Infant Behavior Simulation Based on an Environmental Model and a Developmental Behavior Model*

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Abstract – *A computational approach to understanding comprehensively the behavior of infants and children, which is required in clarification of the dynamics of a system that includes behavior-related accidents, is needed. The present paper describes a method for simulating infant behavior in a virtual environment. The determinant factors of infant behavior are classified into internal factors, such as the physical and cognitive capabilities estimated from the age of the infant, and external factors, such as visual stimuli from surrounding objects. An infant behavior simulator is developed herein by modeling these internal and external factors. The present paper reports the effectiveness of the newly developed simulator. This simulator enables analysis of infant accidents at home from an engineering point of view and will support the design of rooms and houses that are safer for infants.*

Keywords: Behavior simulation, Behavior model, Accidents involving children

1 Introduction

A recent report[1] states that unintentional injury is the leading cause of death among children below 14 years of age, even though the rate of injury has declined approximately 40% over the last ten years. In the United States, unintentional injury claims more than 5,600 lives a year, or an average of 15 children each day. In Japan, unintentional injury is also the leading cause of death among children and accounts for 21.7% of child fatalities. This report clarifies the necessity to recognize child injury as a public health issue, amenable to prevention, rather than as the result of uncontrollable "accidents". Techniques for analyzing child behavior are required for the prevention of unintentional injury of children at home and for the design of safer environments for children.

A computational approach makes it possible to integrate existing knowledge on infant behavior in various research fields and to analyze infant behavior more comprehensively than is currently possible in research fields such as cognitive science or developmental behavior of children.

The present study attempts to establish both a computational approach to understanding child behavior and the dynamics of a system that takes child behavior into account. In addition, a comprehensive and concrete demonstration of the effectiveness of the proposed approach is given by applying the approach to technologies used in preventing child injury and to the construction of an environment that is safe for children.

As a first step, this paper focuses on the behavior of young children[1], including infants and toddlers, for the following reasons:

- Infants have the highest rate of unintentional-injury-related death.

[1] In this paper, the term "infant" refers to children under three years of age

- The developmental behavior of infants has been clarified[2, 3].
- In the earliest stage of the science of child-related accidents, overly complex factors, such as a high level of cognitive abilities, are avoidable, and these can be integrated into the approach incrementally after developing the basic approach.

This paper presents an infant behavior simulator that simulates infant behavior in a virtual environment. In the next section, we analyze the factors related to infant injury accidents at home and clarify the necessary functions of infant behavior simulation. Section 3 presents the newly developed prototype system for infant behavior simulation. In Section 4, we describe the significance of the simulation and infant informatics based on the simulation techniques.

2 Infant Behavior Simulation

2.1 Analysis of factors in accidents involving infants at home

Key factors in accidents involving infants have been reported to include environmental factors (e.g. neighborhood cohesion), parent-related factors (e.g. functionality of family, income, gender of the head of the household, and parenting), and infant-related factors (e.g. age, temper, and history of injuries), as shown in Fig. 1 [4]. In this way, the system of factors affecting accidents involving infants is complex. The dynamics of the system should be clarified in order to help prevent such accidents.

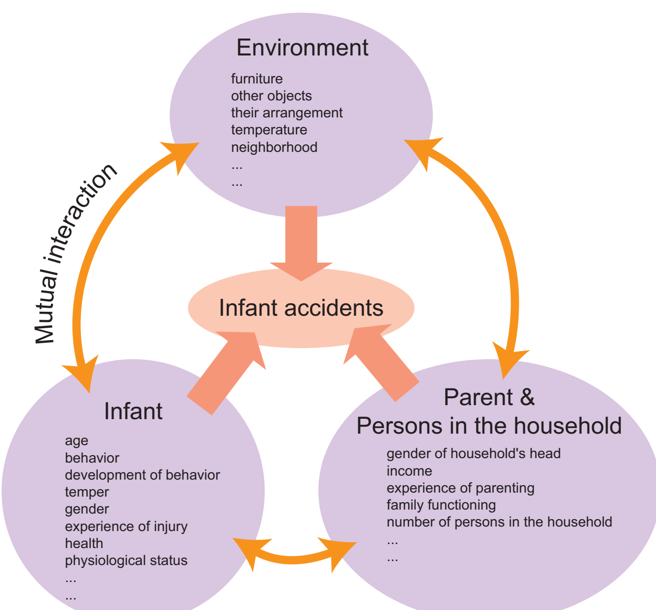

Figure 1: System of factors affecting accidents involving infants

The key causes of accidents involving infants at home are as follows:

