Mechanism and Machine Theory Vol. 16, pp. 21–29
Pergamon Press Ltd., 1981. Printed in Great Britain

0094-114X/81/010021-09$02.00/0

Guide Dog Robot—Its Basic Plan and Some Experiments with MELDOG MARK I

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Received for publication 11 July 1980

Abstract

One of the strong desires of more than a quarter of a million blind persons in Japan is orientation and/or mobility. This project of a guide dog robot, which we call MELDOG after Mechanical Engineering Laboratory, has just started to help the blind walk more safely by applying the techniques of robotics and man-machine system.

The function of a guide dog is composed of two parts: namely, obedience, which corresponds to the guidance, and intelligent disobedience, which corresponds to the obstacle detection. We are aiming at the realization of these functions by machines.

In order to realize the guide dog robot system a designer has to solve four problems. He has to make the robot move along the street and let it know its position and orientation, to establish the communication between the blind person (master) and the robot (guidance of the master), to detect obstacles or dangerous situation, and to construct the organized map of streets for the robot.

We started from the second problem, and so far made an experimental hardware and realized the communication between the master and the robot successfully. In this paper the basic plan of MELDOG and some experiments using this experimental hardware are reported. The robot proceeds in front of the master and is controlled so that its speed is the same as that of the master, keeping the distance between them constant of 1 m. The safety zone is set, in which the master is permitted to walk. When he is out of the zone, the robot warns him using electrocutaneous stimulation.

1. Introduction

Mechanical Engineering Laboratory which belongs to the Ministry of International Trade and Industry has just started a 5-year-project of walk guide robot to help those who unfortunately lost their sights.

This project, which started in the fiscal year of 1977, is a rather fundamental research project to study control and communication problems of a man-machine system, i.e. (1) how the robot guides itself by using landmarks set in a town, and how a blind person follows the robot (control of a man-machine system) and (2) how the blind person can find out obstacles making use of the visual and ultrasonic sensors on board the robot (obstacle detection by man-machine cooperation).

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This project by no means aims at reproducing the guide dog itself completely, but to extract fundamental functions of a guide dog and to realize those functions by a method appropriate to machines. But since the ultimate goal is a guide dog, we call this project MELDOG after the name of our laboratory.

One of the strong desires of more than a quarter of a million blind persons in Japan is orientation and/or mobility. The devices which have been studied are: (i) canes, (ii) electronic devices such as Kay's glasses[1] or the laser cane[2], and (iii) image production by the direct stimulation of visual cortex[3].

Canes (i) relate to the Hoover's technique which is a very fundamental training for the blind in Japan. By this training blind persons can construct their own images of orientation (Mental Map). The training with a long cane is indispensable for using other aids.

The Kay's device fixed to the frames of glasses (ii) which uses the ultrasonic sound like bats do is a very effective device but it feeds back all the information successively without sophisticated processing so it may tire the blind person.

Image production by direct stimulation (iii) is an essential way to solve the problem in a sense, but it is very dangerous in another sense realizing our very limited knowledge about human brains.

The dog guide is a very excellent way to guide a blind person using the animal's wonderful ability of pattern recognition and adaptability. But it also has demerits because it is an animal: Since the breeds of dog which can be trained are limited and training is very hard, the total number of guide dogs is also limited (about 200 at present and will not increase rapidly in future). A guide dog is mortal, may become ill, must be fed, must be walked, and it excretes. Thus it requires much labour of the blind person's family. Adding to this it is inhibited to keep a dog in almost all apartment houses in the metropolitan areas. It means it is very difficult to have a guide dog in metropolitan areas. Thus it is of importance to have a mechanical dog guide in metropolitan areas.

The project of guide dog robot stands between (ii) and (iii), and aims at realization of some fundamental functions of guide dogs (though very limited of course) by applying the techniques of robotics and man-machine systems.

In this paper its basic plan and the experimental hardware MARK I are described and some experiments carried out with MARK I are reported.

2. Specifications of the Guide Dog Robot (MELDOG MARK I)

The functions of a guide dog can be classified into two; namely, obedience and intelligent disobedience.

The dog must obey four spoken words, "Left," "Right," "Straight," and "Stop." We must remember that it does not know where to go unless its master directs it. A blind person, however, forms a picture in his mind of his surroundings (Mental Map). Even if he visits strange places, he can easily ask directions as to the number of blocks and turns he must make to get to his destination. All he needs is a leader. The guide dog, as the leader, guides its blind master along the street, even if the street is winding. But when it encounters a crossing it stops. Then he can tell his dog when to go left, right, or forward. When they come to the curb of a street, the dog stops until its master finds the step. This function is obedience, and it corresponds to the guidance of the guide dog robot using landmarks.

