# Multimodal Sensing System to Enhance the Safety of Infants in the Home Environment

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## Abstract

We propose a system which consists of a multimodal sensing-, reasoning- and actuation-stage to monitor the infant's behavior and sleeping environment, particularly to improve the infant's safety. Moreover, the system advices parents on the child's development. The multi-parametric monitoring system can detect physiological and behavior parameters derived from the infant. Furthermore, people visiting the infant's sleeping environment are identified upon entrance and tracked during their stay in the room. The sensors systems include video, pressure and audio based technologies. High level sensor events are extracted from the raw sensor data, fused and fed into a reasoning system. Depending on the decision outcome, relevant in-home services are automatically actuated to provide feedback to the parents or other caregivers on the behavior of the infant.

**Keywords.** Multimodal sensing systems, contextual decision making, context awareness, video tracking, infant safety.

## Introduction

Many young parents are concerned about the wellbeing of their sleeping child. The presented architecture addresses parent's desire for support in supervision when the infant is unattended in the bedroom. SIDS (Sudden Infant Death Syndrome) is a well-documented fear of many parents and it is the leading cause of death among infants below the age of 12 months [1,2]. Also the comfort of the sleeping child is of course important.

The presented architecture is an ambient intelligent system in the home environment, with the main goal to provide peace of mind to the parents when there is no direct parental supervision. In case of an unsafe situation in the infant's sleeping environment or infant's distress, the system signals the parents. Depending on the significance of the alarm, parents in turn could respond by giving the infant some attention. Moreover, the system includes methods to give the parents insight on the child's development.

The system is developed within the ITEA2 GUARANTEE (Guardian Angel for the Extended Home Environment) project. The project provides technical solutions for personal safety in the home environment. GUARANTEE introduces local and network-supported decision making for safety applications on the basis of sensor input and with immediate response and feedback to the people concerned.

## Method

As starting point of the system design, use case scenarios have been made which define the scope and application context and underline the benefits of the system from a safety enhancing point of view. The use case scenarios were mapped on a high level system architecture that consists of three main stages, i.e. sensing, decision making and actuation. The system takes into account design aspects proposed for Ambient Intelligence (AmI) environments [3]. Each use case scenario contains a set of distinct situations that cause a condition change which may influence a sub-process due to user interaction or situation change in the observed area. For each stage, requirements have been specified which evolved into the architecture illustrated in Figure 1. The system transfers different types of information, i.e. events which could be either safety events (raised by a critical or dangerous situation) or standard events (raised by subsystems or nodes for further processing). A second form of information is data flows which could be either raw measured values or audio/video streams.

**Sensing**

The sensing stage extracts high level events from the raw data acquired by the sensor platform installed in the infant's bedroom. The various sensors comprise vision, audio and pressure based modalities: *(i) Side-view face recognition*: Cameras mounted in the doorpost of the infant's sleeping environment identify individuals visiting the room. Besides identification of an individual, the walking direction is detected to determine if a person enters or leaves the room. Based on the authentication result, the parent may decide if an individual is allowed to be with the infant. The analysis algorithm comprises several processing steps to acquire images suitable for feature extraction. The system uses binary local patterns extracted from gray level images as features for authentication [4]. *(ii) Zone detection:* A stereo vision system installed in the ceiling of the baby room tracks the position of individuals during their stay. In order to compute the tracking coordinates, the stereo cameras first need to be cross-calibrated. Once the cameras are aligned, pixels that are part of the same object are matched across multiple views to build a disparity map [5]. From this information, coordinates of the visible objects are computed which are subsequently fed to a system which performs real-time zone detection, i.e. it detects if this person enters or leaves a predefined zone. In these cases the system generates a zone enter or zone leave event, respectively. The zone events are used in the reasoning stage. The system could for instance detect whether a second child enters the infant's sleeping environment without adult supervision which may provoke an insecure situation or may bother the infant while sleeping. *(iii) Infant's emotion analysis:* This module aims to extract the infant's emotion from an auditory scene. The sound analysis system consists of three main stages. Firstly, audio is captured from a microphone. Next a time frequency analysis is performed which incorporates information from a physical model of the human inner ear (cochlea). Several algorithms extract cues from the cochleogram. These cues are further analyzed to distinguish baby sounds (e.g. crying) from the audio stream. The signaled audio events are interpreted by the decision making process. *(iv) Posture and restlessness detection:* The activity of infants and more specifically the posture of infants is an important aspect in their safety and development. Several independent risk factors for SIDS have been identified, and a combination of preexisting conditions and