- **Rapid development of infant abilities and body shape**
  The cognitive and behavioral ability of infants develops more rapidly than those of both older children and adults. The physical shape of infants also changes rapidly. Therefore, it is difficult for parents to predict their behavior, even though it is simpler than that of adults.
- **Environmental disparity among individuals**
  The arrangement and type of furniture differs among individual homes and can change dynamically. Currently, there are no methods for preventing accidents that can be applied universally.
- **Difficulty in watching infants 24 hours a day**
  It is impossible for parents to monitor their infants 24 hours a day, and many accidents occur when a parent is nearby.

2.2 Necessity of infant behavior simulation

The necessity of infant behavior simulation, i.e. a computational approach, is shown by the following:

- **Necessity for dealing with a complex system of accidents**
  A number of accidents occur due to a combination of multiple factors, such as infant abilities, environmental factors, and parent behavior. A computational approach enables us to integrate these factors using a computer and to conduct an analysis-by-synthesis, so that we can analyze and clarify the dynamics of a system of accidents.
- **Necessity for describing knowledge on a computer**
  Once the factors behind accidents and scientific knowledge of infant behavior are described on a computer, we can evaluate and utilize the computerized knowledge in various applications.
- **Necessity for real-time and one-step-ahead monitoring**
  Ubiquitous sensors[5, 6] for monitoring infant behavior may be available for home use in the near future. Based on simulations, in addition to real-time monitoring of infant behavior, one-step-ahead monitoring is needed in order to prevent injury accidents.
- **Dealing with the "human element"**
  It is impossible to analyze accidents by setting up "artificial accidents". This presents a difficult problem for dealing with accidents scientifically. One solution to this problem is to utilize a database of past accidents.

2.3 Fundamental functions of the infant behavior simulator

This section describes the fundamental functions of the infant behavior simulation.

- **Function for integrating key components affecting infant behavior**
  In this paper, we classify the determinant factors of infant behavior into internal factors, i.e., the physical and cognitive capabilities estimated from the infant's age, and external factors, i.e., visual stimulus from the environment surrounding the infant. A developmental behavior model for describing the internal factors and an environmental model for describing the external factors are presented in detail in the next section. Integration of these two models makes it possible to analyze the dynamics of infant-behavior-related injury accidents by changing key parameters (e.g., infant's age and arrangement of furniture) that affect infant behavior.

- **Function for utilizing simulation results in practical application**
  Infant behavior simulation will have various applications, such as the computer-aided design of a safe environment or the development of a real-time monitoring system for accident prevention. This paper presents the creation of a hazard map as one of fundamental functions in designing a safe environment.

3 Development of an Infant Behavior Simulator

3.1 System configuration

We created a prototype infant behavior simulation system. The simulator consists of an infant accident database, an infant developmental behavior database, an object database, a simulation engine and a visualization engine.

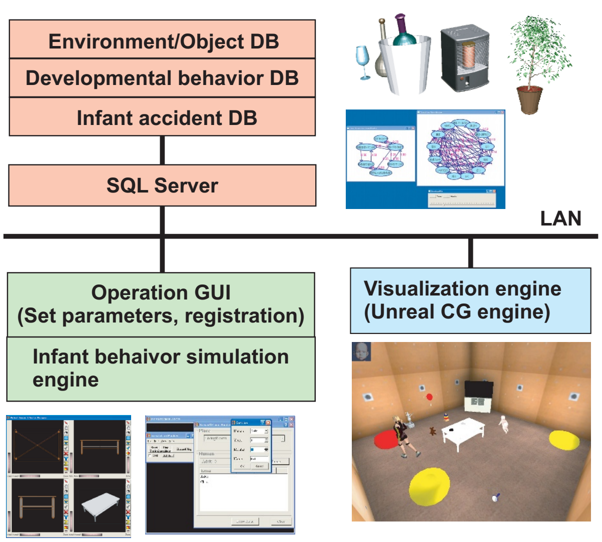

Figure 2: System configuration

3.2 System components

3.2.1 Accident database

An accident database was created using data from over 200 injury accident incidents collected with the cooperation of a doctor at a children's hospital. The database includes information that includes *date, name, age, accident location, type of injury, causative behavior, and causative object.*

3.2.2 Environmental model (environmental database)

The environmental model describes the object characteristics. In this research, an object is considered to be anything that can induce infant behavior. The environmental model includes information on the infant behavior that is induced by the object. The induced behavior is determined using past accident data and data collected in a behavior observation room developed by the authors. The details of the behavior observation room are presented in Section 3.4. The label expressing the induced behavior is selected from the list of behaviors of the developmental behavior model presented in Section 3.2.3.