Suppose that some object blocks the path of dog and master, or there is some overhanging object, like an awning. The master does not know it is there. The command he gives is "Straight". But the dog does not obey the master's command, lest its master bump his body or head. This function is intelligent disobedience. And this corresponds to the detection of obstruction by the guide dog robot.

Adding to these two main functions, the communication between the master and the dog is also necessary. In the case of the real dog, this is done by voice (from man to dog) and by a leather harness with a long handle rising from the back which is worn by the dog (from dog to man).

In order to realize these main functions by machine we have set the following specifications or functions to the guide dog robot (MELDOG).

(1) The master (the blind person) in principle takes the initiative. The master orders the robot by control switches through a wired link. The robot stops on each landmark which is put

at every crossing, and waits the master's next order (right, left, straight, or stop) and obeys it (Fig. 1).

(2) The robot detects the dangerous situation or obstruction on the road. It no longer obeys the master's command but gives him a warning and stops. Then the master searches the environment using both his remaining senses (for example, hearing or touch) and the robot as visual and ultrasonic sensors. When he finds out the situation, he gives the proper instruction to the robot. Then the robot in turn follows the instruction and guides the master to the next landmark safely (Fig. 2).

(3) The speed of the robot is controlled so that it will coincide with that of the master's walk. So if the master walks slowly, the robot also moves slowly; and if the master walks fast, the robot moves fast. And the distance between them is always kept constant. When the master is out of the safety zone set behind the robot, he is warned by the robot (Fig. 3).

(4) Full automatic guidance by setting the startpoint code and the destination code in the robot may be possible in a town with appropriate landmarks.

3. Hardware

The robot fundamentally travels from one landmark to another setting its steering angle at the value previously stored in the memory of the robot. And when it reaches the next landmark,

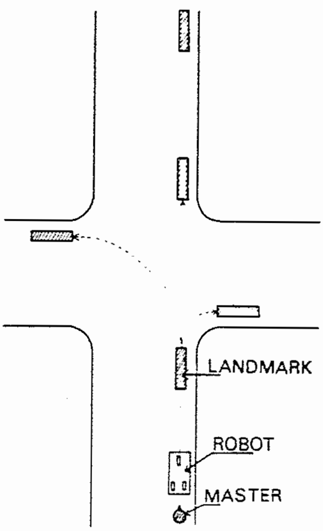

Figure 1. Guidance of robot.

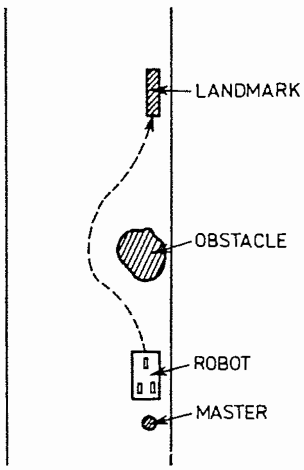

Figure 2. Obstacle detection.

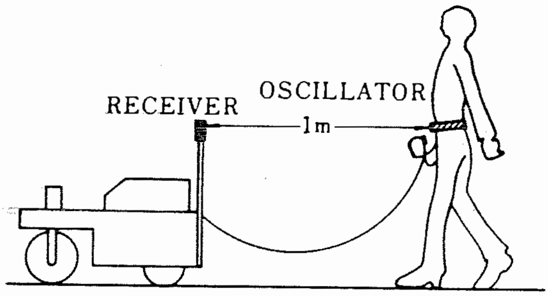

Figure 3. Guidance of master.

it adjusts its orientation and position by following the mark using the landmark sensors so that the error may not be integrated.

This requires the traveling mechanism to reproduce its track precisely and also to have fine controllability to follow the mark. In order to compromise these two requirements we adopted the front-wheel-driven-and-steered-three-wheel mechanism. For this type reproducibility of the track is mainly determined by the reproducibility of the steering angle, and this can be accomplished by using the digital shaft encoder.

