

# Behavior Analysis Based On Nine Degrees-of-Freedom Sensor for Emergency Rescue Evacuation Support System

Maeng-Hwan Hyun, Dae-Man Do, Young-Bok Choi

**Abstract**—Around the world, there are frequent incidents of natural disasters, such as earthquakes, tsunamis, floods, and snowstorms, as well as manmade disasters such as fires, arsons, and acts of terror. These diverse and unpredictable adversities have resulted in a number of fatalities and injuries. If disaster occurrence can be assessed quickly and information such as the exact location of the disaster and evacuation routes can be provided, victims can promptly move to safe locations, minimizing losses. This paper proposes a behavior analysis method based on a nine degrees-of-freedom (9-DOF) sensor that is effective for the emergency rescue evacuation support system (ERESS), which is being researched with an objective of providing evacuation support during disasters. Based on experiments performed using the acceleration sensor and the gyroscope sensor in the 9-DOF sensor, data are analyzed for human behavior regarding stationary position, walking, running, and during emergency situation to suggest guidelines for system judgment. Using the results of the experiments performed to determine disaster occurrence, it was confirmed that the proposed method quickly determines whether a disaster has occurred.

**Keywords**—Behavior Analysis, Nine degrees-of-freedom sensor, Emergency rescue.

## I. INTRODUCTION

THERE have been frequent occurrences of natural disasters, such as earthquakes, tsunamis, floods, and snowstorms, as well as manmade disasters such as fires, arsons, and acts of terror around the world. These diverse and unpredictable adversities have resulted in a number of fatalities and injuries. During these natural and manmade disasters, victims need to access information such as the exact location of the disaster and adequate evacuation routes in order to evacuate to safe locations [1], [2]. Without such information, victims will fall into a panic mode and be unable to take appropriate actions for evacuation, possibly leading to secondary afflictions. A tragic example of a secondary affliction was a fire that occurred in a karaoke hall in Bujeon-Dong, Busan on May 5, 2012. Due to the maze-like paths and flammable materials that caught fire, those who could not quickly evaluate the building were exposed to toxic gases and thick smoke, causing nine fatalities and 25 with serious injuries. Therefore, during a disaster, it is important to compile appropriate information as quickly as possible so that the victims do not fall into a panic mode.

This paper proposes a behavior analysis system based on a

nine degrees-of-freedom (9-DOF) sensor that can effectively support the emergency rescue evacuation support system (ERESS) in large public spaces, such as train stations and airports, during emergency disaster situations. Following the introduction in Chapter I, Chapter II describes the ERESS, which is the basis of this paper. Chapter III proposes the behavior analysis algorithm based on 9-DOF sensor for the ERESS. In Chapter IV, human behavior is analyzed using the 9-DOF sensor and the results are provided for the performance evaluation performed based on the data compiled from the experiments conducted with an assumption of disaster occurrence. Finally, Chapter V presents the conclusion of the paper and proposes topics for future research and areas of improvement.

## II. EMERGENCY RESCUE EVACUATION SUPPORT SYSTEM

The ERESS provides real-time information about a disaster to people in adjacent areas to support emergency evacuation. The objective of the system is to safely evacuate those who could be harmed by a disaster and to minimize damages. The system allows victims to monitor the disaster in real time using their mobile devices, quickly guides them to a safe location, and enables rescuers to promptly find and rescue the victims [3], [4].

## III. BEHAVIOR ANALYSIS ALGORITHM BASED ON 9-DOF SENSOR FOR ERESS

In this chapter, an algorithm is proposed to assess people's movement in indoor public places using the ERESS terminal device to determine an emergency situation has occurred and to transmit the information to the ERESS server. When the server detects an emergency situation, it uses people's movement data from terminal devices to confirm the situation and immediately notifies of the emergency to nearby devices to induce relocation and evacuation [5], [6].

