelungsmethode kann ein der beim menschlichen Gehen auf der Ebene erwiesenen Charakteristik gleichendes Bewegungsbild darstellen.

1. Advent of Robot

The Group of Bio-Engineering in Waseda University has been carrying out a robot project these five years. Principal particulars of the specification are as follows:

A. To move on a human-type biped walking machine.
B. To work with bilateral artificial hands of a human type.
C. To provide hands and feet with joint angle sensors for each joint as proprioceptive means.
D. To provide a sense of equilibrium for a biped move.
E. To provide hands with contact sense for work.
F. To provide artificial eyes as remote receptors.
G. To use a minicomputer as the brain.
H. To speak and listen Japanese sentences.

We named the robot "WABOT (WASEDA ROBOT)-1". Fig. 1 shows the complete figure of Wabot-1.

2. Construction of Biped Walking Machine WL-5

The basic construction of the machine model is a joint construction of a revolving movement type, with each being of a hinge structure with one degree of freedom (Fig. 2). The machine model possesses 11 joints i.e. two plantal joints to incline the whole feet to the left or right for shifting the center of gravity to the left or right, two ankle joints, two knee joints, two hip joints, two loin joints for direction change and one body joint to incline the upper part of body to the left or right to help a lateral shift of the center of gravity. Hydraulic pressure is employed as a drive source and hydraulic circuit components except a power unit are built in. Further, the actuator is a cylinder of a direct-acting type. The weight of the machine proper is approx. 130 kg, and a meter-out system (and partially a meter-in system) is employed in the hydraulic circuit with a working pressure of 70kg/cm^2.

Each joint employs a rotary type of potentiometer to form an angle control mechanism. This mechanism is controlled in applying the gait pattern, which corresponds to a continuous walking behaviour and is divided into some characteristic phases. By realizing such discontinuous phases successively by the angle control mechanism, one gait pattern is performed. This gait pattern is stored in CPU as digital data and gives out each phase one after another when an order for walking is given from outside (man or other subsystems: eyes and ears). The components of the system and their operations are explained as follows. Upon an order for walking, a phase stored in the first address is given out from CPU. (Fig.3).

CPU digital output unit: Within CPU, one phase is stored in one address and a collection of such phases constitutes one gait pattern.

Discrimination circuit: Each phase is a set of angle values to be taken by each joint. The value of the aim angle is D/A-converted and compared with the value (obtainable from a potentiometer) of the existing angle of each joint.

Mechanical model: Depending on whether the error is positive or negative, the cylinder expands or shrinks and as a result, each joint reaches an aim angle required by the phase.

Detecting circuit: The phase is realized when all the joints have reached those aim angles. A pulse is given out at that time.

CPU digital input: If the said pulse enters CPU, the address advances by one step and the next phase stored in the second address is given out.

By achieving a series of phases successively in this way, one gait pattern is accomplished and walking is realized. Further, in any phase during such walk, the center of gravity of feet falls within the sole in a standing phase and therefore a statically stable walk takes place at all times.

3. Human-type Bilateral Artificial Hands

The manipulators are of a human type and same in construction for left and right hands. Each hand has 7 degrees of freedom as in Fig. 4, comprising shoulder rotation, upper arm rotation, elbow revolution, wrist rotation, vertical wrist movement, horizontal wrist movement and opening and closing of fingers. The hand region comprises 5 fingers of a linked joint structure. Each joint is provided with a DC motor by way of a reduction gear.

As the external information detectors, microswitches acting as tactual sensation, 8 per hand, are provided in the hand region. Six of them for fingertips and palm are used for detection of a gripping condition and connected to the computer by way of a logic circuit. Signals from search microswitches, two per hand, fitted to the left and right ends of the hand region become interruption signals after passing the logic circuit.

As for the internal information detectors, potentiometers are provided for angle detection of the respective drive joints. However, the condition of opening and closing of fingers is detected by a microswitch.

Concerning the software, a program system of a hierarchical structure has been developed to simplify the orders to be given by the operator. The program comprises:

(1) A control program

(2) A basic work program module group

(3) A basic program module group

(4) A typewriter-control main program

(5) A typewriter-control subprogram module group

The control program is a program intended for causing artificial hands to perform work by controlling a basic work program.

