Human-body Detection Based on Measurement of Electromagnetic Waves: An Approach Using Beacon Signal of Wireless LAN

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***Abstract*— This paper describes a method of the human-body detection by using beacon signals of a wireless LAN. To achieve stable and accurate detection, we focus on the variance of measured beacon signals over time as a signal processing technique. On the basis of evaluation in a real environment, we confirmed that the proposed scheme can achieved the detection rate of more than 90%, meaning that our scheme is effective for detecting the movement of human bodies as crime prevention measures.**
Key words: wireless LAN, beacon, sensor, intrusion detection system

I. Introduction

With increases in crime, the demand for intruder-detection systems for home security has increased in recent years. Present intruder-detection systems for home security problems generally use infrared or vibration sensors. However, an infrared sensor cannot provide complete coverage because it has strong directivity. Therefore, we must use many sensors to fully cover the target area for detecting an intruder.

To solve this problem, intruder-detection systems that use environmental electromagnetic waves such as TV and radio waves have been proposed [1]-[3]. These electromagnetic wave-based methods efficiently detect an intruder who enters an out-of-sight area because of their diffraction and reflection characteristics. Previous studies have shown that the existing TV receiving waves can be applied to intruder-detection systems for detecting the movement of the human body [1], [2]. However, these TV signal-based schemes sometimes may fail human detection because the influence of the outside environment can affect receiving sensors located in the target area. For example, the movement of cars outside the target building may affect the responses of sensors even if there are no intruders. Other systems that do not use environmental signals radiated from outside the target building, therefore, need to be developed to provide more stable and accurate human detection information.

This paper proposes a new intruder-detection system, which uses a wireless LAN signal, for detecting the movement of human bodies [3]-[5]. Section 2 of this paper presents the proposed human body detection scheme that uses beacon signals of wireless LANs, which are set inside a target building. Then, on the basis of an evaluation using a real wireless LAN, the applicability of the proposed scheme is confirmed in section 3.

II. Detection Methods

This section explains the principle of detecting intruders using environmental electromagnetic waves. The waves, for instance TV broadcasting waves from a broadcasting station, propagate inside a room and form multiple paths by reflecting off the walls and furniture in the room. Under such a condition, the multi-path interference changes by reflecting and absorbing the electromagnetic radiation by the human body. The electric field strength in the vicinity of the reception antenna changes greatly when the person enters the room and it moves. Thus, we can detect a person's intrusion and movement from the change of the received voltage level in the indoor space by measuring electric field strength at this time. However, the previous methods that use electromagnetic waves sometimes may fail to provide accurate information, as described in the introduction.

We propose a new system using a wireless LAN set inside the target building. In our system, the beacon signal of a wireless LAN, which is radiated continuously from the access point, is used as an electromagnetic radiation signal. The proposed system is not affected by outside environment, because the wireless LAN access point is set up indoors. However, these waves are discrete signals, and the transmission output level changes with time so that we require an appropriate signal processing to use this signal.

An example of measured beacon signal in the time domain is shown in Fig. 1, where the discrete peaks in the figure correspond to the beacon signals. Then, the peak value at beacon intervals is assumed to be a received voltage, which is denoted by $V(i)$ ($i = 1,2,\ldots N$; N is the total number of measurements), of the beacon signal, and the variation is measured during that time. The variation of the received voltage level has the appropriate interval time that depends on person's movement and its moving speed. Therefore, a certain interval of time T needs to be set for analysis.

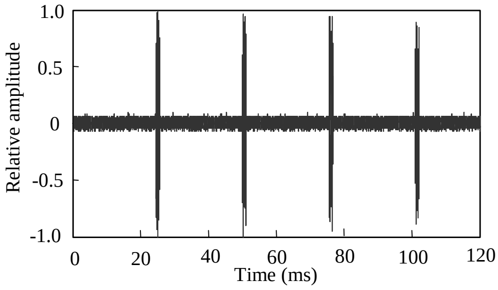


Fig. 1 An example of measured beacon signal in time domain.

To perform accurate and stable detections of human body movements, we use the variance of received voltage V (m) of beacon signals at time step m. Here, the variance V_{var} (m) is given by

$$V_{var}(m) = (1/n) \sum_{i=m-n+1}^{m} \{V(i) - V_{ave}(m)\}^2 \qquad (m > n) \ , \quad (1)$$

where n is the number of the data set for analysis in the target time interval T, and $V_{ave}(m)$ is the mean value of V(i) in T (from i = m-n+1 to i = m).

To detect human body movement from the obtained variance $V_{var}(m)$ over time, the threshold value V_{th} is defined as follows:

$$V_{th} = \alpha V_{var0}, \qquad (2)$$

where α is a parameter, and V_{var0} is the variance value of received voltage in an uninhabited environment.