### A. Terminal Device Algorithm

Fig. 1 displays the algorithm executed in the terminal device. If an emergency is detected by assessing people's movement, the device notifies the situation to the ERESS server. The ERESS terminal device algorithm is as follows. After initialization, the terminal device assesses whether there the user is moving. When there is no movement, the terminal determines that the user is in a stationary position and the situation is safe, and displays safe status. When user's movement is detected, the terminal determines whether the user

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is walking or running based on the data from the acceleration sensor and the gyroscope sensor. If the user is determined to be walking, the terminal device displays safe status. If the user is running, the running message is displayed on the terminal and also sent to the ERESS server. If the user is running at a consistent pace, it is not deemed an emergency situation, and the terminal does not send an emergency situation message to the ERESS server. If inconsistent and irregular running is detected, the terminal device determines that an emergency situation has occurred and sends an emergency situation message to the ERESS server, which in turn executes the corresponding algorithm.

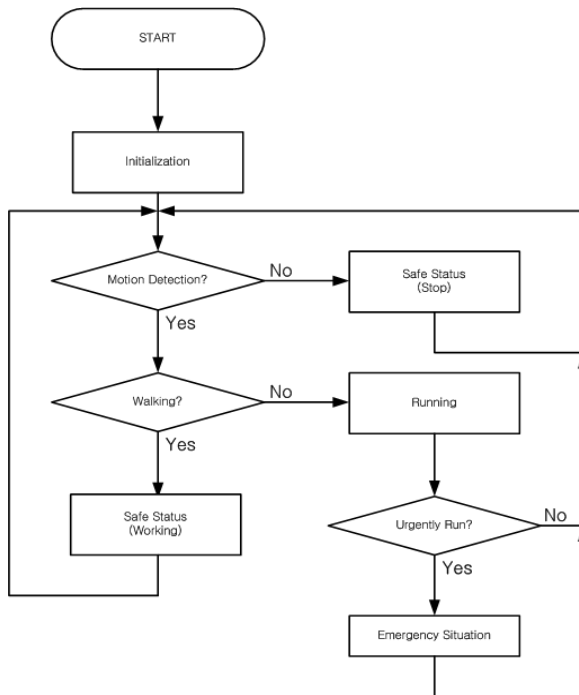


Fig. 1 Terminal device algorithm

### B. Server Algorithm

Fig. 2 displays the algorithm executed by the ERESS server in order to process the user movement data and the emergency situation message sent from the ERESS terminal. After receiving user's movement data from the terminal, the ERESS server stores the information in the terminal status buffer. If the user is running, the running message and the unique terminal number is stored in the buffer. When an emergency situation message is transmitted from the terminal, the message and the unique terminal number is stored in the buffer. When an ERESS terminal sends an emergency situation message to the terminal status buffer, the ERESS server counts the emergency messages and the unique terminal numbers based on the emergency situation messages stored in the buffer for a specific duration. If the number of terminals has sent the emergency situation message is greater than a predefined threshold (for example, 10, 20, or 30), an emergency situation is deemed to have occurred, and an emergency message is sent to all ERESS terminals. An emergency situation is determined based on the

number of terminals sending the emergency message in order to allow the server to quickly detect an emergency situation when a disaster, such as a fire, occurs in an enclosed corner of a large indoor public facility, such as an airport or a train station. When a running status message is received, the ERESS server counts the running status messages and the unique terminal numbers stored in the buffer for a specific duration. If the number of terminals that have sent a running status message exceeds half of all terminals, the ERESS server determines that an emergency situation has occurred and sends an emergency message to all adjacent ERESS terminals. An emergency situation is determined based on the running status information in order to allow the server to quickly detect an emergency situation when a disaster occurs in a large indoor facility with a simple layout, such as a train station. When the server determines there is an emergency situation using the algorithm, the situation is notified to adjacent terminals by sending an emergency message. Upon receiving the notification, the user terminal immediately searches for a safe evacuation route to help the user relocate to a safe location.

