# Development of Active Evacuation System through Computer Vision Technology

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**SUMMARY:**
It is one of the ironclad rules of risk management that we take multiple countermeasures for reducing human casualties in dwellings attacked by hazardous earthquakes. Add to the diagnostic system enable to assist a safety arrangement of furniture, which is classified into the pre-earthquake countermeasures, we propose a seismic alert system recognizing automatically the indoor risky space with computer vision as an application of the earthquake early warning. When the alert signal from the Earthquake Early Warning get into our system, this system tries to automatically recognize the dangerous floor plan out of indoor spaces by converting a two-dimensional (2-D) image from the video scope into a 3-D model, applying the one-point perspective projection. The dangerous spaces of indoor can be determined by using an estimation method for the overturning probability of furniture with considering the size of furniture calculated from the 3-D image. And then our system tries to track the inhabitants in the space using the computer vision technology and to lead the inhabitants staying in the dangerous spaces to the safer spaces without furniture overturned by artificial voice.

*Keywords: Earthquake early warning, Furniture overturned, Human casualty, Active evacuation, Infrared camera, Computer vision*

## 1. INTRODUCTION

What we have learned from recent earthquakes is the fact that most of injuries occur as resulted in overturning or scattering of furniture and fixing the furniture tightly on the wall is essential for preventing human casualties. However, according to the survey results by Kaneko and Murata etc. (2008), effective fixing furniture is implemented only in about 10 % of the whole Japanese households because of psychologically heavy troublesomeness and technically great difficulty of fixing furniture. While, the Japan Meteorological Agency has recently developed Earthquake Early Warning capable of issuing the arrival time of seismic strong motions before the actual shaking. In order to reduce human casualties in dwellings attacked by hazardous earthquakes, we propose a seismic alert system recognizing automatically the indoor risky space with computer vision as a complementary application of the earthquake early warning technology. [Okada, Nakashima, koyama, etc. 2011]

## 2. THE CAUSES OF THE INJURIES

### 2.1 Actual condition of the seismic casualty

Among a lot of papers and reports dealing with resent earthquake published, we have a special interest in papers by Nachi and Okada (2007) which focus on the seismic casualty in indoor. They discussed about causes of the seismic casualty, with actual condition of the seismic casualty in recent earthquake (See Table 2.1.). Table2.1. shows the causes of seismic casualty that took place in the 6 earthquakes. This table shows the earthquake names, the causes of the seismic casualty, the seismic casualty ratio. The causes of in the injuries by The 1995 Southern Hyogo prefecture Earthquake showed that ~46.2% are related to the overturning furniture, 29.2% are related to the scattering furniture , while 21.5% are related to other case. Also, analysis of the causes of in the injuries by the 2004 The 2004 Mid Niigata Prefecture Earthquake showed that ~28.6% are related to the overturning furniture, 42.9% are related to the scattering furniture, while 28.6% are related to other case. In this way, most of injuries occur as resulted in overturning or scattering of furniture. Therefore, vulnerable furniture tends to be neglected and cause human casualty in repeated earthquakes.

Table 2.1. Actual condition of the seismic casualty by recently earthquake

| The causes of casualty | The 1994 Hokkaido Toho-oki Earthquakes | The 1994 offshore Sanriku Earthquake | The 1995 Southern Hyogo prefecture Earthquake | The 2000 Western Tottori Earthquake | The 2003 Tokachi-Oki Earthquake | The 2004 Mid Niigata Prefecture Earthquake |
|---|---|---|---|---|---|---|
| Structural element | | | 3.1% | | | |
| Fittings | | | | 11.1% | | |
| Building equipment | 4.0% | | | | | |
| Furniture | 24.0% | 43.4% | 46.2% | 33.3% | 18.2% | 28.6% |
| Scattering | 60.0% | 24.0% | 29.2% | 11.1% | 50.0% | 42.9% |
| Cooking food | | 13.9% | | | | 14.3% |
| Drop | 11.0% | 10.1% | | 44.4% | 18.2% | 14.3% |
| Move | | 7.1% | | | | |
| Other | 1.0% | 1.5% | 21.5% | | 13.6% | |