Finally, the detection rate D is defined as follows:

$$D = N_S/N \times 100 \ [\%], \qquad (3)$$

where N_S is the number of detections more than the threshold value in the observation period .

In our scheme, we first measure the responses of beacon signals from a wireless LAN located in a target room or building. Then, the values of variance V_{var} for measured signals in a time period T are repeatedly calculated over time. Finally, the detection rate of D, which is defined by counting the number of V_{var} greater than a certain threshold, is checked for monitoring human body movement.

III. CASE STUDY

A. Measurement Setup

To check the applicability of our scheme, we measured fluctuations of beacon signals from a real wireless LAN in a room as a case study. The measurement setup is shown in Figure 2. The room is 7.4 × 6 m^2, three sides are concrete walls (one contains a metal door) and one side is a glass window. The sensor system is composed of a 1/4 λ monopole antenna that is set up from the floor to 1 m, detection circuit, 16-bit A/D converter, and personal computer for accumulating measured data. In this room, we received the beacon signal of a wireless LAN by using a 1/4 λ monopole antenna located at the left under of the measurement room. The wireless LAN access point was located at the upper right of the measurement room. The beacon signal in the 2.4-GHz band, which is the standard of IEEE 802.11g, was used, and the time interval was set at 20 ms.

Here, we explain the method of measurement. The measurement schedule is shown Table 1. First, a person moved to the stop point along the route indicated by the dotted line. Two moving speeds were assumed. One was the standard walking speed 1 m/s; in this case (Case 1), the movement time was 20 s. The other was faster than the standard walking speed 2 m/s; in this case (Case 2), the movement time was 10 s. Then, a person stopped for 20 s at the start point. We worked out the above in accordance with Table 1.

TABLE I MEASUREMENT SCHEDULE

	Time Schedule [s]				
Case1 <1 [m/s]>	0 - 20	20 - 40	40 - 60	60 - 80	80 -100
Case2 <2 [m/s]>	0 - 10	10 - 30	30 - 40	40 - 60	60 - 70
State	Movement (M1)	Stationary (S1)	Movement (M2)	Stationary (S2)	Movement (M3)

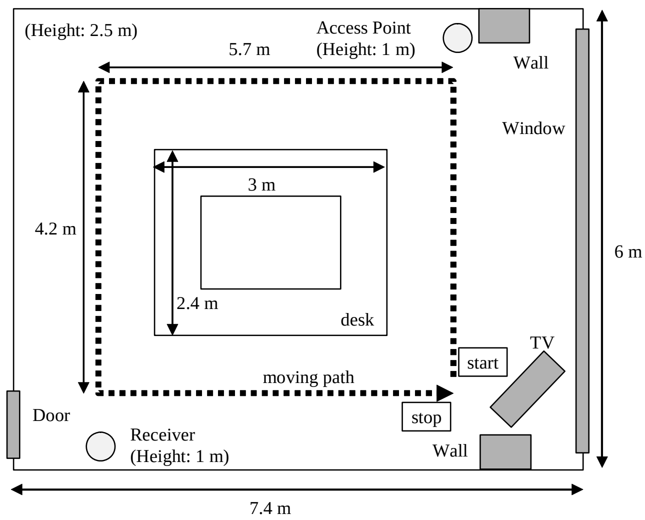
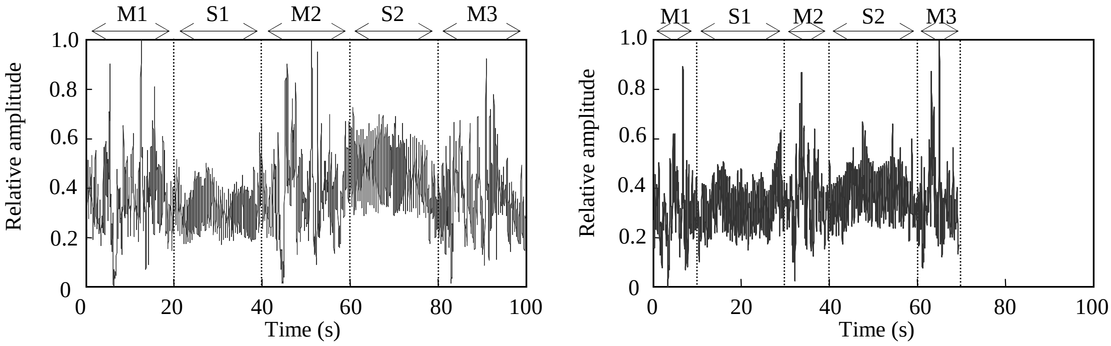


Fig. 2 Measurement room and moving path.

