Study on Guide Dog (Seeing-Eye) Robot (I)

— its basic plan and some experiments with MELDOG MARK I —

by
Susumu Tachi, Kazuo Tanie,
Kiyoshi Komoriya, Yuji Hosoda,
and Minoru Abe

SUMMARY

One of the strong desires of more than four hundred thousand blind persons in Japan is orientation and/or mobility. This project of a guide dog robot (or Seeing-eye 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 can be classified into two: 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.

To realize this guide dog robot system, there seem to be four problems to solve: 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 situations, and to construct the organized map of streets for the robot.

For its first step, taking up the second problem, we have so far made experimental hardware and realized the communication between the blind person and the robot successfully. In this paper the basic plan of MELDOG project and some experiments using the experimental hardware (MARK I) are reported. That is to say, the robot proceeds in front of the master and is controlled so that its speed coincides with that of the master, keeping the distance between them constant at 1 [m]. The safety zone is set, in which the master is permitted to walk. When he is out of the zone, he is warned by the robot using electrocutaneous stimulation.

INTRODUCTION

Mechanical Engineering Laboratory which belongs to the Ministry of International Trade & Industry has just started a five-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); (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).

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 four hundred thousand 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 Galsses [1], Travel Pathsounder [2], or the laser cane [3], and (iii) image production by the direct stimulation of the visual cortex [4,5].

Canes (i) relate to the Hoover's technique which is very fundamental training for the blind in Japan. By this training blind persons can construct their own images of orientation (Mental Map). So 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 filtering nor 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 a very dangerous in another sense realizing our very limited knowledge about human brains.

The dog guide is a very excellent way to guide the blind 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 the future). A guide dog is mortal, may become ill, must be fed, must be walked, and it excretes. So it requires much labor of the blind person's family. Adding to this it is prohibited 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. So it is of importance to have a mechanical dog guide in the 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 the basic plan and the experimental hardware MARK I are described and some experiments carried out with MARK I are reported.

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 the dog encounters a crossing it stops. Then the master 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 objects 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, 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 worm 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 a 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's visual and ultra-sonic sensors. When he understands 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)
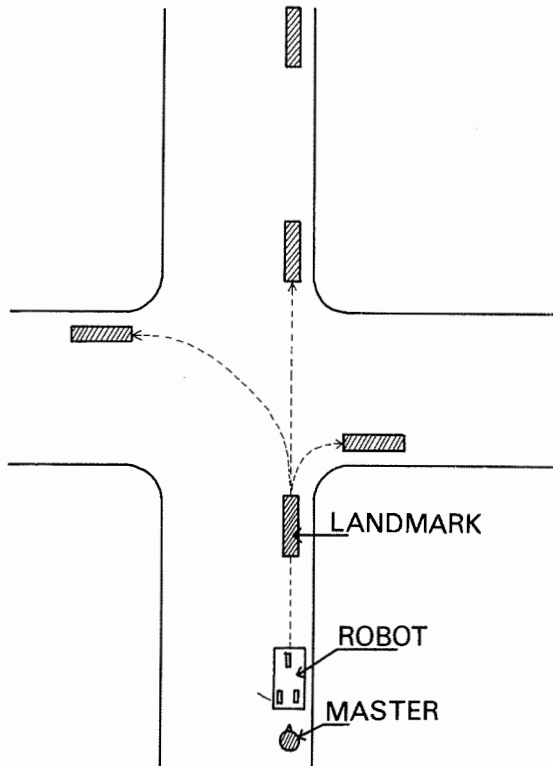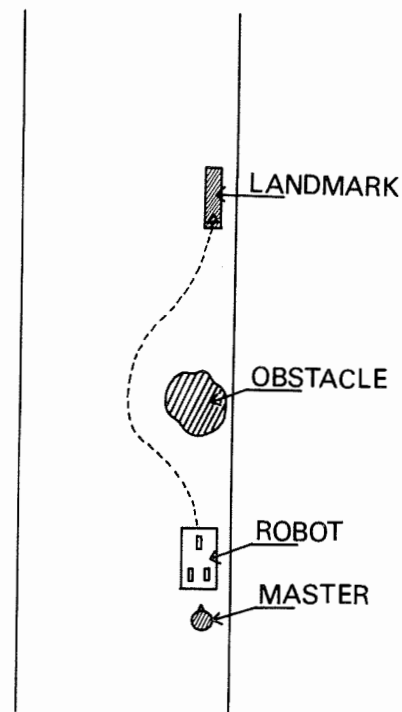

Fig. 1 Guidance of the robot using landmarks.