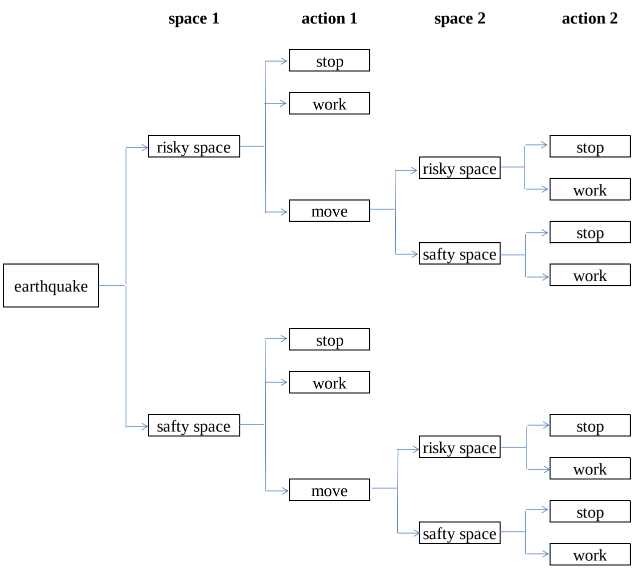
**2.2 Relation between injuries and behaviour when during the earthquake**

This section discusses seismic injury from the point of view of relation between injuries and behaviour with the actual data of hearing investigation into The 1995 Southern Hyogo Prefecture Earthquake and The 2003 Tokachi-oki Earthquake and The 2004 Mid Niigata Prefecture Earthquake and The 2007 Noto Hanto Earthquake. Outline of hearing investigation are shown in Table 2.2 by Aoki and Nakashima and Okada (2008). We examined 355 peoples from 4 earthquake events.

Figure 2.1.shows relation between seismic injuries and behaviour when during the earthquake by consolidating and classifying hearing investigation data in 4 earthquake events of 355 people. The space 1 means the location of people at just before earthquake. And, Space 2 means the location of people at immediately after the earthquake. The space is roughly divided into three classes: risky space and safety space. Risky space means overturning space of furniture. Also, the action is roughly divided into three classes: stop and work and move. The stop means resident is keep still. The work means resident is working in the place. The move means that the residents have moved. Analysis of the causes of in the seismic injuries during the earthquake by 4 earthquakes showed that 85% of the seismic injuries are related to stop or work in the risky space, 4% is related to stop or work in the safety space. In addition, resident that has moved in risky space, the injury rate is 100%. Resultantly, the ratio of seismic injury in risky space is much more than that of in safety area. To prevent injury, evacuation to the safety space of residence is important.

Table2.2. Outline of hearing investigation

| | The 1995 Southern Hyogo Prefecture Earthquake | The 2000 Western Tottori Earthquake | The 2004 Mid Niigata Prefecture Earthquake | The 2007 Noto Hanto Earthquake | Total |
|---|---|---|---|---|---|
| The number of household | 25 | 69 | 27 | 21 | 142 |
| The number of person | 58 | 103 | 71 | 40 | 355 |
| The number of injured | 54 | 17 | 7 | 5 | 88 |




| Number of persons | Number of injured | Injury rate |
|---|---|---|
| 6 | 5 | 83% |
| 4 | 2 | 50% |
| 2 | 2 | 100% |
| 1 | 1 | 100% |
| 31 | 1 | 3% |
| 8 | 0 | 0% |
| 133 | 7 | 5% |
| 27 | 1 | 4% |
| 4 | 4 | 100% |
| 3 | 3 | 100% |
| 43 | 2 | 5% |
| 7 | 0 | 0% |

Figure 2.1 Relation between injuries and human behaviour when during the earthquake

## 3. DEVELOPMENT OF ACTIVE EVACUATION SYSTEM

In the previous section we have seen when, where and how many of the injury in several earthquakes have taken place. In order to reduce human casualties in dwellings attacked by hazardous earthquakes, we propose a seismic alert system recognizing automatically the indoor risky space with computer vision as a complementary application of the earthquake early warning technology. The system we proposed is simply composed of the video scope as a Web Camera or an infrared night-vision scope and the mobile computer. Component parts of this system are four; first part is acquisition of 3-D information in the indoor space. Second part is calculation of risk space, third part is acquisition of position information about the resident, and fourth part is evacuation guidance (See Figure3.1).

