Much is expected from ITS as activities to solve problems involved in the automobile traffic environment today. There is “human-friendly vehicle” among those activities. When driving a car on an ordinary road, drivers must pay attention to pedestrians. Our ultimate goal is to have an eye-like capability on a system which would distinguish the pedestrians from other obstacles and provide distinctive information. For this subject, we use a micro-wave & millimeter-wave radar (dual band radar) which can detect obstacle at relatively long distance even in conditions of poor visibility, and carried out a feasibility study of a pedestrian detection sensor using a unique characteristic in reflection and absorption with respect to frequency.

INTRODUCTION

The subject on which we addressed in this study was a system which would distinguish pedestrians from other obstacles and provide distinctive information. In Japan, five national government offices drew up a “General Plan for Promotion of ITS” and nine development programs were set up in Plan. One of the nine is “Pedestrian Support” and much importance is attached to preventive safety to prevent bodily injury to persons. For the driver to drive safely, exact recognition of the lanes and obstacles in front is necessary. The driver must pay more attention to pedestrians and bicycles which are apt to suddenly change their course, than to other obstacles. Providing information about such moving objects will lead to preventive safety. In this paper, a feasibility study of an RF radar pedestrian sensor is discussed. The sensor has the potential for long detection range for use in an on board system which warns the driver of the presence of pedestrians in mixed traffic.

PEDESTRIAN DETECTION METHOD

Many studies were carried out on a sensor to detect pedestrians in the past. These are described below with their respective features.

1. Pedestrian notification through infrared imaging or pattern recognition using an infrared imaging device
   Currently, the imaging device market is very limited. Because it responds to the heated mufflers of preceding vehicle as well, fairly sophisticated image processing is necessary for reliable recognition as pedestrian.

2. Human body recognition by means of a pyroelectric infrared sensor
   This is widely used for pedestrian detection at seeing-eye doors. The problem with this is its limited detection range of several meters. And also because the sensor responds to any moving object with different background temperature it cannot be used on a moving vehicle.

3. Pedestrian recognition by means of a solid-state camera and image signal
processing. Solid-state cameras are widely used and can easily be used on vehicle. However, the image processing electronics for pedestrian recognition is relatively complex. At night, recognition is impossible except within the illuminated field of the headlights. In addition further developments are necessary to deal with optical disturbances such as backlight and shadows.

4) Scanning laser radar for pedestrian recognition
Since laser radar can only detect the return pulse from objects, it cannot discriminate living beings from other objects. Therefore, although laser radar can inform drivers of the presence of stationary objects, but predictions regarding the movement of the target can not be made.

5) Pedestrian recognition by sonar (ultrasonic radar)
Its maximum detection range is about 10 meters and it is not suited for walking pedestrians. A shape recognizing algorithm is necessary in order to discriminate pedestrians from other obstacles.

As above, there are several detection techniques. In study, we examined these from the following point of view: (1) it is expected that use of electromagnetic wave (EMW) radar on automobiles will increase and related technologies will become popular in the near future, (2) there is a theoretical possibility of pedestrian detection independent of the color and brightness of their clothing at a distance worth notification, for example, about 40 meters from the equipped vehicle, and (3) method which can discriminate pedestrians (living beings) from other objects (vehicles, traffic signs, concrete structures) using characteristics other than their form. If a technique (3) became available, sophisticated software processing required for pattern recognition will be eliminated and the system can be simplified.

DISCRIMINATION METHOD

Figure 1 shows the reflectance of electromagnetic wave from the human body as a function of frequency. This is the date of reported by Dr. Miyagawa characteristic of human body MITI’s Electrotechnical Laboratory in 1981. He measured complex dielectric constants on a living body at several frequencies. On the assumption that the human body has a 3-layer structure consisting of a low hat layer (skin), a high fat layer (subcutaneous fat layer), and a low fat layer (muscle tissue), he regarded this as a parallel plate structure and applied Fresnel’s formulas to that structure. The characteristic curve in figure 1 is result. A steep reflectance drop can be found beyond the frequency of 40 GHz. This motivated us to see if it is possible to recognize a living being pedestrian discriminating from other objects by comparison in power of reflected signals of dual band radars at 10 GHz and 60 GHz. The ratio of the reflectance at 10 GHz to that at 60 GHz is about 1.5. If 76 GHz is used instead of 60 GHz, the ratio is improved to about 2.
The ratio of the receiving power in the 10-GHz band to that in 60-GHz band is represented by $R(\text{reception})$ \[(1)\]

$$R(\text{rec}) = \frac{P_{t60}}{P_{t10}} \times \frac{P_{r10}}{P_{r60}}$$

Substituting the radar equation into Expression (1) and rearranging yields by $R(\text{reflection})$ \[(2)\]

$$R(\text{ref}) = \frac{(4\pi)^4 \cdot R^4 \cdot P_{t10} \cdot G_{10}^2 \cdot \lambda_{10}^2}{(4\pi)^4 \cdot R^4 \cdot P_{t60} \cdot G_{60}^2 \cdot \lambda_{60}^2} \times \frac{\sigma_{10}}{\sigma_{10}}$$

where $P_t$: transmitted power, : wavelength, $G$: antenna gain, $P_r$: receiving power, : radar cross section, $D$: distance, $R(\text{rec})$: ratio reception power, $R(\text{ref})$: ratio reflection power