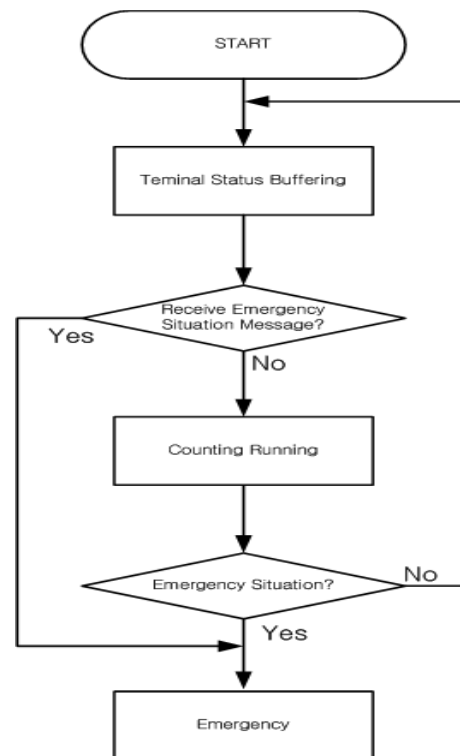


Fig. 2 Server algorithm

## IV. PERFORMANCE EVALUATION

In this chapter, people's movement is detected using a 9-DOF sensor that supports the ERESS, and an emergency situation is simulated to assess the situation based on people's movement.

### A. Experimental Environment

In order to assess people's movement, a 9-DOF sensor was

attached to experiment subjects' waist, and the direction of the sensor was maintained in a uniform direction for the experiment. The experiment was repeated while the subjects with 9-DOF sensor attached to their body and went through the actions of maintaining stationary, walking, and evacuating during an emergency situation in a setup indoor environment (Fig. 3).



Fig. 3 Experiment environment

### B. Experimental Results

This section describes the experimental results obtained from subjects' behavior for the specified duration and analyzes the data. The data from the 9-DOF sensor that varied in maintaining stationary, walking, running, and emergency evacuation situations are analyzed, and comparisons are made between the experiment time and the system determination time.

Fig. 4 displays the wave form of the acceleration sensor while the subjects are stationary, walking, and running. While the subject was stationary, the acceleration of the X axis maintained the initial value of 0.9. When the subject was walking, the acceleration of the X axis changed to 1.3–1.6. When running, the acceleration of the X axis increased to a level greater than 2.0. Therefore, the ERESS determines people's behavior using the average maximum acceleration of the X axis as stationary (less than 1.3), walking (1.3–2.0), and running (greater than 2.0).

Fig. 5 displays the process of extracting the maximum acceleration along the X axis using the moving average filter when the subjects are stationary, walking, and running, as well as the actual times it took to carry out the actions and the times required for the system to determine the actions. In terms of system determination, there were 0.8 sec of errors for both stationary state and walking. When the subjects were running, the error increased to 1.7 sec.