When the alert signal from the Earthquake Early Warning get into our system, this system tries to automatically recognize the dangerous floor plan out of indoor spaces by converting a two-dimensional (2-D) image from the video scope (See Figure3.2.) into a 3-D model, applying the one-point perspective projection. The dangerous spaces of indoor can be determined by using an estimation method for the overturning rate of furniture with considering the size of furniture calculated from the 3-D image. And then our system tries to track the inhabitants in the space using the computer vision technology and to lead the inhabitants staying in the dangerous spaces to the safer spaces without furniture overturned by artificial voice.

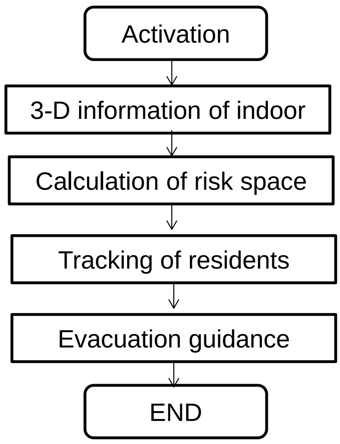



Figure3.1. Outline of the system

Figure3.2. Image of the video scope

### 3.1 Converting a two-dimensional (2-D) image from the video scope into a 3-D mode

This system tries to automatically recognize the dangerous floor plan out of indoor spaces by converting a two-dimensional (2-D) image from the video scope into a 3-D model, applying the one-point perspective projection. The conversion to 3-D model will be done by mouse click on the screen. The following shows a summary of them.

*3.1.1 Setting of focus point and measuring point*

First, set the focus point and the measuring point .The focus point($X_0$,$Y_0$) is obtained automatically as the coordinate, only considering the four points (point A,B,C,D into Figure3.3.) on the vertical line for the reference plane by mouse click on the screen as follows:

$$Y_0 = a_1 X_0 + b_1 \tag{3.1}$$

$$Y_0 = a_2 X_0 + b_2 \tag{3.2}$$

The measuring point is obtained automatically as the coordinate, only considering the two points on the Point E and point F by mouse click on the screen. (See Figure3.3)

*3.1.2 Setting of floor surface*

Secondly, set the floor surface. Floor surface is extracted by clicking on the point G, using to the three points have been obtained. (See Figure 3.4)

*3.1.3 Setting of reference plane*

Third, set the reference plane. Reference plane is a wall with a focus. The reference plane is obtained automatically as the coordinate, only considering the two points (point H and point I) by mouse click on the screen. (See Figure 3.4)

*3.1.4 Setting the ratio of depth*

Finally, set the ratio of depth. In this section, this system is tried converting a two-dimensional (2-D) image from the video scope into a 3-D model. (See Figure 3.5)

Origin is the lower left of the screen. In addition, the X axis is set to the horizontal of the origin. The Y axis is set to the vertical of the origin. The Z axis is set to the depth of the origin. Assuming that measured in the reference plane, it is possible to calculate the actual distance x and y by connecting the focal point. The depth of the indoor (Z axis) can be expressed using the ratio of the actual range in length by using the measurement point. In other words, segment ratio (AB: BC) and projection line segment ratio (A'B ': B'C') are equal.

Square is placed in the reference plane in order to give the actual length of the depth represented by the ratio. (See Figure 3.6) Assume that DE = n and D'E '= n', α coefficient is calculated as follows:

$$\alpha = nl / n' \tag{3.3}$$

Where, the actual length $z$ in the reference plane is calculated by segment length $z'$ and coefficient $\alpha$ as follows:

$$z = \alpha z' / l \tag{3.4}$$

In this way, coefficient $\alpha$ to convert the three-dimensional coordinates are calculated.