Fig. 2 Obstacle detection by the robot, and obstacle perception by the master using the robot as a sensory substitution device.

(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. 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)
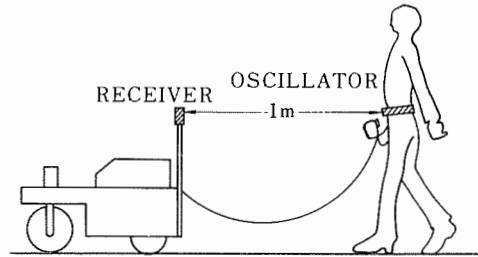

Fig. 3 Guidance of the master. The speed of the robot is controlled to coincide with that of the master.

(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.

HARDWARE

Photo. 1 shows the general view of the trial-made experimental hardware (MARK I).

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, 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. The reproducibility of the track for this mechanism 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 dc 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 speed 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 control circuit, which uses a digital alsolute 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 ±0.3 [m] for each steering angle.
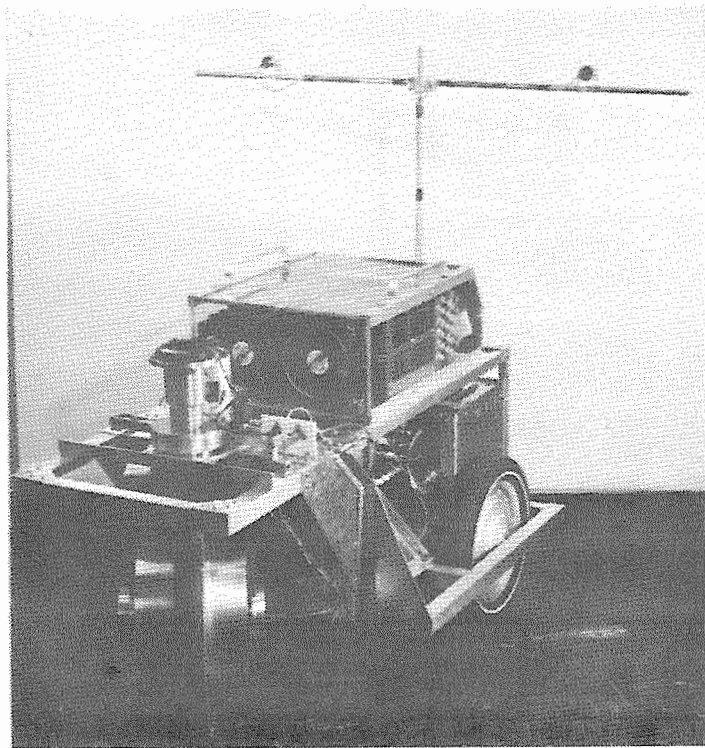
Photo. 1 General view of the MARK I robot.
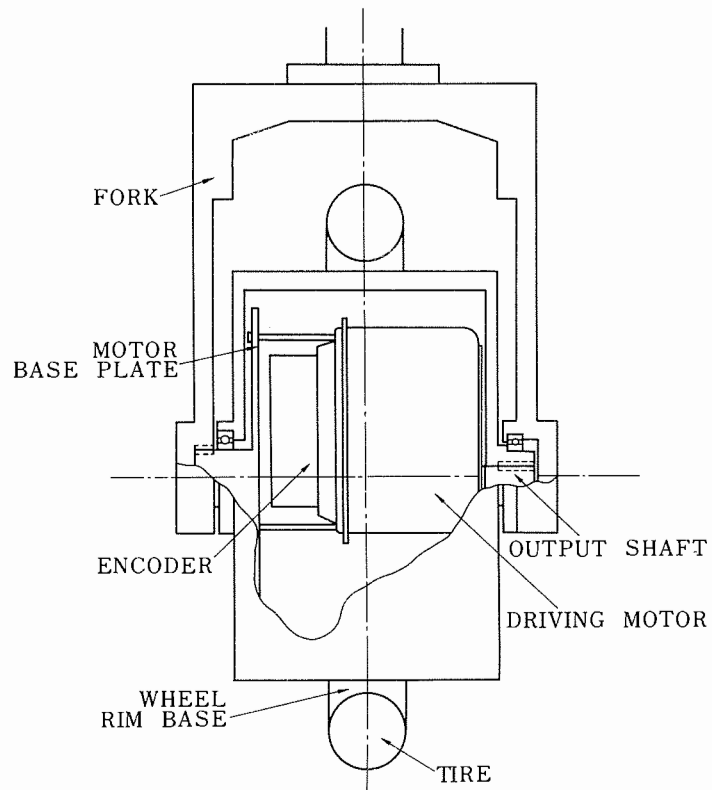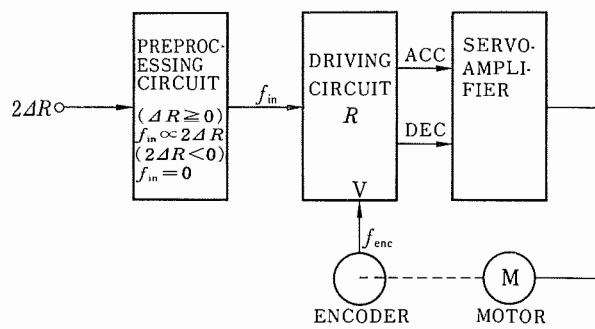
Fig. 4 Front wheel mechanism.