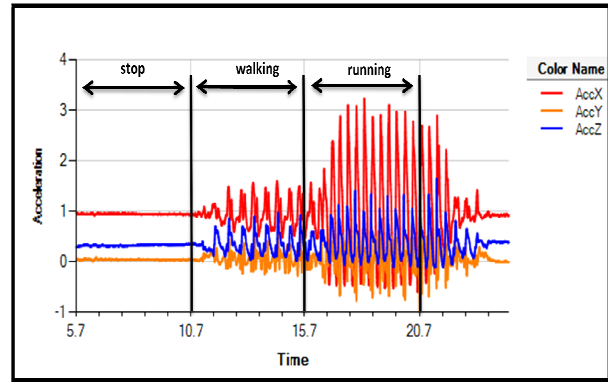


Fig. 4 Acceleration sensor during continuous movement

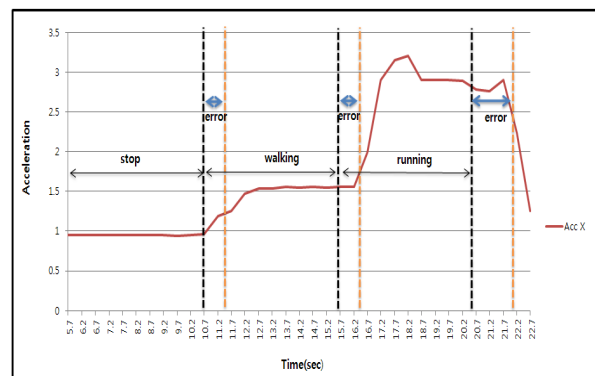


Fig. 5 Movement determination using acceleration along X axis

Fig. 6 displays the wave form of the gyroscope sensor while the subjects' movements were changed from stationary to walking and running. When stationary, the gyroscope's yaw axis maintained the initial value of 30. During walking, the value fluctuated between +50 and -50. When the subjects were running, the range of yaw axis fluctuation increased to between +150 and -150. Therefore, the ERESS determines people's behavior using the average maximum of gyroscope sensor's yaw axis as stationary (less than 35), walking (35–150), and running (greater than 150).

Fig. 7 displays the process of extracting the maximum gyroscope's yaw axis using the moving average filter when the subjects are stationary, walking, and running, as well as the actual times it takes to carry out the actions and the times required for the system to determine the actions. In terms of system determination, there were 1.2 sec and 0.9 sec of errors for stationary and walking respectively. When the subjects were running, the error increased to 1.7 sec.

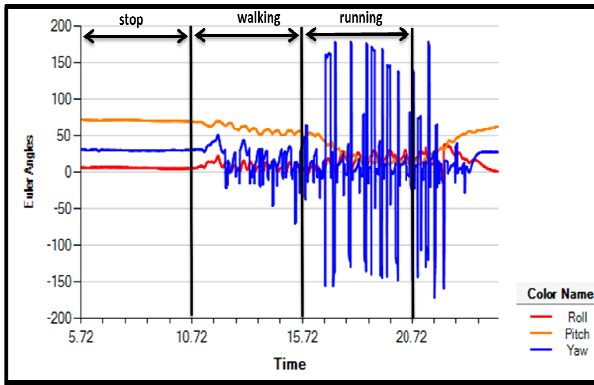


Fig. 6 Gyroscope sensor during continuous movement

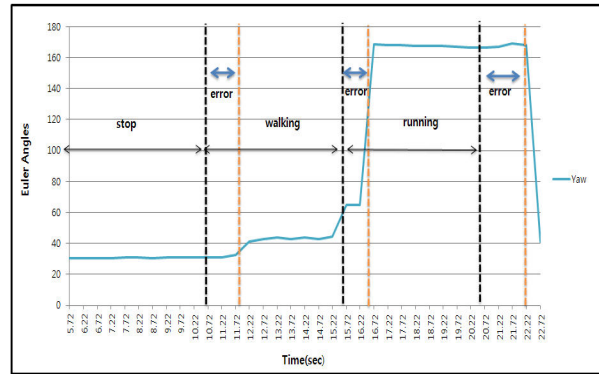


Fig. 7 Movement determination using gyroscope's yaw axis

Table I shows the time errors between system determination and the actual time measured from the data acquired by repeatedly performing the experiment consisting of a continuous series of stationary, walking, and running actions in same durations. Table I indicates that time errors occurred in the system that determined subjects' behavior based on the data from accelerator's X axis and gyroscope's yaw axis. It can also be confirmed that the error of gyroscope's yaw axis is greater than that of accelerator's X axis.

TABLE I  
SYSTEM DETERMINATION TIME FOR THREE TYPES OF ACTION

No. of Experiments	20					
	Measurement time (sec)		Determination time (sec)		Error (sec)	
	Accelerator	Gyroscope	Accelerator	Gyroscope	Accelerator	Gyroscope
Stationary	5		5.7	6.1	0.7	1.1
Walking	5		5.8	6.0	0.8	1
Running	5		6.3	6.5	1.3	1.5

Fig. 8 shows the wave form of the gyroscope sensor displayed according to emergency situations when a disaster occurs. Analysis of gyroscope's yaw axis indicates that the ERESS determined the emergency situation as running because the yaw axis data was deemed to be identical to the running yaw axis data. Therefore, it was concluded that determining an emergency situation would be difficult with data from the yaw axis alone. Analyzing axes other than the yaw axis, it was confirmed that there was a drastic increase in the value of the roll axis, which hardly changes under normal behavior. Accordingly, an emergency situation should be determined using gyroscope's roll axis.