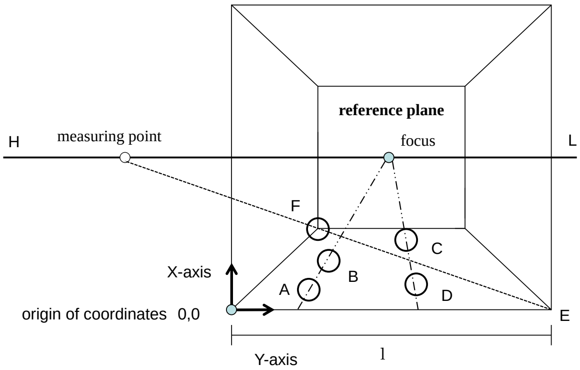



Figure3.3. Setting of focus point and measuring point

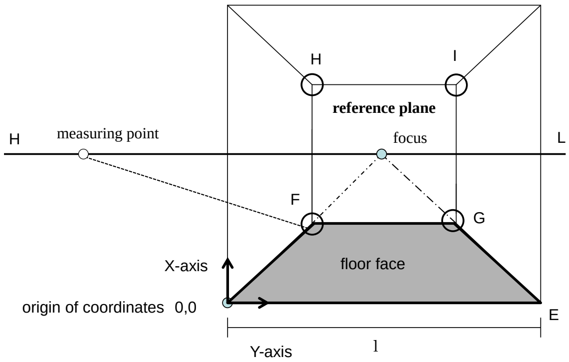



Figure3.4. Setting of floor surface and reference plane

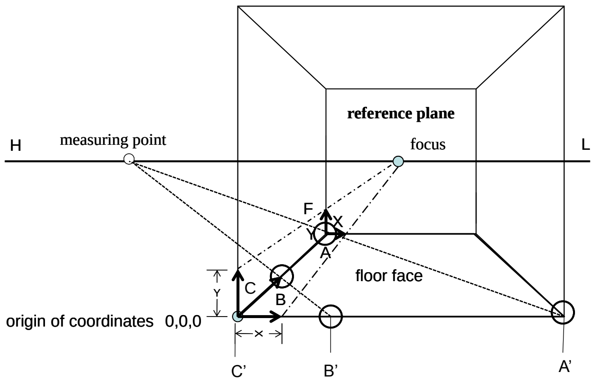



Figure3.5. Calculate the actual distance x and y

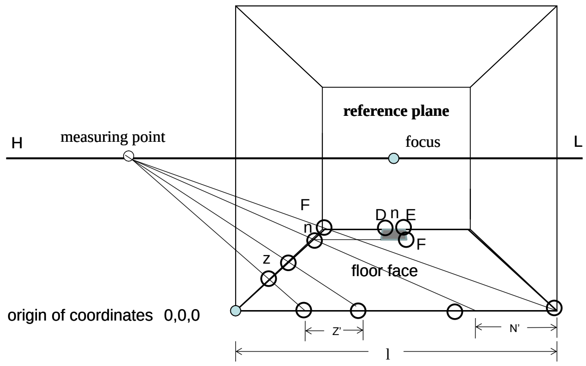



Figure3.6. Setting the depth ratio

## 3.2 Three-dimensional information of furniture

Similarly, this system can to automatically recognize the actual size of furniture by converting a two-dimensional (2-D) image from the video scope into a 3-D model, applying the one-point perspective projection. Assume that furniture is a rectangular solid, there obtained coordinates of the image data about the tilt of the reference plane and height and depth and height and width of the furniture. They are obtained automatically as the coordinate, only considering the four or five corner of furniture by mouse click on the screen. Thus, the actual size of the furniture can be obtained using to the relationship between the coordinate distance and the coefficient α. As shown in Figure3.7, the furniture placement is allowed at any angle for the reference plane. In this case, the width *W* and depth *D* of furniture is obtained by the following equation:

$$W = \sqrt{R^2 + (\alpha Z / l)^2} \tag{3.5}$$

$$D = \sqrt{r^2 + (\alpha z / l)^2} \tag{3.6}$$

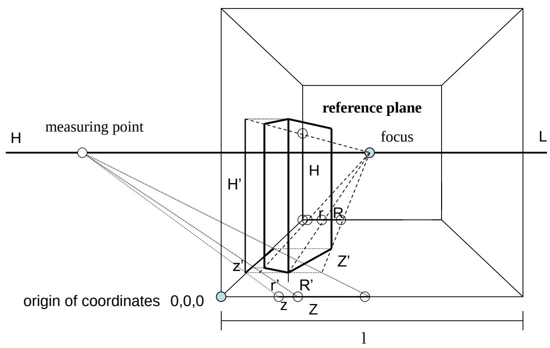



Figure3.7. Three-dimensional information of furniture

### 3.3 Estimation of overturning ratio of furniture

For the actual size of the furniture were obtained in the previous section,the risky spaces of indoor can be determined by using an estimation method for the overturning probability of furniture with considering the size of furniture calculated from the 3-D image. Overturning rate estimation equation is to use an expression that focuses on the aspect ratio of the furniture by Kaneko (2002). This expression is necessary to know the maximum acceleration *Af* and maximum velocity *Vf*. However, Earthquake early warning is provided only intensity information. Therefore, the maximum acceleration *Af* to convert the intensity *I* using the equation by Kawasumi (1943). In addition, the maximum velocity *Vf* to convert the seismic intensity using the equation by Muramatu (1993). Thus, equation (3.7) can be derived to estimate the probability of overturning furniture *R(I)*.

$$R(I) = \alpha \cdot \phi((\beta(I) - \lambda)/\zeta) \quad (3.7)$$

$$e^{\lambda} = A_{R=50} = \begin{cases} D/H \cdot g \cdot (1 + D/H) & at \quad F_f \le F_b \\ 10D/\sqrt{H} \cdot (1 + D/H)^{2.5} \cdot 2\pi F_f & at \quad F_f > F_b \end{cases} \quad (3.8)$$

$$F_f = A_f /(2\pi V_f) \quad (3.9)$$

$$F_b = 15.6/\sqrt{H} \cdot (1 + D/H)^{-1.5} \quad (3.10)$$

Where *B(I)* is maximum acceleration ( $=ln\ A_f$ ) . $\Phi$ represents the standard normal distribution function. The parameters $\lambda$ and $\zeta$($\zeta$ is fixed to 0.58), representing the mean value and the standard deviation. α is the coefficient of friction between the floor and furniture (α is fixed to 0.8). *D / H* is the aspect ratio of furniture. *g* is the acceleration due to gravity. *Ff* is the equivalent frequency response floor [Hz] (*Ff* is fixed 3.18). *Fb* is the number of boundary vibration of furniture [Hz].

As mentioned above, the probability of overturning furniture can be determined only by the furniture aspect ratio and intensity. The estimation models are shown in Figure3.8. Probability of overturning furniture has become larger in the same intensity as the aspect ratio is small. In addition, the furniture aspect ratio is calculated automatically at the time of the previous section.

