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STUDY ON A GUIDE-DOG ROBOT -guidance of a man by a robot-

by

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SUMMARY

This paper deals with a trial which aims to help the blind walk outdoors freely by using a machine, i.e. a robot. In the first half of the paper several methods of walking aids for the blind are examined and compared with each other. As a result, use of a guide dog is found to be the best existing way because of its intelligent functions. But it also has some problems due to the fact that it is an animal. We present a guidance system using a robot which replaces some functions of a real guide dog. In the latter half we develop the design concept of a guide dog robot system and investigate the problems concerning with the realization of the functions of a guide dog by a machine system.

INTRODUCTION

Sight is the most important sinse for daily life among the human senses. It can be easily understood by imagining the inconvenience which we would experience if we lost our sight. In 1980 the number of visually handicapped persons who live in Japan suffering from that inconvenience is as high as about three hundred and thirty-six thousands. Their acute requirements are the free communication and the orientation/mobility. The latter is the basis of the independent outdoor travel.

There have been many attempts to help the blind for their independent travel. Owing to the recent advancement of electronic techniques it has become possible to process complex information by a comparatively small processor, and devices for walking aids which use these techniques have been developed. But the information processing of these devices are so simple that their function only works well owing to the help of user's remaining information processing ability. Consequently the use of these devices forces the user to pay attention to them and, if prolonged, tires the user. These devices need improvement in these aspects. It is also meaningful to add other new functions such as the function of route guidance in a town.

Basically there are two ways to assist the walk of the blind systematically. One is to invest in the environment and make a system that sends information about the environment to the blind by devices located in many places of the environment. The other is that the blind person carries a device which searches the surrounding around him and obtains the information which enables him to walk.

The former way contains following examples. Rugged plastic plates called "braille blocks" can be placed along an edge of a platform of a railway station and be used to inform the blind not to fall down from the platform. Traffic lights can send sound information, especially by music. The difference of the level between a pedestrian way and a motorway where they are crossing can be eliminated for easy walking. The latter way contains a guide dog and new devices which assist walking.

Of course it is favorable if both ways are achieved simultaneously. But the former way is difficult because of the following problems. One is that the financial support becomes large because the living area is two-dimensional and the number of devices which we must set to guide the blind becomes so great. Another problem is that such devices have conflicts with existing facilities set in the town such as signs or marks for the traffic. In the latter way on the contrary we aim to restrict the financial investiment to be as small as possible and give excellent functions to the equipment which a man can carry to assist his walk. The functions of the equipment include recognition of its environment, knowledge of its position and orientation, detection of the obstacles or dangerous stuations which disturb its course and guidance of a blind person while informing him of a suitable way. Though we cannot give all of these ideal functions to the equipment immediately, this way seems to be the main way which leads to the true independent travel.

EXISTING AIDS FOR INDEPENDENT TRAVEL

A white cane is the most basic, widely used and useful tool to support the walk of the blind. This tool is used with the remaining senses, i.e. auditory and tactile senses. A blind person constructs his mental map about the area by searching around him with this tool. He also uses it when he walks with his remaining senses according to his mental map.

A guide dog is used to guide a blind person outdoors using its fine functions proper to a living thing. Reportedly, this method was first attempted in good earnest in 1916 in Germany. Since then it has been used exploiting its high information processing ability, especially the ability of pattern recognition and the fast adaptation to the changes of its environment. But a guide dog also has its inherent defects. Among these are the difficulity of training, its short life as compared with man's life, the need for the place to keep it and the care it requires of its keeper as intense as it would require to have one more family member. These problems limit the number of the guide dogs which are in use in Japan to be much smaller than the number of the potential users.

New devices which come from the development of the electronic technology are beginning to be used. A blind person carries such a device with him and it searches in front of him with its sonic or optical sensors to acquire the necessary data. After processing the data, it sends information about the walking space to him. Thus he can know the condition in front of him as he walks. One of these devices is called a laser cane[1]. A small semiconductor transmitter of laser is set in a cane. Laser pulses are sent in three derections, i.e. upward, forward and downward, and their reflections are collected by lenses and are detected by photo-diodes. The existance of obstacles are detected by the magnitude of these signals. This information is presented by means of sound to the man. Kay developed sonic glasses[2] which utilize the ultrasound skillfully. Ultrasound whose frequency is changed with time in the shape of triangular pulses is sent from the transmitter attached on the glasses. The reflected sound is mixed with the transmitted sound to make beat which a man can hear. A blind person hears this signal through earphones. It is said that the user can know the distance to the obstacle, its direction and the characteristics of its surface from the pitch, the magnitude and the tone of the beat, respectively. There is still another type of devices which utilizes ultrasound. Among these are Pathsounder[3], the Mowat Sonor[4], etc. The difference between the latter type of devices and the previously mentioned type is that these devices check whether there is an obstacle which the user can not detect and warn him only if there is one.