The basic work program module group is designed for causing action as the basis of work to be done and comprises a movement routine, a search routine and a finger closing-opening routine, etc.. The movement routine is so designed that in case where the present point of hand and the target point for movement are given in three-dimensional rectangular coordinates and the hand posture in a direction cosine, it calculates transit points dividing a straight route from the present point to the target point in 8 equal parts in terms of the three-dimensional rectangular coordinates by means of a transit point calculation routine, converts the three-dimensional rectangular coordinates of the next transit point into each joint angle by means of a coordinate conversion routine and thereafter makes a move to the next transit point by means of a basic movement routine and in repeating the above processes, achieves a move to the target point via a straight route. In this case, if a calculated transit point is not included in the working range of the artificial hand, a correction is made by a transit point correction routine so as to pass a point within the working range.

In the search routine, first, if a search commencement point is given in the form of three-dimensional rectangular coordinates, one of the left and right hands is selected by left-and-right hands selection routine and a search posture is data-transferred. Each joint angle at the search commencement point is calculated by the coordinate conversion routine from the search commencement point given in the form of three-dimensional rectangular coordinates. If, in this case, the search commencement point falls outside the working range of the artificial hand, stop takes place after giving out a message to that effect. If the search commencement point falls within the working range of the artificial hand, move to the commencement point is made by the basic movement routine and search is commenced by a horizontal movement routine. If, during a horizontal movement , the artificial hand touches the object, a search microswitch provided in the hand region is turned on, applying interruption to CPU. After analyzing it by means of an interruption analyzing routine, touch of the artificial hand with the object is confirmed by a sensor utilization routine, to stop the artificial hand.

The basic program module is a minimum routine constituting the basic work program and comprises a coordinate conversion routine, a basic movement routine , a horizontal movement routine and a transit point calculating routine, etc..

The typewriter-control main program is designed for control of the artificial hand though conversations between man and the computer by way of a typewriter. The typewriter-control subprogram module causes basic actions required for control of the artificial hand through the typewriter to be performed and is controlled by the typewriter-control main program. The typewriter-control sub-program module comprises a memory executing routine and a left-and-right movement routine, etc..

4. A system for Processing Visual Data

Wabot has its eyes constructed by the two TV Cameras in its trunk, whose detector scanning lines and focusing are set by the CPU control. When searching for an object, Wabot's trunk rotates to scan the space in front with its TV Cameras.

When the scanning camera detects an object, it emits a signal which stops the trunk rotating. All data on distance and angle is detected and processed at the same time, as an 8-bit digital value. If the eyes don't detect an object, scanning lines are shifted and the detecting procedure is repeated following the software algorithm. In order to improve the accuracy of measurements, the zone focusing with a 3-step on-off control and the broadening of the visual angle for a short distance are added in the mechanism of TV Camera.

The measuring error of distance is within 7 cm at 5m, and 4cm at the shortest possible working distance of 0.6m.

Calculations of distance and angle and interrupted processing from the hardware are controlled by the software. Wabot's Eyes are built in the body of Wabot as seen in Fig. 1. Fig. 5 shows the interface of the trunk and the eyes.

In order to first catch the object within visual range, the video signals from the object are picked up by both TV Cameras (Camera I, Camera II), using the line selector for the vertical direction and the trunk rotation for the horizontal direction. The gray level of the object signal is sliced and transformed into a binary value. The jumping position of this binary signal in the Camera is counted with a 4MHz oscillator, and the gate is closed through the hold logic. When, with the rotation of the trunk, the signal made by each Camera is detected at the equal distance from the edge of its sight, the rotation is stopped. At this time, since the trunk is facing the object directly, the data for the rotating angle between the legs and the trunk to be sent to the legs is obtained, and thus the walking direction is determined. Since the distance between two cameras is known beforehand, the data for the distance to the object is also determined.

The following is a summary of the essential points to be considered with regard to the specification of the eyes of this 2-legged robot;

(1) Since the robot walks by shifting its center of gravity, many problems arise in detecting an object while walking.
Therefore Wabot's eyes were designed this time to function only when not moving.