Figure 4 shows the mechanism of the front wheel used. A geared d.c. print motor is put in the drum with tire, and the output shaft of the motor drives the drum while the housing of the motor is fixed to the fork. The fork in turn is steered by the steering mechanism of Fig. 7. Figure 5 shows the block diagram of the spend control circuit. Speed reference $2\Delta R$ is v–f converted and compared with the output frequency of the encoder connected to the output of the motor by using PLL (phase locked loop) circuit. When the frequency of f_{enc} is lower or higher than f_{in}, on–off switched acceleration pulse or deceleration pulse is fed to the servo-amplifier, respectively. When f_{enc} and f_{in} are in phase, no energy is consumed. By this control we were able to keep the output speed constant with minimum energy in spite of the change of load torque (Fig. 6).

In order to lessen the required torque and to improve the steering characteristics the axis of steering is set to coincide with the straight line which goes through both the center of the wheel and the touching point of the wheel on the ground. Figure 7 shows the block diagram of the

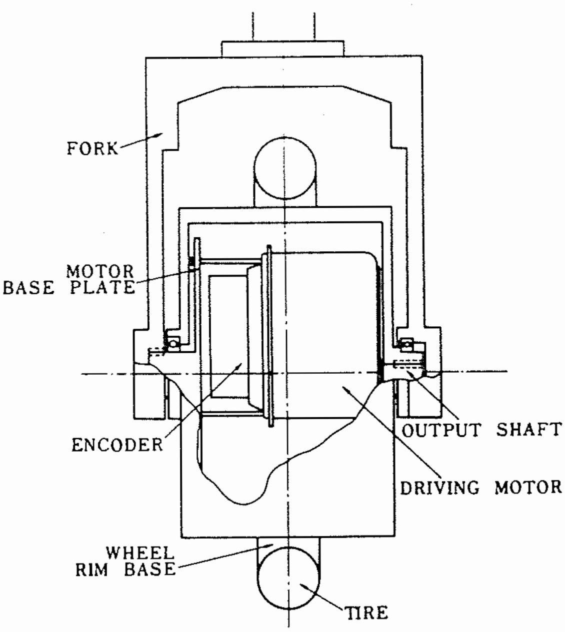

Figure 4. Front wheel mechanism.

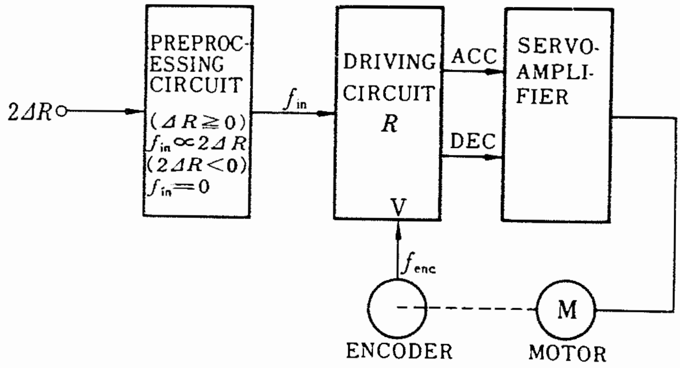

Figure 5. Block diagram of speed control.

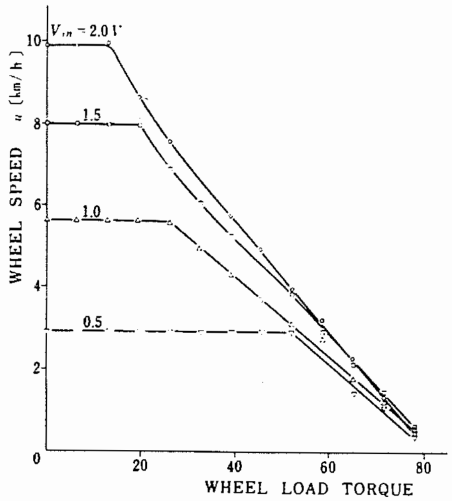

Figure 6. Speed vs load torque.