As the former devices ceaselessly give the signal about the environment to the user, he must concentrate his attention on it and make his decision all the time while he walks outdoors using them. On the other hand the latter devices are better because they send information only when it is necessary to warn the man. But neither of them have enough functions saticfactorily good to aid the walking of the blind. For example, they have not the function to guide the man along the street. A guide dog has more and better functions than these devices.

From this view point we started the MELDOG project in 1977 at the Mechanical Engineering Laboratory to develop a device which has the functions of a guide dog. The rest of this paper describes the design concept of the device and the problems encountered during the construction of the system.

GUIDE DOG ROBOT

From the analysis of the functions of a real suide dos, the functions a suide dos robot should have are :

(1)suidance of its master alons the streets
(2)avoidance of obstacles on the way
(3)communication with its master.

Function (1) is the most basic function which is to suide a man under his commands, i.e. so straisht, turn left or turn risht. There are two modes of suidance. One is successive suidance. In this mode when the robot reaches a landmark of a crossins, it informs the man of the condition of the crossins, e.s. its tyPe is three forked and the next landmark on the risht is #100, the distance to it is 5m, etc. Then the man orders the direction in which he would like to so. The other mode is automatic suidance. In this mode the man tells the robot his destination before he starts. The robot selects a suitable route to the destination and suides him alons the selected route. This is the function which a real suide dos does not have. It is one of the merits of usins a robot.

Function (2) is to detect obstacles and avoid them automatically or in cooPeration with the man, while function (3)is to communicate with the man to work (1) and (2) effectively.

As a Policy to desisn a suide dos robot, we first realize each of its functions by aPProPriate methods for machines. Then we combine them into a man-machine system with harmony. Fisure 1 shows the total system of the suide dos robot with the functions (1), (2) and (3). We selected wheeled locomotion for the suide dos robot for the simPlicity of desisnins assumins the area where it travels is smooth. Other mechanisms such as walkins machines with two, four or six less, thoush they have the adaPtability to uneven surfaces, are now at the stase of study and too remote from Practice for us to emPloy them. The robot consists of several sub-systems each of which does some Part of the aforementioned functions. They are controlled by a micro-comPuter mounted on the robot. We use batteries as the Power source on board the robot.

In order to suide a man by the robot two steps should be taken. The first steP is the suidance of the robot itself alons the streets and the second steP is the suidance of the man by the robot. For the suidance of the robot we avoided the Pattern recosnition of seneral scenes which is a difficult Problem in the field of artificial intellisence, and instead adoPted the method to use marks as a clue for the robot to know its Position and orientation in the streets. In this case these marks should be