(2) Even when Wabot is still, the detector scanning lines of the TV Cameras cannot be fixed even to a stationary object, because of the sight movements made in both vertical and horizontal axes. In the trial system, 64 different scanning lines were made available for selection, and one of them was selected by the software.

(3) The walking direction as well as the distance must be determined prior to starting to walk, since it is necessary to set the robot in the right direction facing the object.

(4) Since a mini-computer is used, data is processed by hardware as much as possible.

5. Speech-Input-Output System

The Speech-Input-Output System recognizes voice commands to the WABOT and makes vocal responses to the operator. It involves the problems of pattern recognition, understanding of meanings and speech synthesis by computer (Fig. 6).

The circumstances around the WABOT and the jobs which it can perform are limited in this case. The command sentence to the WABOT consists of a string of Japanese words which are separately spoken with pauses between them. Japanese sentences have a little flexibility in the order of words which, compose them, so that the system is designed to recognize the differently ordered sentence for the same meaning.

If some words cannot be recognized or the command is not appropriate for the situation the system makes the vocal response such as not understandable , inadequate or impossible and it asks to operator to repeat the command sentence. If an imperfect sentence in meaning was spoken, it asks a question to make the sentence completed. And when the voice command is accepted, it repeats the command by the speech synthetizer and then produces the command codes for the control system to move the WABOT.

(1) Recognition of Speech

Speech sounds (voice commands) are at first preprocessed after catched by a microphone and the features are extracted by the hardware feature extractor. They are fed into a minicomputer in which they are used to generate a string of phonemes by the phoneme recognition program. And the string of phonemes is put into the word recognition program where the values of discriminant functions for the words of candidates are calculated. The discriminant functions are linear functions with variables which represent the transition of phonemes in a string, and the coefficients of which are estimated through a learning process. Because of learning ability, the vocabulary which can be recognized are easily changed.

(2) Understanding of Meaning

It is difficult to treat generally this problem. Therefore in this case the circumstances have been restricted to the situation that the WABOT walks the specified steps, turns round to right or left and stops according to commands.

The command sentences are composed of a string of words, STOP, BEGIN, WAIT, WALK (GO), TURN RIGHT, LEFT, ONE STEP, TWO STEPS, and THREE STEPS. These words are grouped into four classes according to their parts of speech and their meanings, which are VB1, VB2 (verbs), AD1, AD2 (adverbs). Possible sentences from these words are also grouped into six classes according to their structures.

To make it easier to properly recognize what sentence is spoken and what is the meaning, three types of states of the WABOT are introduced. They are:

ST1 : the state waiting for a command,

ST2 : the state after it recognized a command and waiting for the final instruction, "wait" or "begin", and

ST3 : the state carrying out a job and waiting for the command to stop or no command.

In deciding the kind of the sentence was spoken and the meaning, a dynamic programming technique is used.

(3) Synthesis of Speech

The terminal analog synthetizer is used to make vocal responses. The method of synthesis by rule is adopted. A word is made of a string of phonemes, each of which has the specified pitch, length and strength.

6. Central Processing Unit and Interface

Central processing unit (CPU) is a minicomputer with 8k words (16 bits/word) core memories, while interface has been designed to relay all signals between CPU and various subsystems of the WABOT.

(1) Hardware

The interface blockdiagram is illustrated in Fig. 7.

Analog input (AI) includes multiplexer (MPX) sampling and holding circuits, A–D converter (12 bits) and decoder to analyze a control signal from the CPU.

Digital input (DI) part is constructed from data register, interruption register, channel register, channel decoder, timing pulse generator and order decoder to analyze various instructions from the CPU.

Analog output (AO) contains two D–A converters, output gates, instruction decoder. These D–A converters have 12 bits buffer register for each signal.

Digital output (DO) is composed of data register, channel register, channel decoder, timing pulse generator and order decoder to analyze IOC instructions.

Timer generates timing pulses to start A–D conversion, D–A conversion and to control WABOT systems in constant time interval.

(2) Software

Special operating system program (WABOS) is prepared for WABOT use.

WABOS is divided into the following six programs.

(a) Loader

Loader includes two types, WABOL (1) and WABOL (2).