The fore part of Expression (2) is a constant determined by the transmitter section, and the proportion of received power is a value determined by radar cross section. This implies that the ratio of receive power is determined by the target’s characteristics as a function of frequency. Therefore, it is expected that discrimination of pedestrians is possible using this ratio of received power because pedestrians have a unique frequency characteristic.

**SYSTEM CONFIGURATION**

In this study, an experimental set up as shown in Figure 2 (a) was used to evaluate the basic detection principle above. The experiment was carried out in a small microwave chamber and intended for detection of pedestrians and other objects at a very close distance.

The specifications of experimental system are:

1. Radar scheme: FM-CW mode (10 GHz)
2. Transmission and reception frequencies: 10 GHz and 59.9 GHz
3. Transmitted out put power :10 mW for both frequencies
4. Antenna: Electromagnetic horn with beam width of 30 degrees for both bands
5. Detection range: Pedestrians 3 to 5 meters, vehicles 10 meters.
6. Resolution: 0.1 meters.

This sensor system shown is Figure 2 (b) consists of an FM-CW radar in the 10-GHz band having separate receiving and transmitting antennas, a 10-GHz reception level meter as a branch from the above-mentioned receiving antenna, a transmitter and transmitting antenna in the 60-GHz band, the 60-GHz band receiving antenna and reception level meter, and a signal processing unit. In the signal processing unit, there is an FFT analyzer function. This function analyzes the signal from the FM-CW radar and calculates the distance to the object. Considering obstacle detection from a moving vehicle and warning to the driver, it seems that at least 30 to 40 meters of detection range is necessary. However, the specifications above were employed since the system made in this study was solely for desk-top experiments. As a method to increase detection range in the FM-CW mode with 10 mW, scanning is performed with an antenna whose beam divergence is narrowed down 2 or 3 degrees.
TEST METHOD

We evaluated the sensor system to use small microwave anechoic chamber, shown in Figure 3.
SYSTEM EVALUATION

(1) Evaluation results of several kinds of targets fixed in front in shown in Figure 4 (a). If the threshold value for the ratio of proportions of received power is to 5, discrimination is possible between pedestrians and other targets.

(2) We set the ratio of received power to 5 and placed target other than pedestrians in an oblique position. One of the major problems of this approach is that the reflection power characteristics of some angled surfaces appear very similar to that of human bodies. Figure 4 (b) shows the experimental result of angle test for several kinds of materials. Particularly metal plates cause significant detection error as incident angle increases. For metal, all RF energy is reflected at the surface and its back scattered energy toward the receiver highly depends upon the incident angle.

Figure 4 (a) Evaluation results target fixed in front

Figure 4 (b) Evaluation results for targets placed obliquely
CONCLUSIONS
We developed detection means to distinguish pedestrians from other objects using the
dependence of EMW reflective characteristics at the surface of a pedestrian in
frequency and made an experimental sensor system to verify its basic principle. In
addition, we put that sensor system in microwave anechoic chamber and used the
human body and other objects as target to evaluate the discrimination performance of
the system.
For flat materials such as plate metal, plywood and concrete EMW were irradiated at
right angles and reflected energy level were measured. In this case, discrimination of
pedestrians (human body) was possible. In the case of irradiation oblique to those plates,
however, detection errors arose. It is natural that no detection error arose with target
having circular symmetry. These evaluations verified the theoretical effectiveness, and
ascertained problems, of the pedestrians detection sensor using this principle.

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REFERENCES
1. Dr. M. Miyagawa, “Noninvasive Measurement of Temperature Profiles inside
Dielectric Materials” Electrotechnical Laboratory of MITI, Vol. 45, No. 9 and 10,
pp.25-41, 1981
2. N. Kitagawa, M. Imanishi (Nippon Soken INC.), T. Mizuno (Denso Co., Ltd.),
Development of Foreground Obstacle Detection of Crossing Pedestrian, JSAE P.
No. 9637023
3. T. Honda, M. Sakata, S. Morita, H. Hukuhara (Nissan Mortar Corporation),
Development of a Nighttime Pedestrians Monitor System, Nissan Technical Report,
6. 1995
4. T. Adachi, T. Yosioka, S. Morioka, S. Matuoka (Mazda Motor Corporation),
Development of Recognition Algorithm for Crossing Pedestrians Using Laser
Radar System, JSAE P. No. 9632802
Nighttime Pedestrians Monitoring System and Thermal Infrared Technology,
Automobile Technology, Vol. 50. No. 11, 1996