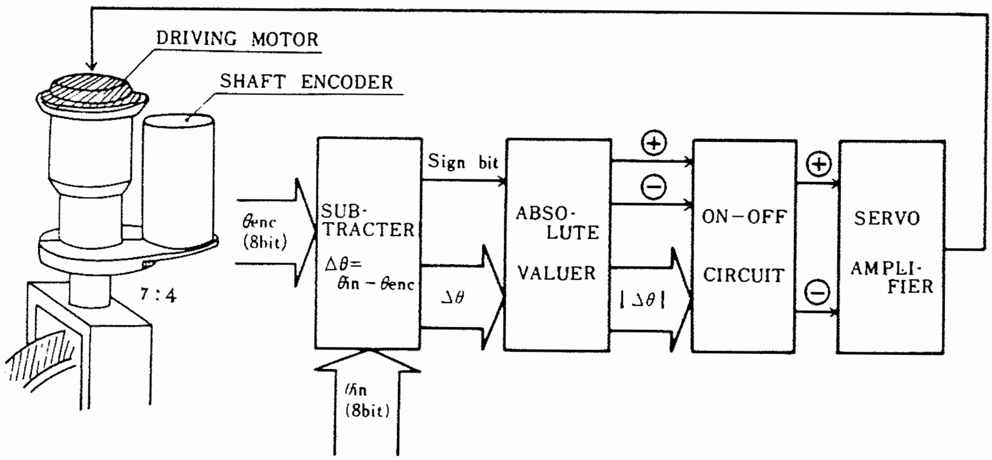

Figure 7. Block diagram of steering control.

control circuit, which uses a digital absolute shaft encoder with double gears. The steering angle is controlled to coincide with the given binary value.

Figure 8 shows an experimental result of reproducibility of the track. The binary numbers at the right-hand side are the given steering angle values and the marks in the figure show the deviation caused as a result of the 10 m traveling with the steering angle controlled to coincide with the given value. The error is within ±30 cm for each steering angle.

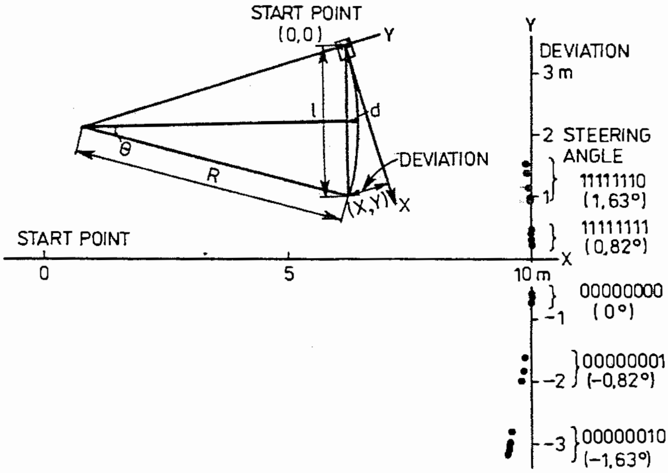

Figure 8. Reproducibility of the track.

4. Some Experiments of Man-Machine Communication (Master Guide)

For the first step of this project we tried to realize the function (3) of Section 2. This is a problem of guiding a master to follow the robot provided that the robot guides itself. In the case of real guide dogs this is done by the harness with a handle. But in the case of the robot it is not appropriate to connect the robot and the man so rigidly, for the machine is rather inflexible. The rigid connection may harm the master or it may interfere the guidance of the robot itself.

We adopted the communication wire system with ultrasonic sound (Master Guide). This consists of the flexible wire link, one end of which is a grip with control switches and electrodes for electrocutaneous stimulation, and the other end is connected to the robot. The control switches are for transmitting the commands of the master to the robot, while the electrocutaneous stimulation is for transmitting the warning signals from the robots to the master. Ultrasonic trigonometric measurement method is applied to measure the relative locational relation