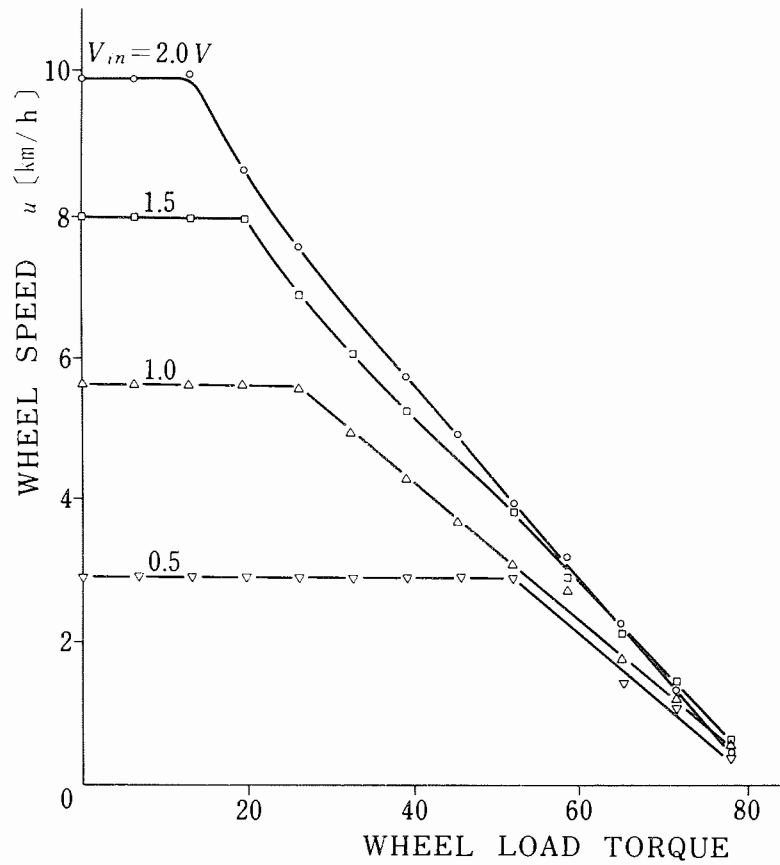Fig. 5 Block diagram of the speed control using phase locked loop.