The former loads a task registered by scheduler to core memory, while the other loads a task by interruption which is not in core memory, during program running state.

(b) Scheduler

Scheduler (SCH) includes two types, SCH (1) and SCH (2).

SCH (1) regists various tasks prior to program performance and SCH (2) passes and receives program control during program running state.

(c) Interrupt analysis routine

The routine analyzes the origin of interruptions.

(d) Interrupt service routine

The routine analyzes every interruptions from input output devices and those from CPU in order to service these request, that is, if the interruption is the one from 10 devices, the routine looks a table (Event control table) and rewrite the table, then transfers control to scheduler (1).

(e) Macro-service routine

Two types of macro-instructions are prepared. There are eight 10 macro-instructions and seven data request macro-instructions.

10 macro-instructions are, for instance, transfer instruction that moves the contents of the accumulator to output data register, read instruction of analog data to the accumulator, etc..

Data request macro-instructions, for instance, CALL instruction is utilized to call subroutines under OS supervisory, END instruction that ends all operations on main task.

(f) Function subroutine

The subroutines are divided into two groupes, basic function subroutines and conversion subroutines.

7. Conclusion

At the present stage because of the restriction of CPU memories the total operation is not yet made. However, the following experiments have been completed for each subsystem:

(A) Foot subsystem

After loading with a load of 20 kg, the machine model was able to perform the various walking a straight walk and a direction change to the left or right under the control of CPU.

(B) Hand subsystem

In an example of work, the machine model receives an information on the position of an object on a desk from the visual information processing system via CPU, searches the vicinity and completes a searching work when the hand microswitch acting for a tactual sensation touches the object and is turned on, grips the object and passes it into the other hand, after which it moves to the garget point.

(C) Eye subsystem

An experiment was conducted by manually setting a command from the computer to the eye interface mechanism, in which the object detection mechanism, angle detection mechanism and WABOT torso control mechanism (TV Camera focus control , sight extension control, torso rotation control) were able to carry out required actions.

(D) Voice subsystem

By combining the speech input-output system and the foot subsystems it was possible to perform limited actions by voice commands.

ACKNOWLEDGEMENTS

The authors wish to thank the Group of Bio-engineering of Waseda University for their cooperation.

The work was financially supported in part by the Group project organized by Science and Engineering Research Laboratory Waseda University and Grant-in-Aid for Fundamental Science Research from Japanese Ministry of Education.