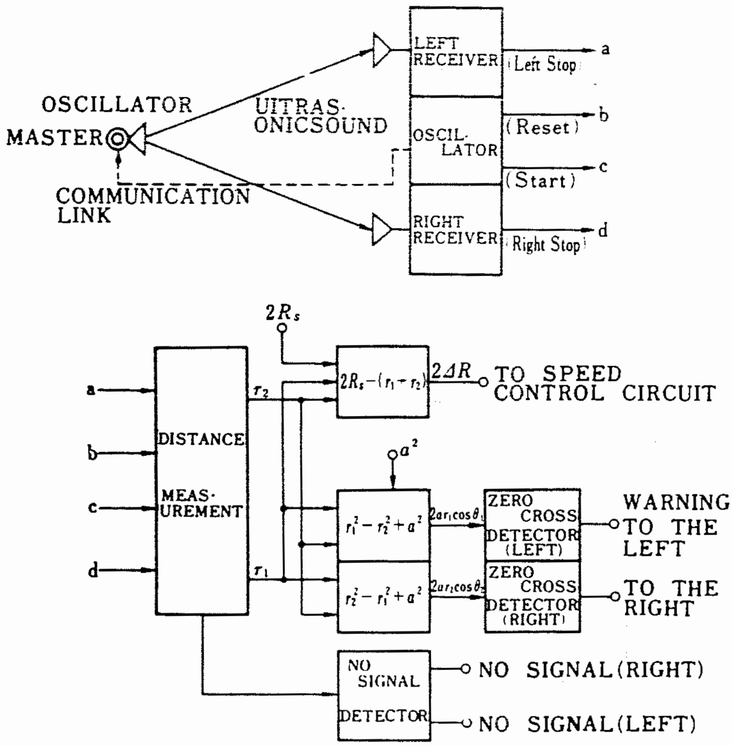

Figure 9. Block diagram of master-guide.

between the master and the robot for controlling the robot's speed to coincide with that of the master's. The result of the trigonometric measurement is also used to transmit the warning signals from the robot to the master.

Figure 9 shows the block diagram of the Master Guide and Fig. 10 shows the relation of the master and the robot. The pulse with repetition rate of 40 kHz is transferred from the robot to the oscillator which is put on the belt of the master. The oscillator in turn transduces this to ultrasonic sound of 40 kHz. The ultrasonic sound is received by the receivers set on the robot.

The distances r_1 and r_2 are measured by counting the time intervals between the transmitted pulse and the received pulse (Fig. 11). Refractory period is set just after the first pulse is received to diminish the effect of echoes and other noises. The threshold level of the comparator is set to -10 dB, for the maximum attenuation (including the characteristics of the saturation amplifier) of the signal was measured to be -6 dB and the minimum attenuation of the echo was measured to be -17.8 dB.

The distance between the master and the robot R is approximated by $(r_1 + r_2)/2$. We tried to control the distance to be nearly 1 m, so the standard distance R_s was set to be 1 m and the difference $\Delta R = R_s - R = [2R_s - (r_1 + r_2)]/2$ was fed back to the speed control circuit of Fig. 5. By this feedback the speed of the robot can be controlled to coincide with that of the master's keeping the distance to be nearly 1 m with slight offset.

Next the safety zone was set behind the robot just as in Fig. 10. The relation that the master is out of the zone is

$$\cos\theta_1 < 0 \qquad \text{or} \qquad \cos\theta_2 < 0,$$

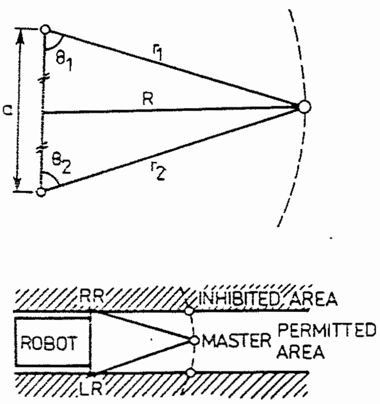

Figure 10. Measurement of distance and setting of safety zone.

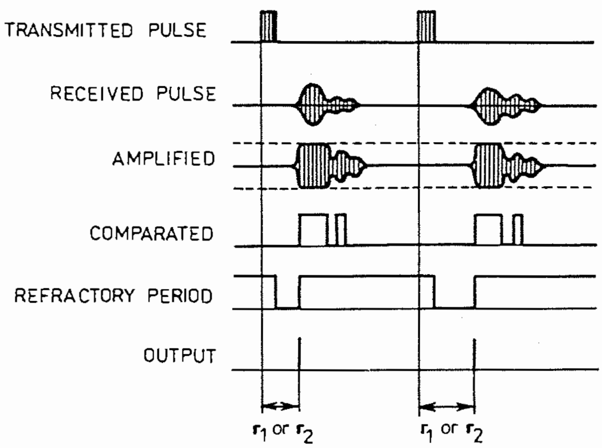

Figure 11. Waveforms of preprocessing circuit.

this relation is rewritten as:

$$r_1^2 - r_2^2 + a^2 < 0, \tag{1}$$

$$r_2^2 - r_1^2 + a^2 < 0. \tag{2}$$

So the conditions (1) and (2) were calculated using analog *IC*'s and the warning signals W_L (step to left) and W_R (step to right) were transmitted according to the conditions (1) and (2), respectively.

Moreover when the orientation of the master was bad and the ultrasonic sound was not received by the robot, no signal warnings were also transmitted from the robot to the master.