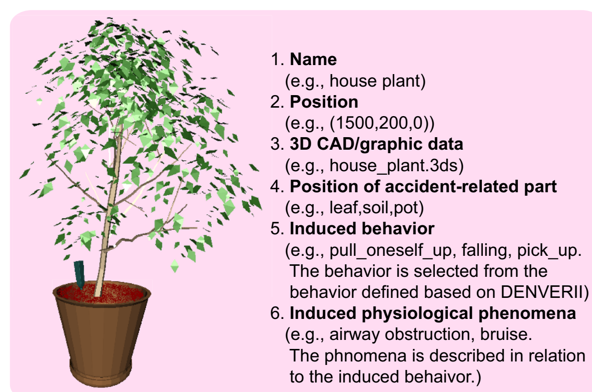

Figure 3: Data structure of an object

3.2.3 Developmental behavior model (Developmental behavior database)

We based the developmental behavior model on DENVER II[2, 3], which was originally used for evaluating the developmental level of infant behavior. Some examples of rough-and-large behavior of the entire body used in DENVER II are "lie on infant front", "roll over", "lie face up", "crawl", "sit", "stand", "fall", "walk", "run", "jump", "pull oneself up", "walk backward", "climb up", "kick", "throw", "stand on one foot", and "pick up". Some examples of rough-and-large behavior of the hands are "place hands together", "reach hand for object", "rake with hand", "hold object in both hands", "change hands", "pinch with thumb", and "move only thumb". The developmental behavior model includes a list of the above behaviors in relation to infant age and state transition of behavior. An example of the state transition used in the model is shown in Fig. 4. The state transition changes largely depending on age, as shown in Fig. 5. In Fig. 5, the left-hand side of each of the six figures indicates the state transition related to rough-and-large behavior of the hands, and the right-hand side of these figures shows the state transition related to rough-and-large behavior of the entire body. The figure indicates that the transition becomes complex as the infant becomes older.