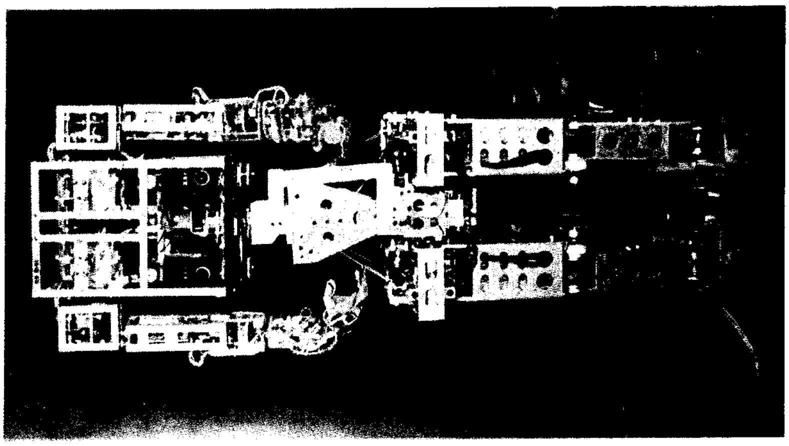

fig. 1 Wabot-1

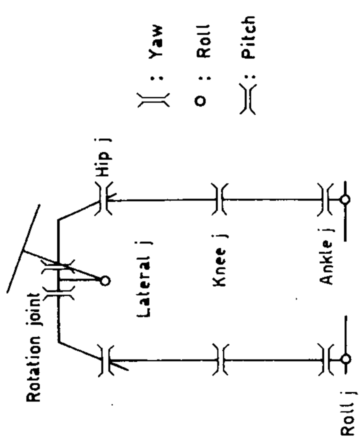

fig. 2 Degrees of freedom of WL-5

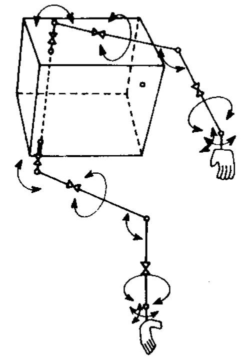

fig. 4 Degrees of freedom of WAM-4

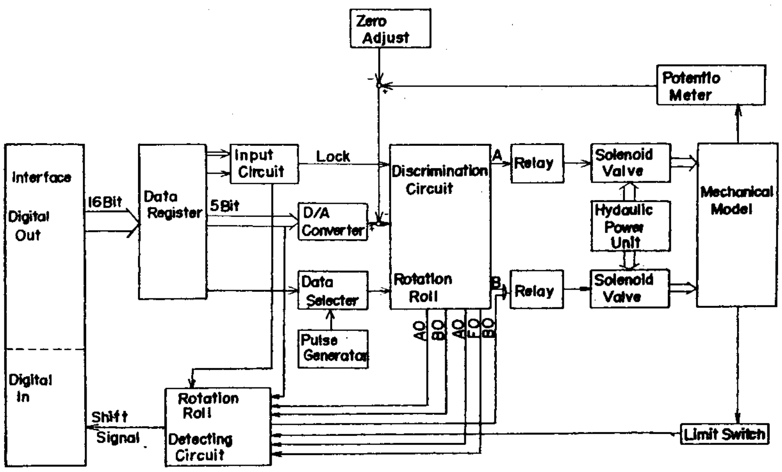

fig. 3 The control system of WL-5

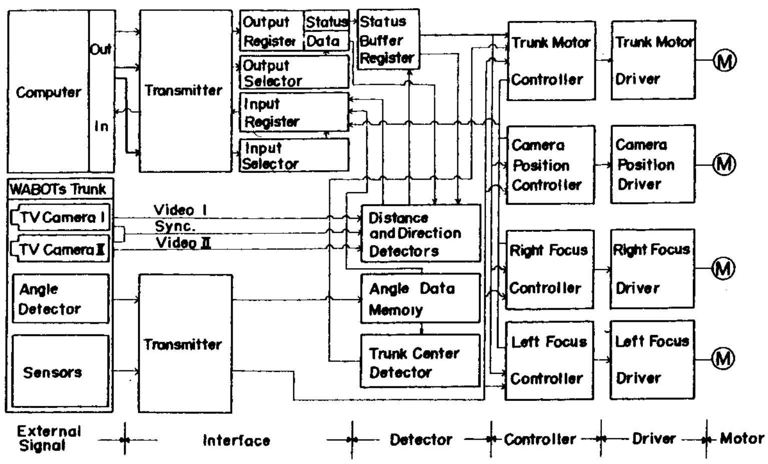

fig. 5 Block diagram of Wabot's eyes and their control system

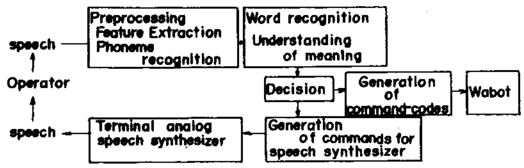

fig. 6 Block diagram for speech-input-output system

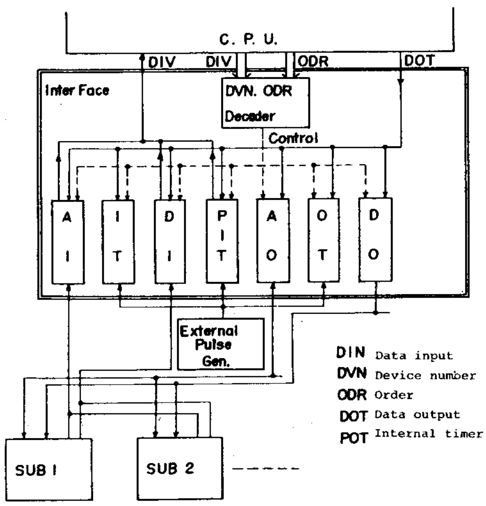

fig. 7 Interface