These signals were transmitted through the wire and presented to the master in the form of electrocutaneous stimulation on the skin. Two sets of Ag–AgCl wet electrodes (Beckman) were located on the skin of both brachia. The signals used were pulse train with pulse width of 100 μs, pulse height of 5 mA and duration time of 1 s. The repetition rate were 100 Hz for the

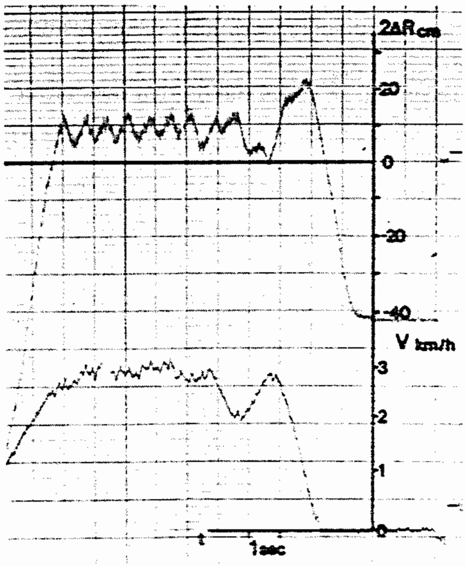

Figure 12. Result of field test.

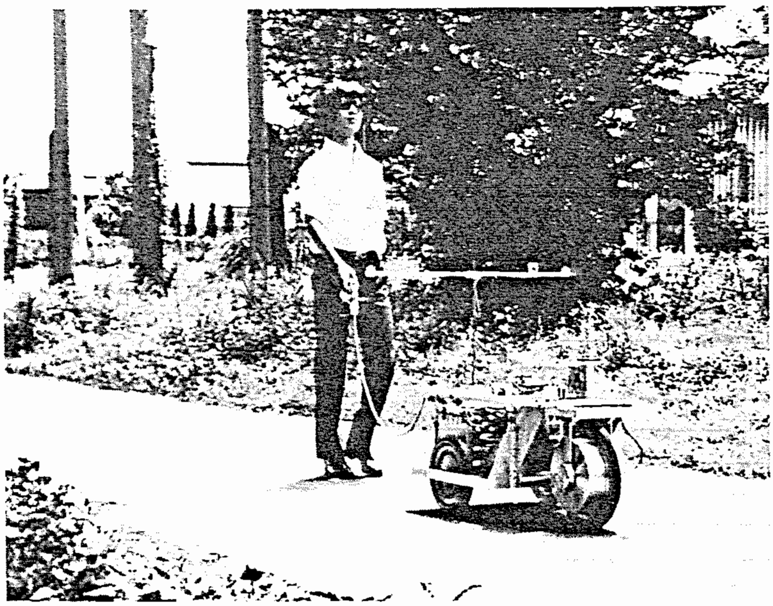

Figure 13. General view of the system.

usual warning and 10 Hz for no signal warning. For example, the signal presented to the right arm with 100 Hz means he should step to the right and with 10 Hz means he should turn his body counterclockwise.

5. Experiments

Figure 13 shows the general view of the experimental robot MELDOG MARK I. The master was satisfactorily guided by the robot. Figure 12 shows a record of $2\Delta R$ and the speed of the robot V. The record should be read from the right to left. $2\Delta R = 0$ means that the distance between the master and the robot is 1 m.

First the distance between them was about 1.4 m. The master started, but the robot didn't move. When $2\Delta R$ became positive, the robot began to move and its speed rapidly increased to the almost constant value of 3 km/h keeping their distance of almost about 1 m minus 0.1 m of offset.

Acknowledgements—We are most grateful to the following members of our laboratory staff for their contribution to this paper: Mr. T. Ohno and H. Nakajima contributed substantially to the development of the hardware design and realization: Dr. K. Tani provided a great deal of valuable counsel and evaluation comment. We are also thankful to Professor I. Kato of Waseda University and Professor S. Fujimura of University of Electro-Communications for their kind support.

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CHIEN-ROBOT SERVANT DE GUIDE PROJET DE BASE ET QUELQUES ESSAIS AVEC MELDOG MARQUE I

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Résumé - L'orientation et/ou la mobilité constituent l'un des ardents désirs de plus d'un quart de million d'aveugles au Japon. Ce mémoire décrit l'étude et l'expérimentation du concept "chien-robot servant de guide dénommé Meldog". Ce robot dont le nom vient de Mechanical Engineering Laboratory a commencé à aider des personnes aveugles à marcher avec plus de sécurité en appliquant les techniques de l'automatique et les systèmes homme/machine.