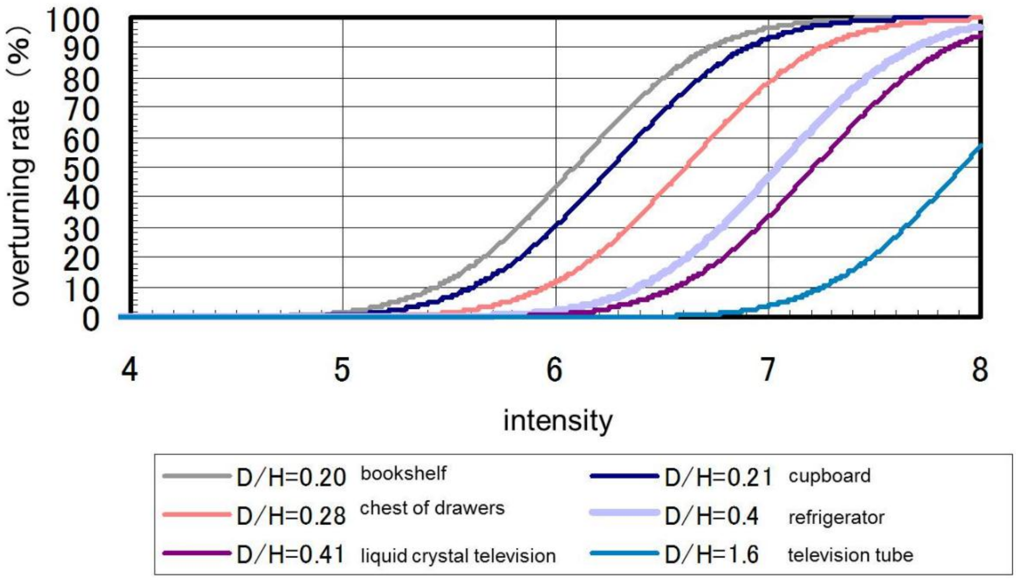



Figure3.8. Overturning rate of furniture

### 3.4 Degree of seismic injury by types of furniture

The degree of seismic injury to residents when hit depending on the type of furniture is different, because furniture is different about weight and shape. Therefore, we use the AIS (Abbreviated Injury Scale) that has been used in the field of disaster medicine in order to indicate the degree of an injury. Table 3.1. shows the AIS of furniture were calculated from the survey results in recent earthquakes. AIS is understood that varied depending on the furniture as shown in this table. If the furniture is more than one hit, it is determined by the total of the AIS. AIS value has the following meaning. If the AIS value is less than 3, it means a slight injury (Degree of seismic injury is requiring medical attention or simple does not require much attention). Also, if the AIS value 3 or greater, it means a serious injury (Degree of seismic injury is the requiring hospitalization or a mortal wound).

Table 3.1. Degree of seismic injury by types of furniture

| Furniture | condition | AIS |
|---|---|---|
| **Vase** | Overturning | 1.5 |
| **Glass case** | Overturning | 1.5 |
| **Television** | Overturning | 1.5 |
| **Family Buddhist altar(small)** | Overturning | 1.5 |
| **Full-length mirror** | Overturning | 2 |
| **Shoe boxes** | Overturning or Overturning and scattering | 3 |
| **Washing machine** | Overturning | 3 |
| **Writing bureau** | Overturning or Overturning and scattering | 3.5 |
| **Bunk bed** | Overturning | 3.5 |
| **Bookshelf** | Overturning or Overturning and scattering | 4 |
| **Family Buddhist altar(large)** | Overturning or Overturning and scattering | 4 |
| **Sideboard** | Overturning or Overturning and scattering | 4 |
| **Refrigerator** | Overturning or Overturning and scattering | 4 |
| **Chest of drawer** | Overturning or Overturning and scattering | 4 |

### 3.5 Tracking of resident and evacuation guidance

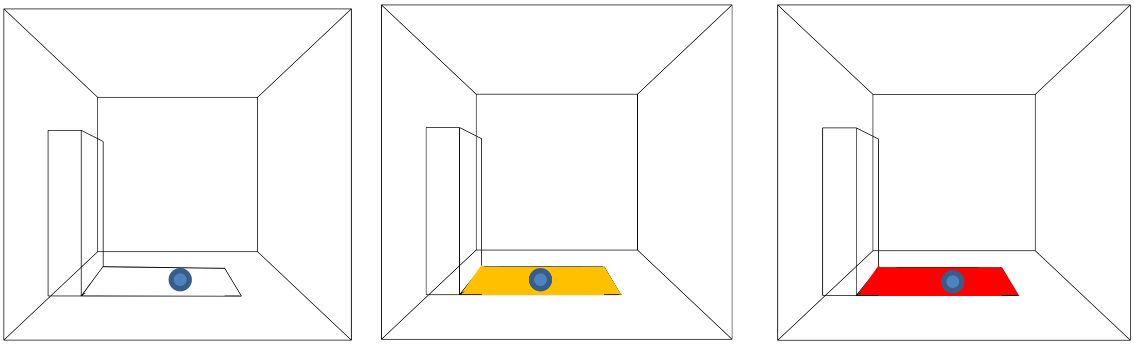
We know from Figure 2.1 that in order to prevent an injury, evacuation to the safety area of resident is important. This system is a human extraction by using a background subtraction method to capture video images from the CCD camera. In addition, it will automatically track the location of residents in a room by taking the contour of the foot. If any inhabitants stay in dangerous spaces violated by the high probability of furniture overturned when the alert signal from the Earthquake Early Warning get into our system, the artificial voices from this system tell them to hasten to evacuate from the dangerous spaces. In this case, the risk of indoor space was set as follows: If overturning rate of furniture is greater than or equal to 30%, space is displayed as red squares. If overturning rate of furniture is greater than 0 and less than 30, space is displayed as yellow squares. If overturning rate of furniture is equal to 0, space is displayed as white squares. Also, voice evacuation information by severity level was set as follows:

①Safe space(white space) → Please do not move.