Fig. 6 Wheel speed vs. load torque.

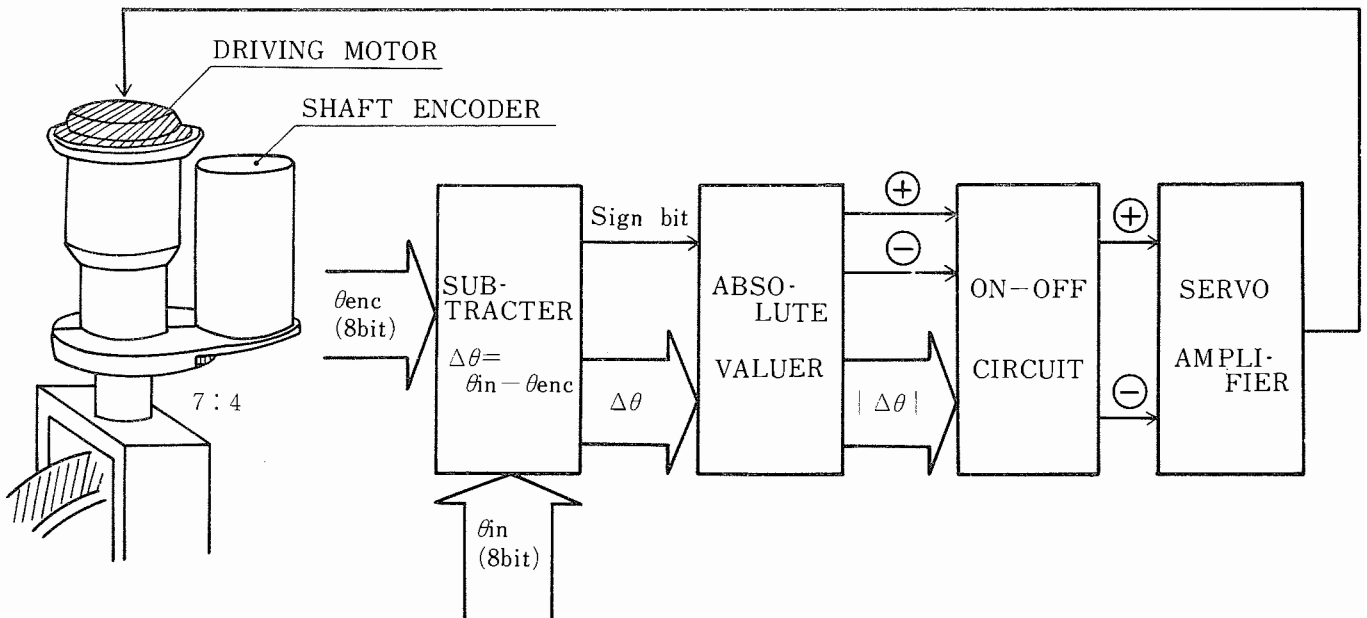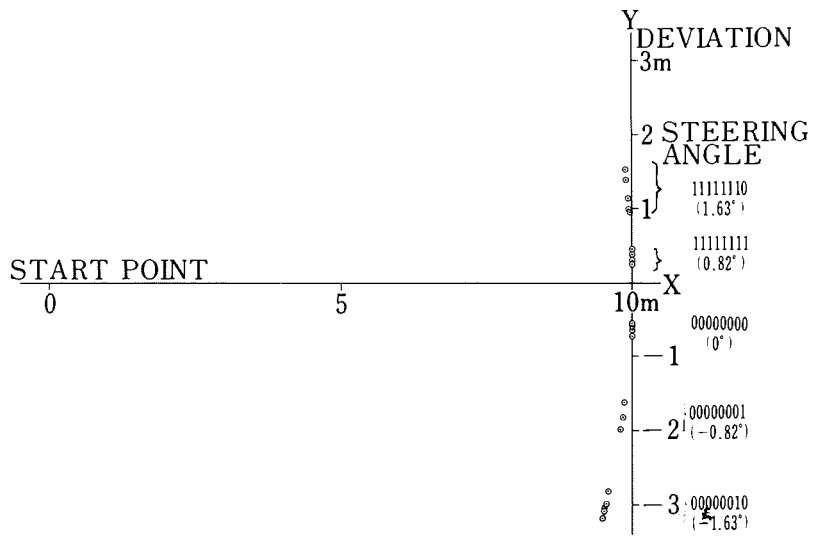Fig. 7 Block diagram of the steering control used.