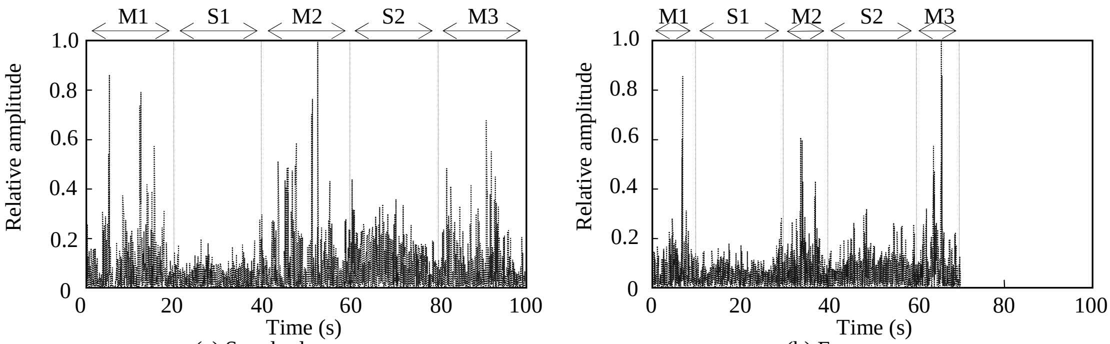
B. Result of intrusion detection

The measured original beacon signals are shown in Fig. 3, in which results both for (a) the standard movement (Case 1 / 1 m/s) and (b) the fast movement (Case 2 / 2 m/s) are plotted. Here, x- and y-axes indicate the time and received voltages normalized by their maximum values, respectively. In these figures, we see that received voltages during the movement period tend to be more greatly fluctuating than those of a stationary period. Moreover, we also see that there was a case where the received voltages change greatly during a period when a person was stationary. It is assumed to be due to unexpected varying components caused by the transmission output level changes according to time. Therefore, we can say that the some quantitative properties need to be extracted from original received signals to establish more stable detections of human body movements.



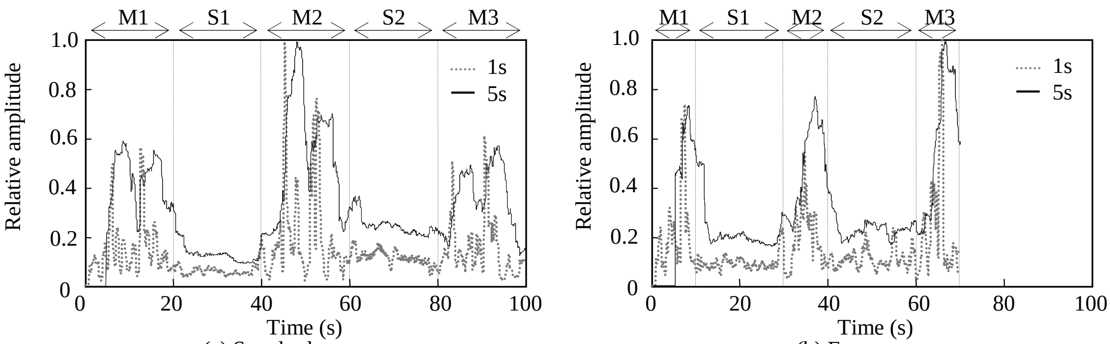
(a) Standard movement (b) Fast movement

Fig. 3 Measurement results.



(a) Standard movement (b) Fast movement

Fig. 4 Square of difference of measurement signal.



(a) Standard movement (b) Fast movement

Fig. 5 Variance of measurement signal (T is 1 and 5 seconds).

Then, in checking fluctuations of received signals, we derived the square of the difference between measured consecutive signals (V_i, V_{i-1}) using the method of Ref. [3]. The obtained results are shown in Fig. 4, where the corresponding values for Fig. 3 are plotted. We see that unexpected varying components during a stationary period remain though the difference between the movement and stationary periods became clear compared with the original received voltage waveforms shown in Fig. 3. Therefore, we conclude that the square of the difference of received signals cannot fully reflect the movement of the human body due to instability of the beacon signal of a wireless LAN. In making the detection of human body movement more stable, therefore, we derive the variance of received signals by shifting the target time period from the starting point.

Then, we evaluated the human body detection by using equation (1). The calculation results are shown in Fig. 5, where (a) and (b) are the same as Fig. 3. The dotted line indicates the case of T = 1 s, and the solid line indicates T = 5 s. Looking at the time interval T = 1 s for both cases, we found that the waveforms were greatly fluctuating in the movement periods, and the detected waveforms in the stationary period were smooth, so there were few unexpected varying components in the stationary period. When T = 5 s for both cases, unexpected varying components tend to be removed, and the values gradually changed in comparison with T = 1 s during the stationary period.