②Dangerous space (yellow space) → Dangerous

③Very dangerous space (red space) → Very dangerous

In addition, this system is shown in real time the position of the resident. Residents can determine the degree of risk by the image. Figure3.9. is indicating the position of resident and risk. And then our system tries to track the inhabitants in the space using the computer vision technology and to lead the inhabitants staying in the dangerous spaces to the safer spaces without furniture overturned by artificial voice.



Safe space Dangerous space Very dangerous space

Figure 3.9. Evacuation guidance

## 4. THE WORKING EXAMPLE

Figure 4.1 is the working example. We developed the new procedure for image processing to subtract the unique trace of inhabitants out of infrared images through the temperature noise reduction by which background images are renewed at every a few seconds. In this way the location of inhabitants can be clearly traced at all times. If any inhabitants stay in dangerous spaces violated by the high probability of furniture overturned when the alert signal from the Earthquake Early Warning get into our system, the artificial voices from this system tell them to hasten to evacuate from the dangerous spaces. In figure 4.1, the original image is the left, and image of extracted human is the middle, and right image is information of overturning space and including the location of the residents. As the central figure suggests, residents is extracted in the shape of human. In the right figure, the positions of the human foot are displayed in the overturning space of furniture the image. An announcement states that evacuation information when there is foot point in risky space.

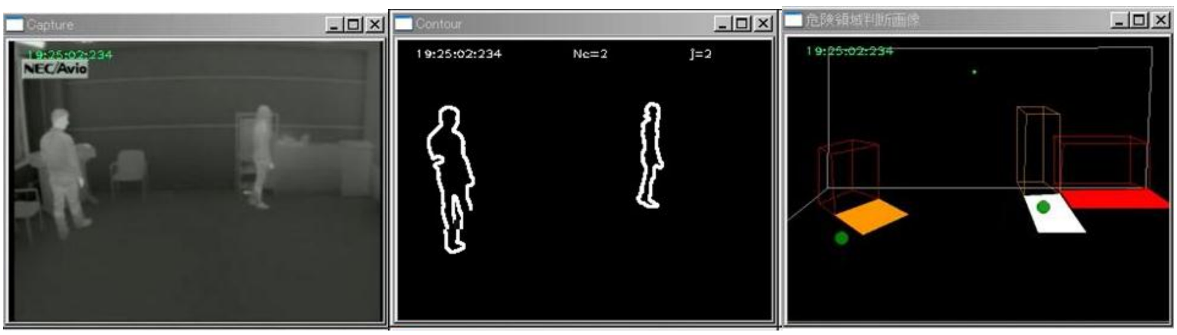



Figure 4.1. The working example

## 5. CONCLUSIONS

In the ubiquitous info-network environment utilizing the proposed system, which contributes to reduce human casualty in indoor space, will be enhancing the potentiality for seismic safety in the dwelling space.

## REFERENCES

Kaneko Mika, Murata Akiko, Yoshimura Masahiro, Yamada Kazuki, Fukui Hiroko(2008) : Analyses of questionnaire survey on numbers and fixing conditions of household goods, Journal of architecture and building science 14(28), 685-688.

Okada Shigeyuki, Nakashima Tadayoshi. Koyama Maki (2011): Development of active evacuation system through computer vision technology: as a part of multi-countermeasures for reducing seismic casualties in

dwellings Journal of social safety science (12・13), 213-221.
Nachi Noriyuki, Okada Shigeyuki(2008): Probabilistic Seismic Casualty Models and Simplified Method to Evaluate Seismic Casualty Risk, Journal of structural and construction engineering. Transactions of AIJ (616), 97-104.
Aoki Toshinori , Nakashima Tadayoshi , Okada Shigeyuki(2009)： Estimation Method of Human Casualty due to Indoor Damage in Earthquakes in Terms of Medical Approach using Injury Severity Score, summaries of technical papers of tokai meeting Architectural Institute of Japan., 47, pp.201-204.
Kaneko Mika(2002): Method to Estimate Overturning Ratios of Furniture during Earthquakes Journal of structural and construction engineering. Transactions of AIJ (551), 61-68.
Kawazumi Hiroshi (1943) ：Intensity and scale of seismic intensity, Journal of the Seismological Society of Japan, 15, pp.6-12.
Muramatu I.(1993)：Expectation of maximum velocity of earthquake motion within 50 years throughout Japan, Sci.Rep.Gifu Univ., 3, pp.470-481.