START POINT
(0,0)

Y
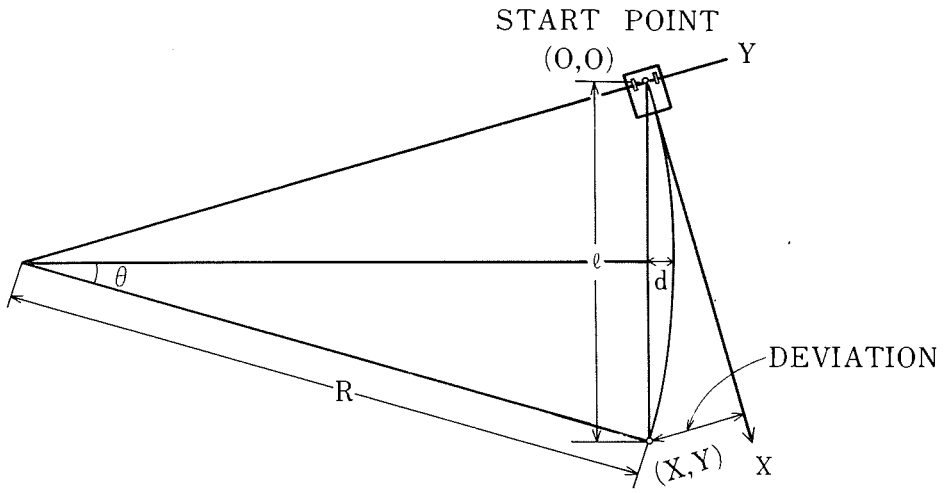
θ

ℓ

d

DEVIATION

R

(X,Y)

X

Fig. 8 Reproducibility of the track.

SOME EXPERIMENTS IN MAN-MACHINE COMMUNICATION
(MASTER GUIDE)

For the first step of this project we tried to realize the function (3) on page 4. 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 with 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 robot to the master. Ultrasonic trigonometric measurement method is applied to measure the relative locational relation 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 of the robot and 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:

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

this relation is rewritten as:

$$r_1{}^2 - r_2{}^2 + a^2 < 0 \qquad\qquad (1)$$
$$r_2{}^2 - r_1{}^2 + a^2 < 0 \qquad\qquad (2).$$

So the conditions (1) and (2) were calculated using analog IC's and the warning signals W_L (step to the left) and W_R (step to the 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 to let him know

the situation.

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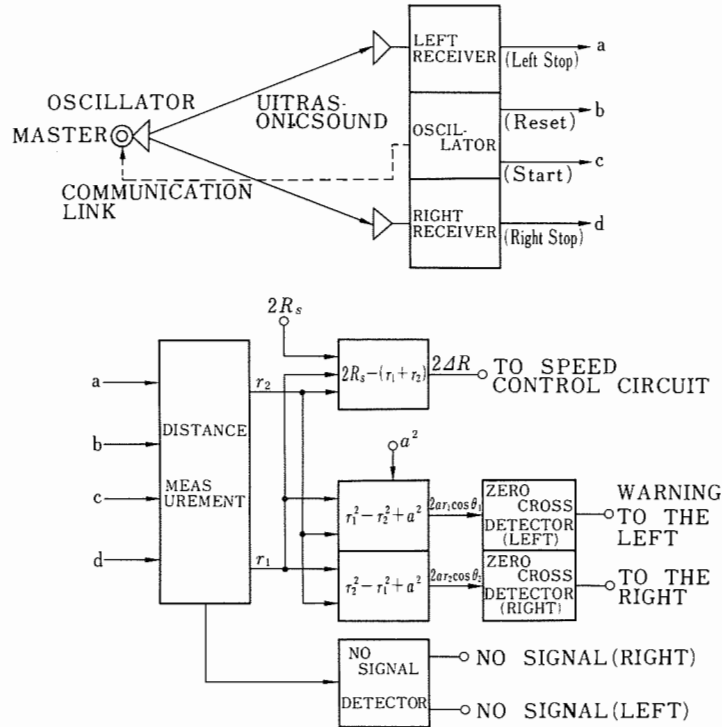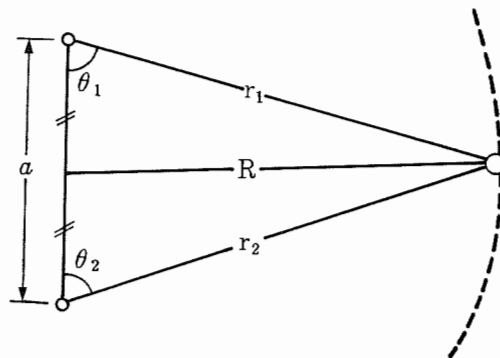