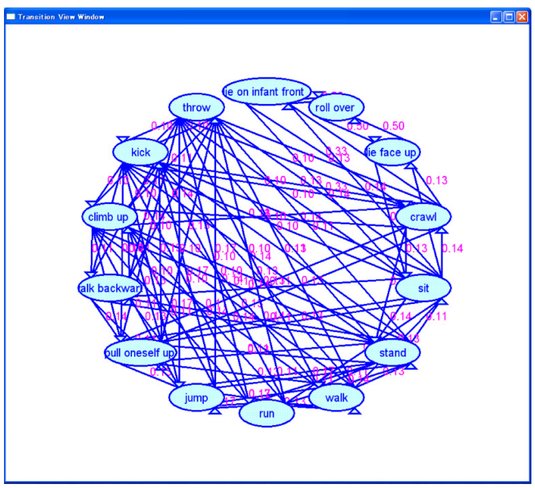

Figure 4: State transition for the case of a 1.5-year-old child

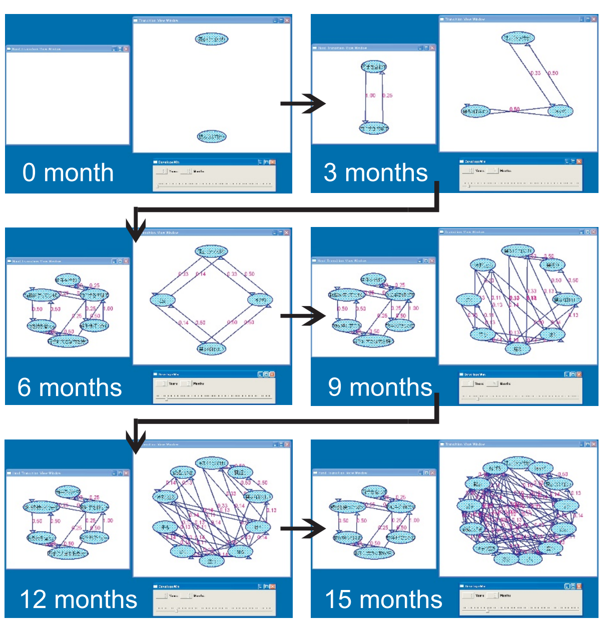

Figure 5: Change in the state transition of behavior with respect to infant age

3.2.4 Visualization

Visualization is realized using UnrealEngine2[7], which is originally a graphic engine for creating video games. The simulation engine generates the behavior that can be performed by the infant at a given moment and sends the behavior data to the visualization engine via TCP/IP. The visualization engine then displays the infant's behavior in the virtual room, as shown in Fig. 6.

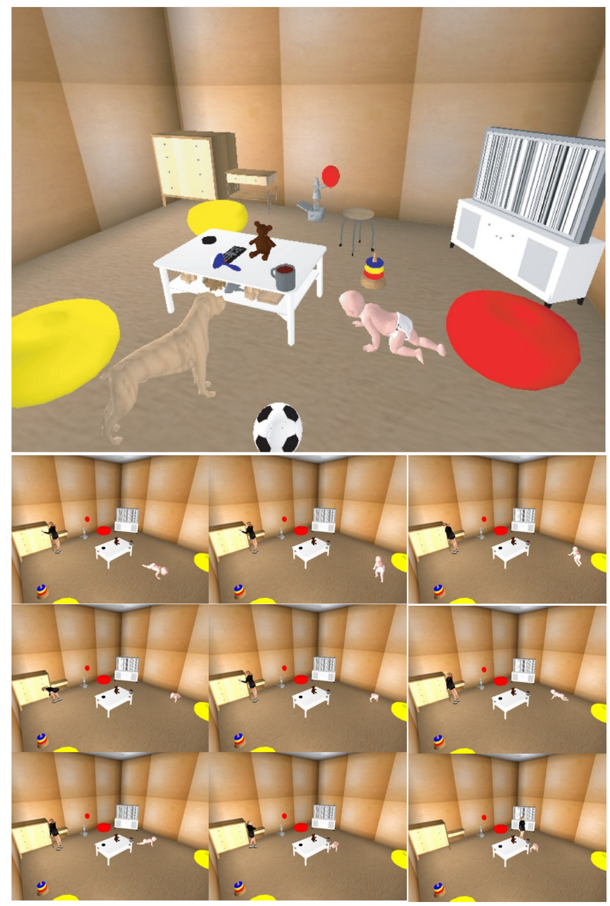

Figure 6: Example of visualization of behavior simulation

3.3 Simulation flow

The steps for generating infant behavior are as follows:

1. Get list of possible behaviors (Behavior set B_d) from the developmental behavior model by inputting the infant's age.
2. Calculate distances from the infant to objects and find the nearest objects.
3. Get list of induced behaviors (Behavior set B_i) from the environmental model of the nearest objects.
4. Get the product set $B_d \cap B_i$ of B_d and B_i.
5. Generate the next infant behavior by selecting an element from $B_d \cap B_i$.

6. If necessary, search potential injury accidents using the selected behavior.

7. Repeat 2 to 6.

The infant simulator can be used for hazard analysis. If we can define hazard levels of accidents, the simulator can calculate a hazard map of the room, as shown in Fig. 7. In this figure, the red areas indicate high hazard levels.

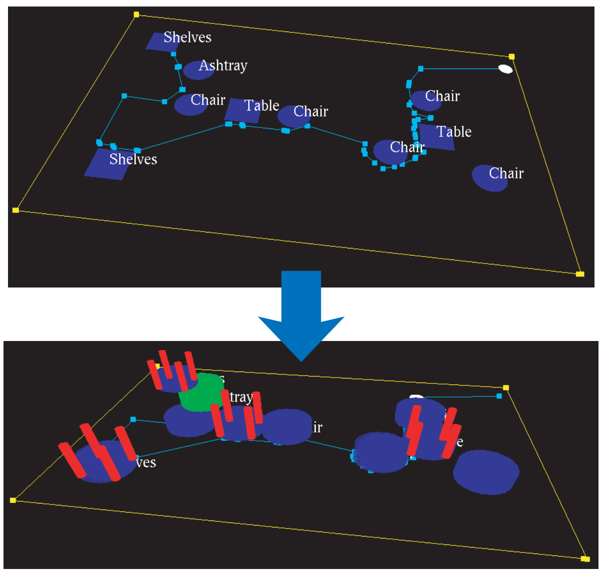

Figure 7: Example of a hazard map created based on the infant behavior simulation