As a result, these figures show that obtained variances in the time domain can provide effective information for detecting movement of the human body in two different walking patterns.

Next, to determine the appropriate time interval T in terms of an accurate detection of human body movement, we need to evaluate the quantitative measure of the variance V_{var} for different values of the time interval T.

Here, the variance expresses the degree of dispersion from the average of measured signals. So, when the amount of variance is larger, the person's intrusion and movement is more easily detected. Therefore, we integrated the obtained variance in the time period M2 (see Table 1) for two walking speed cases (standard movement 1 m/s and fast movement 2 m/s).

The results are shown in Fig. 6, where the x axis indicates the time interval T and the y axis indicates the sum of variance. From this figure, we found that the amount of the change of variance attained a peak value for the change in T. The obtained values take a peak level at around T = 5-7 s for standard movement (1 m/s), and around T = 3-6 s for fast movement (2 m/s). The obtained integrated values reflect the degree of human body movement for each case, so the time interval at around 5 s seems to provide an appropriate measure in our case study.

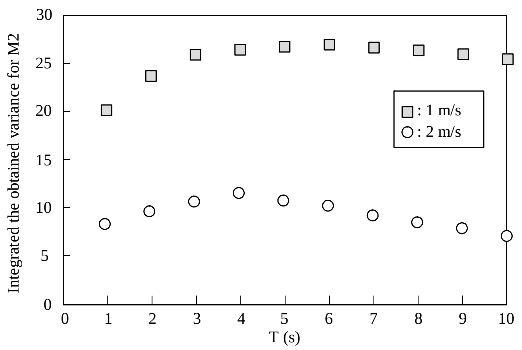


Fig. 6 Summation value when interval of variance of time was changed.

Next, to determine an efficient detection of human body movements, we evaluated the detection rate defined by eqs. (2) and (3). Here, we define a threshold level by measuring the sensor responses in an uninhabited environment, as described in section 2. In this case study, the basic threshold level V_{var0} was set to 0.00016 (derived from a 2-min.-measurement in an uninhabited room).

The relationships between the parameter α and the detection rates are shown in Fig. 7, where the results correspond to two walking patterns (Cases 1 & 2) and an uninhabited case (derived from a 2-min.-measurement in an uninhabited room). Regarding the movement periods for two cases, we see that the detection rate takes higher values compared with others, although the detection rate decreases with increases in the parameter α. Then, the detection rate in the stationary period for two cases also tends to take high values (such as 40-90%) especially when the parameter α is less than 2. We estimate that this high-detection rate in the stationary period is due to the high variance values caused by the person's movement just before the stationary period. In checking an uninhabited case, on the other hand, the detection rate is more than 5-6% when the parameter α is less than 2. This means that the beacon signals of the wireless LAN was fluctuating in the uninhabited room, so we need to set the parameter α to more than certain levels (such as 2) to avoid misdetections.

As a result, we confirmed that our scheme using beacon signals of wireless LANs is effective for detecting the movement of human body in real environments. By setting appropriate values in the signal processing, the results show that our scheme can achieve the detection rate of more than 90% and be used as an intruder-detection system for home security.

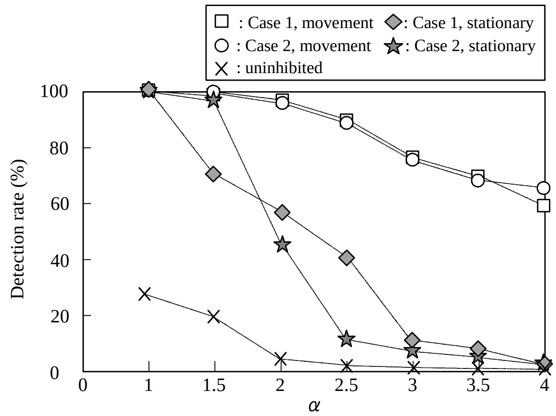


Fig. 7 Detection rate change according to parameter α.

IV. Conclusion

We investigated a method of detecting intruders by using the beacon signal of a wireless LAN. To develop an efficient system for detecting human body movement, we proposed an algorithm that derives the variance of received beacon signals over time.

On the basis of our evaluation in a real environment, we confirmed that the proposed method is suitable for correct detections during an observation period because this method mitigates the effect of unexpected varying components due to the fluctuation of beacon signals.

Results also confirmed that the proposed scheme is effective for efficiently detecting the movement of the human body. When we set the time interval for analysis to 5 s in our case study, this intruder-detection system can achieve the detection rate of more than 90% for the person's movement.

Future studies will analyze the fluctuation of electromagnetic waves by using a numerical simulation and further evaluate the difference between humans and pets.

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