Fig. 9 Block diagram of the master-guide.

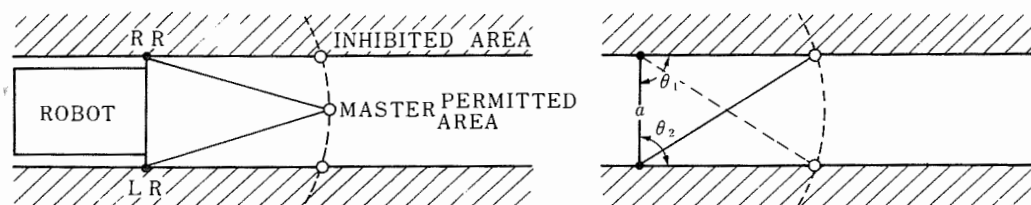Fig. 10 Principle of the distance measurement (A), and the safety zone set (B).
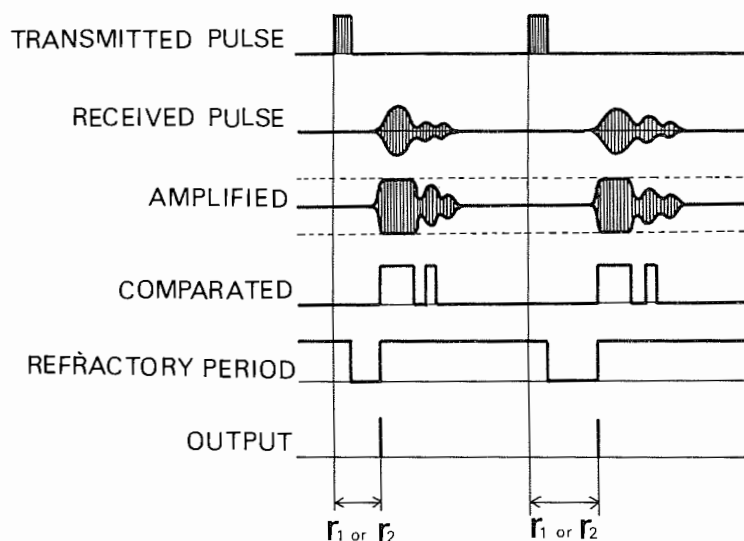
Fig. 10 (B)

Fig. 11 Waveforms of the preprocessing circuit.