Fig. 9 displays the process of extracting the maximum value of gyroscope's roll axis data using the moving average filter when the subjects take evacuation actions because an emergency situation that occurred while they were stationary or walking. Fig. 8 also displays the actual experiment time and the time determined by the ERESS. An emergency situation was determined if the average maximum value of the roll axis was greater than 110. Whereas the subjects began to take evacuation actions 5 seconds after the start of the experiment, the system determined an emergency situation 6.2 seconds after the experiment started, resulting in a 1.2-second error.

Experimental results indicate that the proposed method is effective for enabling the server to quickly determine an emergency situation when a disaster, such as a fire, occurs in an enclosed corner of a large, complex public facility, such as an airport or train station.

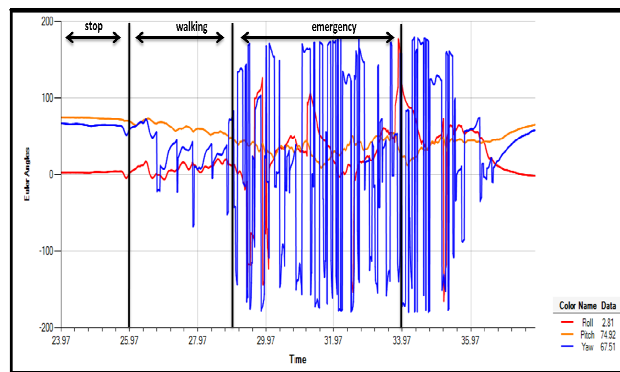


Fig. 8 Gyroscope sensor in emergency situation

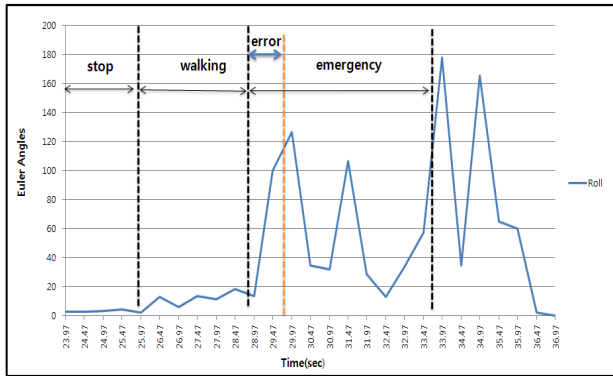


Fig. 9 Determination of emergency situation using Gyroscope's yaw axis

Table II shows the time errors between system determination and the actual time measured from the data acquired from the experiment of repeating the evacuation action. Table II indicates that an average error of 1.3 seconds occurs in a system that determines an emergency situation using gyroscope's roll axis.

TABLE II  
SYSTEM DETERMINATION TIME DURING EMERGENCY SITUATION

No. of Experiments	20		
	Measurement time (sec)	Determination time (sec) Gyroscope Roll	Error (sec) Gyroscope Roll
Emergency Situation	5	6.3	1.3

## V. CONCLUSION

This paper has proposed a behavior analysis method based on a 9-DOF sensor that can effectively support the ERESS to aid evacuation in times of disaster. Based on experiments performed using the acceleration sensor and the gyroscope sensor in the 9-DOF sensor, data were analyzed for human behavior regarding stationary position, walking, and running. In addition, guidelines were suggested to allow the system to determine an emergency situation for each action. This paper also analyzed sensor data regarding human behavior during emergency situation and proposed system's determination criteria to promptly detect occurrence of a disaster. Experimental results indicate that there is an error between the measured time and system's determination time; however, the error ratio is sufficiently low, and the proposed method should be effective in ERESS applications. Research on ERESS is being conducted in collaboration with Kansai University in Japan, and further collaborative research and experiments should be performed in the future to apply the results of this study to an existing ERESS.

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