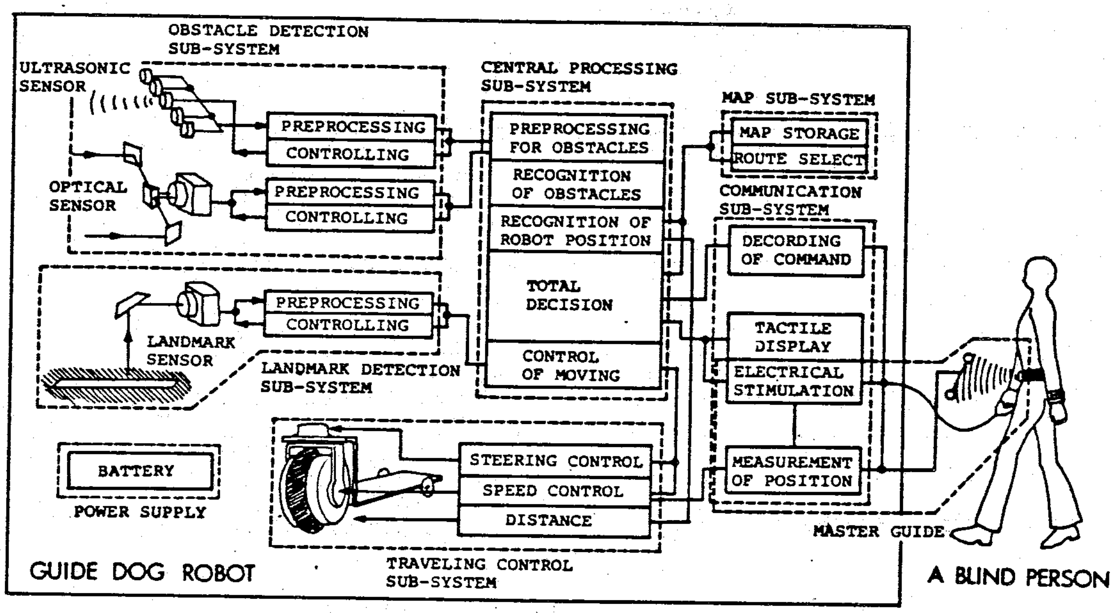
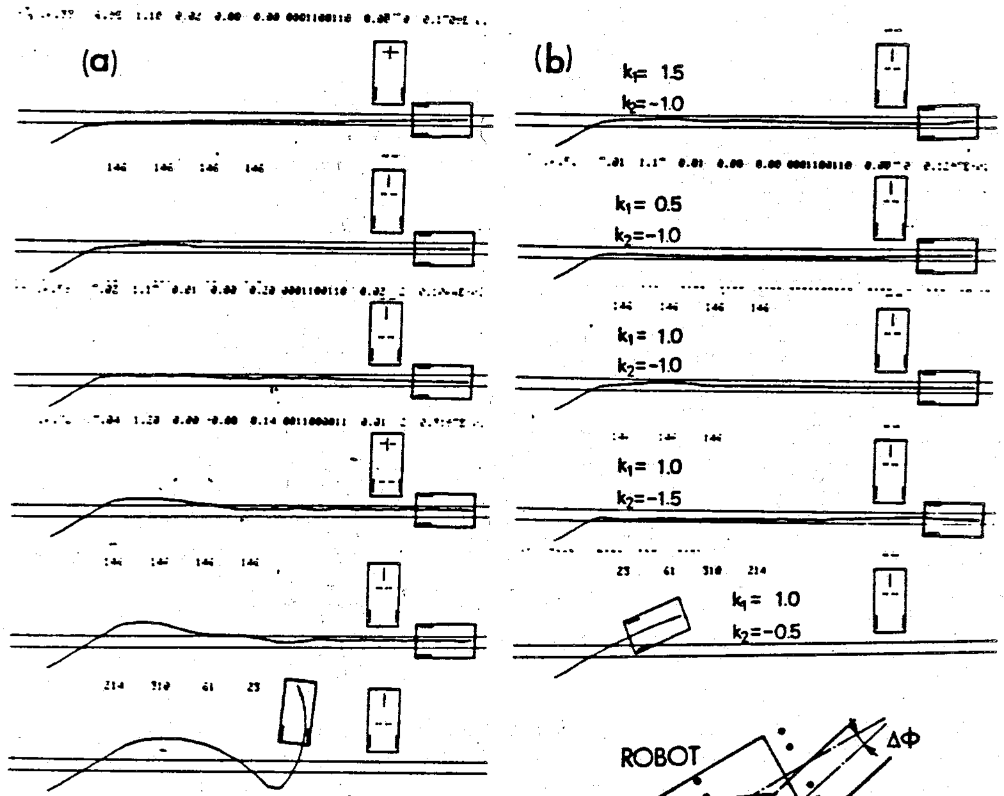
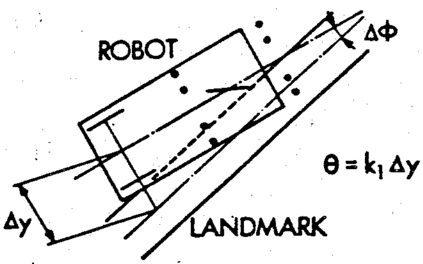


Fig.1 Guide Dog Robot System

simple so that the investiment for marks will be small. We used a white straight line with a width of 15 cm and a length of about 2.0 m, which is called a landmark. The robot collects its orientation error which arises during its running between marks by tracking the mark. The tracking peformance of the robot is checked by the computer simulation. Figure 2 shows the examples of the computer simulation. Further results of the simulation and the tracking performance of the test hardware were reported in [5].