EXPERIMENTS

Photo 2 shows the general view of the experimental robot MELDOG MARK I under test. 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 the 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 [km/h] keeping their distance at almost about 1 [m] minus 0.1 [m] of offset.
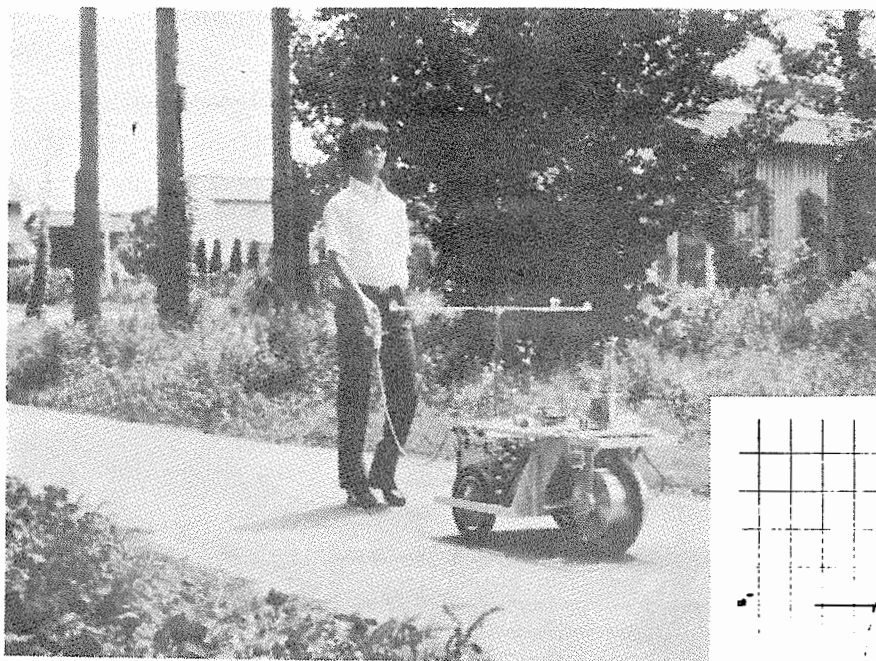
ACKNOWLEDGMENTS
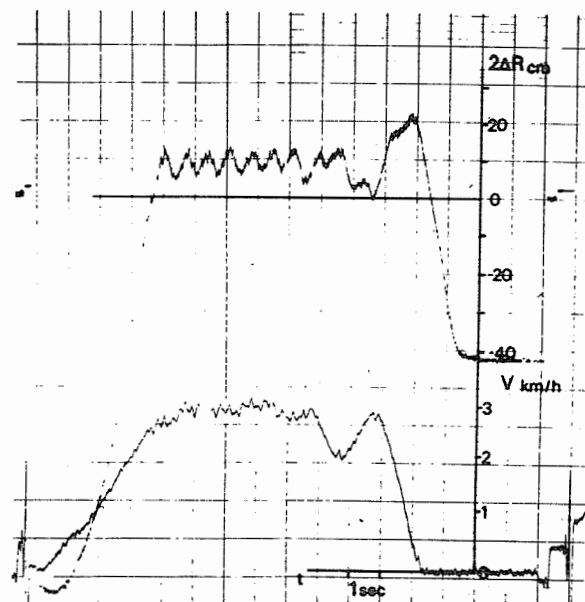
Photo 2 Field test situation.

Fig. 12 Result of the field test.

REFERENCES

1) L. Kay, "Ultrasonic spectacles for the blind," Proc. Int. Cof. on Sensory Devices for the Blind, St. Dunstans, London (1966).

2) L. Russell, "Travel Path Sounder – further results," Proc. Int. Conf. on Sensory Devices for the Blind, St. Dunstans, London (1966).

3) J.M. Benjamin Jr., T.A. Bolgiano, and E.D. Meeks Jr., "A laser cane for the blind," Digest 7th Int. Conf. on Med. and Biol. Eng., Stockholm (1967).

4) G.S. Brindley and W.S. Lewin, "The sensation produced by electric stimulation of the visual cortex," J. Physiol. (London), vol. 196, pp.479–493 (1968).

5) W.H. Dobelle and M.G. Mladejovsky, "Phosphenes produced by electrical stimulation of human occipital cortex, and their application to the development of a prosthesis for the blind," J. Physiol., vol. 243, pp.553–576 (1974).

6) S. Tachi, K. Tanie, K. Komoriya, Y. Hosoda, and M. Abe, "Guide Dog Robot – its basic plan and some experiments with MELDOG MARK I," 3rd CISM-IFToMM Symposium on Theory and Practice of Robots and Manipulators, Udine, Italy, September (1978).