3.4 Behavior observation room

Observing infant-object interaction is important in order to create a model of how objects affect infant behavior. As such, we constructed a behavior observation room in order to study how infants interact with objects and furniture.

Figure 8 shows the behavior observation room, in which ultrasonic location sensors[8] and a camera are installed. The ultrasonic location system consists of an ultrasonic receiving system, an ultrasonic transmission system, a time-of-flight measurement system, a network, and a personal computer. The ultrasonic receiving system receives ultrasonic pulses emitted from the ultrasonic transmitters and amplifies the received signal. The time-of-flight measurement system records the travel time of the signal from transmission to reception. The network synchronizes the ultrasonic location system and collects time-of-flight data from the ultrasonic receiving system. The positions of objects are calculated based on more than three time-of-flight results. The sampling frequency of the proposed ultrasonic location system is 50 Hz. The proposed system can detect the positions of objects and infants within 30 mm for all objects/infants to which ultrasonic transmitters are attached (ultrasonic 3D Tag in Fig. 8).

Figure 9 shows the measured trajectories of an infant when the infant moves as shown in Fig. 10.

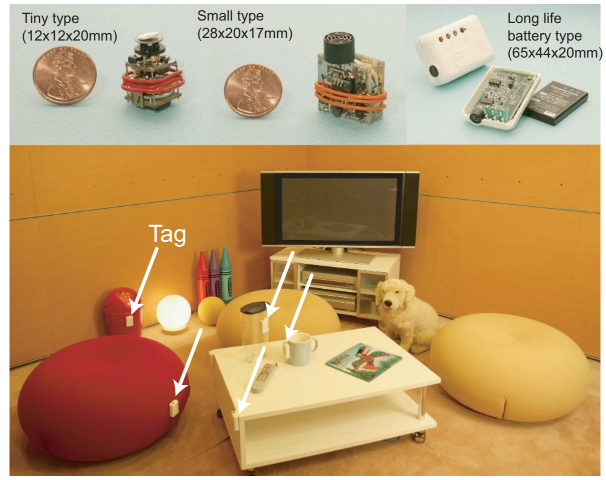

Figure 8: Behavior observation room equipped with ultrasonic location sensors and a camera