The robot also knows its position in the area from the code assigned to each mark. Another function of this mark is its use in a map. For example if we make a map (a kind of data base) which contains the relations of the marks, e.g. the code of the mark next to a certain mark, the distance to it, the necessary steering angle to reach it, and the condition of the road around it, the robot can read the map and get the information necessary for guidance. The map can also be useful as the a priori knowledge when the robot analyzes scene data in order to find obstacles. Selection of the optimal route in the automatic guidance mode[5] is carried out using this map. The robot gets the necessary information of the crossing from this map and transmits it to the man in successive guidance mode. This map may be stored in a mass storage such as cassette tapes.





$$\theta = k_1 \Delta y + k_2 \Delta \Phi \qquad \text{....(1)}$$

Fig.2 (a) Computer simulation of the track of the robot. Dots around the robot indicate the detector of landmark. The robot tracks faster and more stable as the position of the detectors moves forward on board the robot. (b) Characteristics of the tracking change according to the parameters of the equation (1) which decides the steering angle from the measurements of the landmark detectors.

When a blind person walks with a guide dog, he holds the harness attached to his dog and is guided by it. This is not a good way in the case of a guide dog robot because it makes the control of the robot's traveling difficult and may put the man in a dangerous situation. Thus we developed an ultrasonic measurement system for the robot to measure the position of the man behind it. We call this system "master guide"[6]. Figure 3 shows the master guide of MELDOG MARK II. An ultrasonic transmitter is attached to the belt of the blind person and two ultrasonic receivers are mounted on the upper end of the robot. Two distances between the transmitter and the receivers, r1 and r2, are measured from the traveling time of the ultrasound. Using r1 and r2 both the distance of the man from the robot and his direction relative to the robot are calculated by the principle of triangulation. The man takes the initiative in deciding the walking speed, for the speed of the robot is controlled to be the same as that of the man keeping the distance between them constant 1m. If the man goes out of the permitted zone behind the robot while he walks, the robot sends a signal for him to correct his lateral position error. The feasibility and effectiveness of these functions aforesaid were checked by an outdoor experiment using the test hardware MELDOG MARK I and II [5], [6]. Figure 4 shows the outdoor experiment with MELDOG MARK III.

In order to realize the function (2) we note the velocity and the distance of the obstacles. We define Vro as the velocity of the object relative to the robot and v as the component of Vro parallel to the line which connects the obstacle and the robot. Dealing with a moving obstacle depends largely on v.

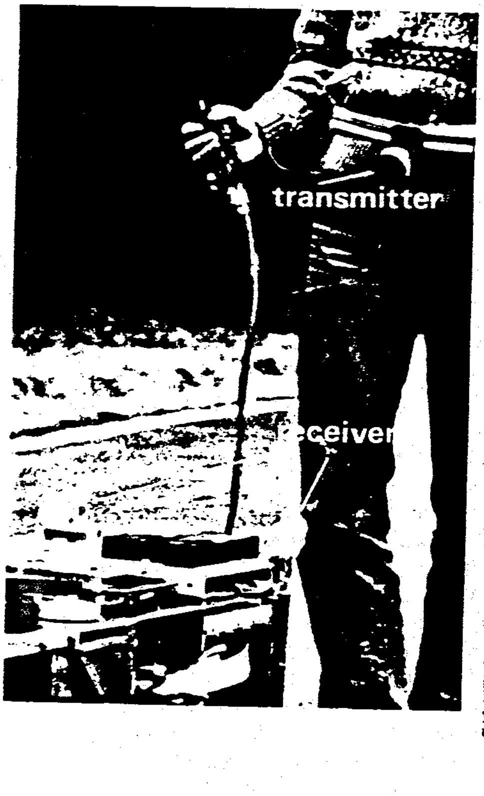
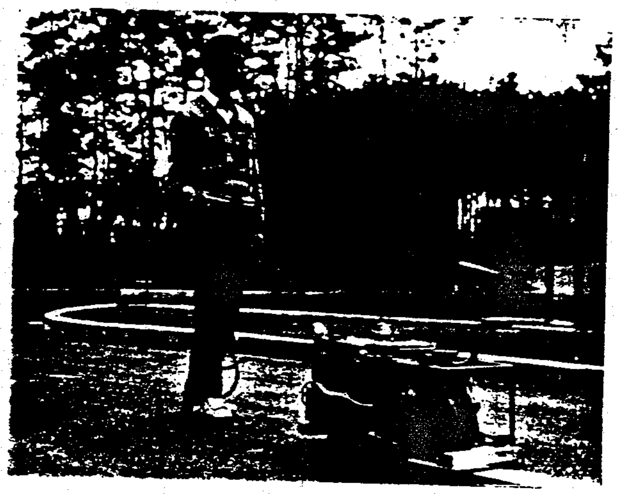


Fig.3 Master Guide

Fig.4 Outdoor experiment with MELDOG MARK III.