РОБОТ СОБАКИ-ПОВОДЫРЯ

—основной план и некоторые опыты с СОБАКОЙ МЭЛ МАРКИ 1 —

проведенные
С. Тачи, К. Таниэ, К. Комория, Ю. Госода и М. Абэ
Машиностроительная Лаборатория, МИТИ
Игуса, Сугинами-ку, Токио, 167, Япония

Одними из насущных желаний более четырёхсот тысяч слепых людей в Японии является ориентирование и/или маневренность. Этот проект робота собаки-поводыря или робота со Зрячим глазом, который мы называем СОБАКОЙ МЭЛ по Машиностроительной Лаборатории, только что начал помогать слепым ходить более безопасносно применением технологии по роботам и системы человека-машины.

Функции собаки-поводыря могут быть подразделены в две: а именно повиновение, относящееся к водительству, и неповиновение, относящееся к обнаружению препятствий. Мы добиваемся реализации этих двух функций машинами.

Для реализации системы робота собаки-поводыря существуют, кажется, четыре проблемы: заставлять робот двигаться по улицам и узнавать свое местонахождение и ориентацию, устанавливать связь между слепым (хозяйном) и роботом (руководством хозяйна) и обнаруживать препятствия или опасные положения и составлять уличные карты, предназначенные для робота.

Как первый шаг берясь за вторую проблему, мы пока изготовили опытное оборудование и установили связь между хозяйном и роботом. На этой бумаге саобщаются основной план СОБОКИ МЭЛ и некоторые опыты по применению этого опытного оборудования. То есть, робот идет впереди хозяйна и управляется, чтобы его скорость совпадали со скоростью хозяйна, сохраняя растояние между ними постоянным в 1 м. Установлена зона безопасности, в которой хозяйн допускается ходить. Когда он выходит из зоны, он предупреждается роботом по электрокожной стимулятии.

ROBOT CHIEN-GUIDE
− Plan de base et quelques expériences menées
sur le MELDOG MARK I −

Par

S. Tachi, K. Tanie, K. Komoriya, Y. Hosoda, et M. Abe

du

Mechanical Engineering Laboratory, MITI

Igusa, Suginami-ku, Tokyo, 167, Japon

L'un des plus grands espoirs pour plus de 400.000 aveugles au Japon est de pouvoir s'orienter et/ou se déplacer. Ce projet de Robot Chien-Guide (Guide dog robot) apelé encore Robot à perception visuelle (Seeing eye robot) et que nous désignons sous le terme de MELDOG, d'après le nom de notre laboratoire, Mechanical Engineering Laboratory, vient tout juste de commencer à aider les aveugles à se déplacer avec plus de sécurité, grâce à l'application des techniques de l'automatisme et du système de relation homme-machine.

Les fonctions du Chien-guide peuvent être définies selon deux principes: celui d'obéissance, qui correspond à la fonction de guidage, et celui de non-obéissance, qui correspond à la fonction de détection des obstacles. Nous nous efforçons actuellement de réaliser ces deux fonctions automatiquement.

Pour parvenir à réaliser ce système de robot Chien-guide, il nous semble que quatre problèmes se posent:
— Faire se déplacer le robot le long des rues et lui faire connaître sa position et son orientation.
— Etablir la communication entre la personne aveugle (le maître) et le robot (le guide du maître).
— Détecter les obstacles et les situations dangereuses.
— Etablir, à l'intention du robot, une carte élaboré des rues.

Pour ses premiers pas, nous nous sommes attachés au second problème et nous sommes parvenus, à ce jour, à mettre au point l'appareil expérimental et à réaliser la communication entre le maître et le robot. Dans ce document, le plan de base du robot MELDOG et quelques exériences menées à partir de l'appareil exérimental sont rapportés. Le robot est situé à l'avant du maître et est programmé de façon que sa vitesse coïncide avec celle du maître, en conservant une distance constante de 1 mètre. Une zone de sécurité est ainsi délimitée, dans laquelle le maître est en mesure de marcher en sécurité. S'il s'éloigne de cette zone, il en est averti par le robot au moyen d'une stimulation électro-cutanée.