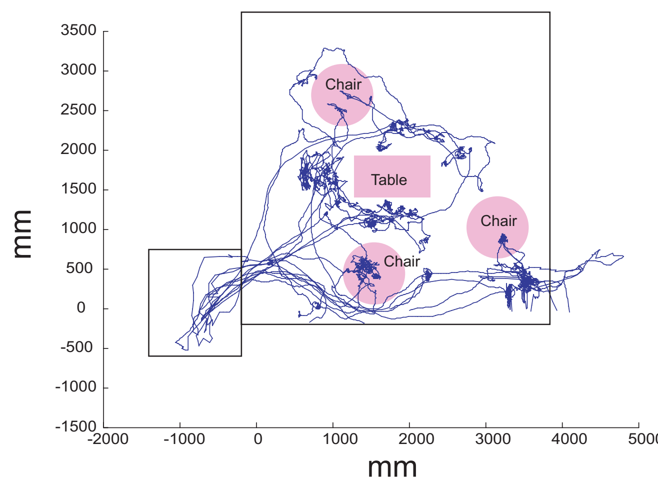

Figure 9: Example of measured trajectory for a 1.5-year-old child

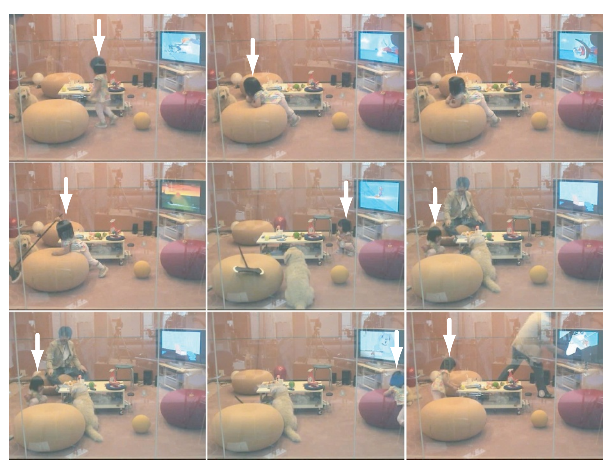

Figure 10: Example of infant activities

4 Significance of the infant behavior simulation

This section describes the significance of the proposed infant behavior simulation.

- **Helpful in designing an environment that is safe for infants**
  In designing ordinary homes, nursing homes, daycare centers for children, and kindergartens, for example, the safety of such environments can be evaluated in advance. The proposed simulator will also make it possible to improve existing homes in order to reduce the risk of injury accidents involving infants.

- **Helpful in educating parents for the purpose of preventing accidents**
  Knowledge applicable to individual homes can be obtained in order to help prevent injury accidents. Effective education will be possible by combining the simulation with realistic graphics.

- **Real-time monitoring of infants for the purpose of preventing accidents**
  Real-time monitoring of infants in order to prevent accidents will be possible by integrating the proposed simulation and a sensing system. Inexpensive sensors, sensor networking technology, and ubiquitous computing technology have already been developed.

- **Development of infant informatics**
  The proposed simulation contributes to the development of a new research area, which can be referred to as infant informatics or child informatics. Infant informatics attempts to comprehensively understand infant behavior by considering infant behavior from an informatics perspective.

5 Conclusions

This paper described the necessity for scientific study of infant-related injury accidents, the associated difficulties, and the significance of a computational approach as a method to address the problem of child safety in the home. As one computational approach, the authors proposed an infant behavior simulation system that enables the simulation of infant behavior in a virtual environment based on past accident data. To create the simulator, the authors classified the determinant factors of infant behaviors as either internal factors or external factors. The internal factors were modeled as a developmental behavior model. The model describes behaviors displayed by an infant in relation to the infant's age. The capabilities are modeled using knowledge of the developmental behavior of infants. The external factors were modeled as an environmental model that includes objects around the infant, as well as their positions. The environmental model contains information on the behavior induced by the objects surrounding the infant. The infant behavior induced by the object was selected using past accident data and data collected in a behavior observation room developed by the authors. Finally, the significance of the infant behavior simulation was described.

Further development of the proposed system will involve the collection of accident data, expansion of the database, the incremental addition of physiological and other factors to the internal factor, and experimental evaluation of the performance of the simulation.

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References

[1] A.L. Wallis, B.E. Cody, A.D. Mickalide, "Report to the Nation: Trends in Unintentional Childhood Injury Mortality, 1987-2000," National SAFE KIDS Campaign, 2003 (http://www.safekids.org/content_documents/nskw03_report.pdf)

[2] W.K. Frankenburg, J. Dodds, P. Archer, et al., *The DENVER II Training Manual,* Denver, CO: Denver Developmental Materials, Inc., 1992

[3] The Japanese Society of Child Health, *Japanese Edition DENVER II*, The Japanese Child Medical Press, 2003

[4] H. Soubhi, P. Raina, D. Kohen, "Effects of Neighbourhood, Family, and Child Behaviour on Childhood Injury in Canada," Human Resources Development Canada, 2001 (which can be obtained from http://www11.sdc.gc.ca/en/cs/sp/arb/publications/research/2001-000067/iw-01-1-6e.pdf)

[5] U. Hansmann, L. Merk, M.S. Nicklous, T. Stober, *Pervasive Computing Handbook. The Mobile World*, Springer-Verlag Telos, 2001

[6] J. Fraden, *Handbook of Modern Sensors: Physics, Designs, and Applications*, AIP Press, 2003

[7] http://udn.epicgames.com/Two/UnrealEngine2Runtime

[8] Y. Nishida, H. Aizawa, T. Hori, N.H. Hoffman, T. Kanade, M. Kakikura, "3D Ultrasonic Tagging System for Observing Human Activity, " *Proceedings of IEEE International Conference on Intelligent Robots and Systems (IROS2003)*, pp.785-791, October 2003