For simplicity let us first consider the one-dimensional cases, that is, the robot and the obstacle move on a same obstacle is going away from the robot, and the robot can continue its usual guidance because no trouble will happen with the obstacle. When v is equal to o, the obstacle is going in front of the robot at the same speed as the robot and there will be no problem unless the robot speeds up for some reason. If v directs in the opposite direction of the obstacle and its absolute value is smaller than the robot's speed, that means the obstacle is going in the same direction with smaller speed, and the robot must slow down until its speed coincides with that of the obstacle. In this case the robot informs the man that it has reduced its speed. If v is equal to the robot's speed, the obstacle is static. If the absolute value of v directs to the opposite direction of the obstacle and its absolute value is greater than that of the robot's speed, the obstacle is absolutely coming toward the robot. In this case the robot immediately stops and warns the obstacle and the man' and if possible avoids the obstacle in cooperation with the man.

In the case that an obstacle is not moving, the robot should detect its position and size. If there is enough space to pass through, the robot may proceed avoiding the obstacle. But if it is impossible for the robot to pass through, the robot must turn back and choose another route which leads to the same destination.

As for two-demensional cases, let us consider the three typical cases shown in Fig.5, i.e. (a) the obstacle is crossing the robot's course perpendicularly, (b) the obstacle is crossing the robot's course obliquely and (c) the obstacle is moving parallel to the robot's course. The relative velocity of the obstacle to the robot, Vro, is time-invariant and is shown as the vector Vro in each cases. The component of Vro parallel to the line which connects the obstacle and the robot, v, changes as the robot proceeds. Supposing the direction, the distance and the relative velocity component v of the obstacle are detected, we use the following criterion to avoid an obstacle: $x=m1*d+m2*v$ where d is the position vector of the obstacle relative to the robot whose norm is the distance between them, m1 and m2 are parameters selected properly. The meaning of this equation is as follows. If v directs in the opposite direction of the obstacle, that means the obstacle is coming toward the robot, and if d is so large that vector x directs to the obstacle, there will be no opportunity for the robot and the obstacle to collide with each other. On the other hand, if d is small, that is, the obstacle is near the robot and if v is large enough for vector x to direct in the opposite direction of the obstacle, there is a possibility for the robot and the obstacle to collide with each other. Generally if x directs to the obstacle and its absolute value is greater than some threshold properly given, the robot can take its normal guidance mode.

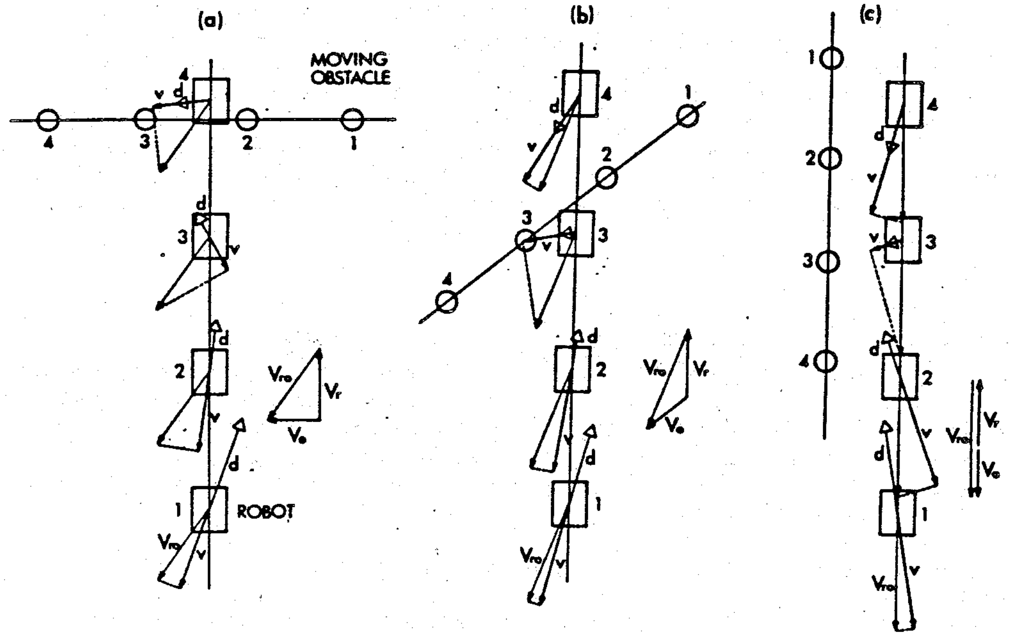


Fig.5 Avoidance of obstacles.
Vr: Velocity of a robot, Vo: Velocity of an obstacle
d : Position vector of an obstacle relative to a robot

We plan to use semiconductor cameras and arrays of ultrasonic sensors to detect obstacles on the way. These sensors search a comparatively small area(5m radius) around them and detect both the direction and the distance of an obstacle. The velocity component v can be obtained from the two sets of data measured at a short time interval. We now have constructed an experimental off-line system and are studying the reliable detection of the necessary data.

For the function (3) a problem arises about what communication channel should be used between the man and the robot. Two kind of senses, auditory and tactile senses, are widely used as channels to transmit information between a man and a machine in many man-machine system. However, we do not want to use these senses for the guide dog robot because the blind use these remaining senses to get information about the environment more intensely than if they had sight. We restricted the use of hearing only to an emergency case. Consequently we adopted a new channel of electrocutanous stimulation using energy controlled pulses. This method is an application of our study about the information trasmission using electrocutaneous stimulation[7], [8]. The information is coded by the energy value and the repetition rate of the electrocutaneous stimulation pulse and sent to the man. We used this method to test the function (2) to present the man his lateral position error by an energy modurated pulse signal and succeeded in the guidance of him by MELDOG MARK I. So far we have discussed the communication from the robot to the man. For the communication in inverse direction we may use switches and possibly voices to give commands to the machine.

RESULTS AND FUTURE PROBLEMS

In this paper we aim to realize by machines the functions of a guide dog. A principle to design these functions is presented. The feasibility of some part of these functions was demonstrated by the experiment using the test hardware and was already reported. But there are still many problems left to be solved in the future. They are as follows.

- Mechanism for a moving machine which has high adaptability to uneven surfaces.
- Pattern recognition that enables the robot to use the existing objects as landmarks for guidance.
- Method for detecting obstacles quickly with high reliability.
- Optimal communication way from the machine to the man.
- Effective display method of the two-dimensional data such as scene data to the man.
- Design of machines based on human-factors engineering.
- Reduction of sizes and weights of machines.
- Improvement of reliability and safety of a system.
- Energy supply for machines.

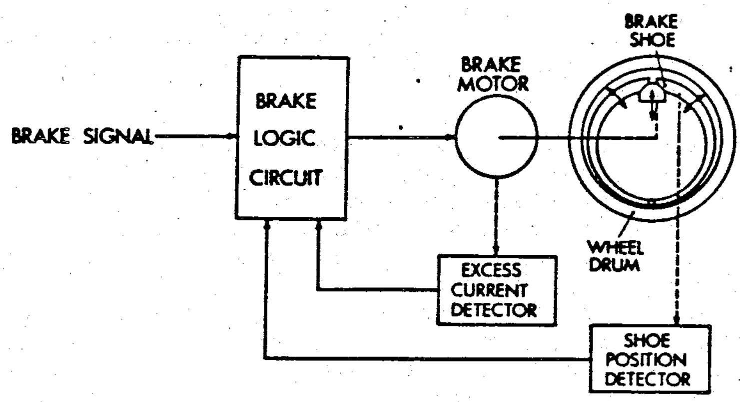


Fig.6 Mechanical brake of MELDOG MARK II.

As for the last problem we should use low power consumption devices such as CMOS type micro-computers as processing units of a robot and also should save power consumed for controlling motors by swiching its supply current according to the difference between its rotation rate and the reference. For this purpose, for example, we designed a mechanical brake for our test hardware, which does not consume power while it is working by self-locking system. Fig.6 shows its system.

Even a dog has excellent abilities which we cannot imitate by machines. In our project we gave only a few functions of a guide dog to our guide dog robot.

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