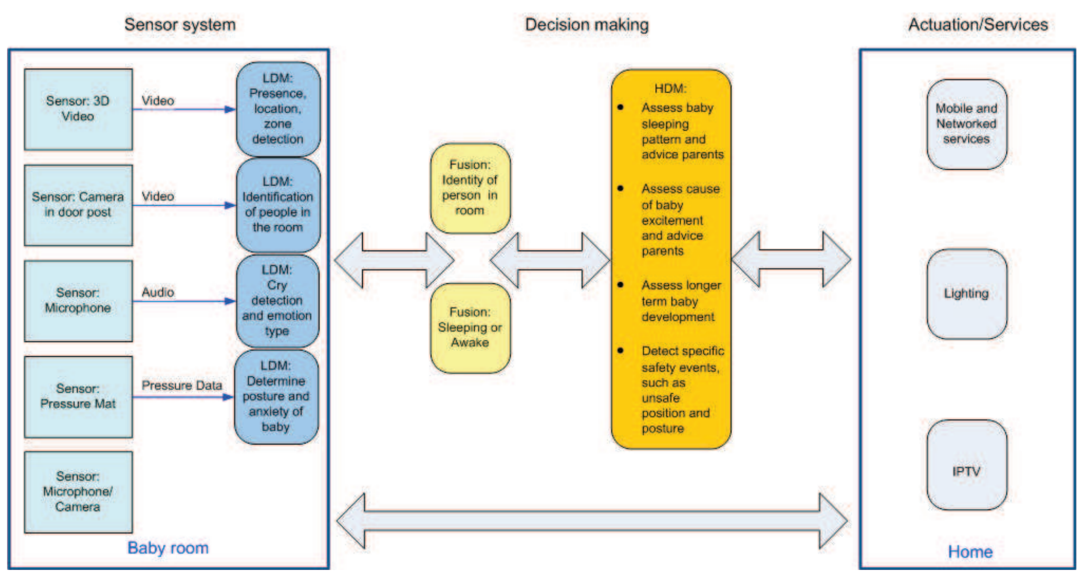


Figure 1. High level infant monitoring architecture consisting of three stages: sensing, reasoning and actuation.

initiating events may lead to SIDS. In view of safety, the supine sleeping position is widely regarded as advised sleeping position for a infant opposed to the prone position which is considered as an individual SIDS risk factor [1][6]. In order to enhance the safety of the infant, we propose a pressure sensitive mat which is positioned under the mattress in the infant's bed, to determine different postures and restlessness levels of the infant when present in the bed [7]. Postures that could be detected by the pressure mat module include: sitting, standing, supine- and prone-position. The infant's activity level is determined by analyzing the variation in applied pressure over time. The observed behavior of the infant is transferred to the decision engine.

**Decision making**

The sensor events generated by the different modalities are aggregated, fused and translated into safety events. The actual interpretation of the safety events is done in the second stage by means of an autonomous decision making process. The process is event driven and depends on the current received sensor event message, current state of the process and previously logged data. The decision making process models the current behavior of the infant and other occupants in the infant's room and updates the information based on the received sensor events. A received sensor event comprises typically several attributes, e.g. parameter values, priority and timestamp. High level sensor information, relevant for storage, is logged in memory. Different situation dependent services, defined in the third stage are actuated by the decision making module.

**Actuation**

The actuators and services provide insight on the current situation in the baby room. Most of the baby monitoring systems rely on audio signaling to notify the restless of infants or inactivity (no-breathing). Such signaling can be achieved by transmitting baby sound or audio warnings. Such audio notifications are in some situations not adequate and alternative 'silent mode' notifications are desired. Moreover, modern video baby monitors add a constant video stream to provide visual information about the infant's state. In the proposed architecture, the in-home services are three fold and are excited by the decision engine: *(i) Smartphone*: The system uses a smartphone application to visualize the status in the infant's room, in particular the child's emotion and posture, and the schedule of entrance/exit of individuals visiting the room. According to the type of event that is detected by sensors, the application displays an alert. *(ii) IPTV*: An IP-based baby camera attached to the baby crib is proposed that can send its video stream to different connected display devices in the home, e.g. a TV or smartphone. In case the behavior of the infant desires visual feedback to the parent, a notification service is pushed by the decision engine which overrides the TV image or smartphone current view. *(iii) Lighting*: The infant's activity level or emotional state is associated to a certain color within the light spectrum and is represented by a color LED lamp. Such lighting service could be integrated with the home light atmosphere and provide the parents a way to remotely keep an eye on their child. As an example, blue would indicate that the infant is calm and red would indicate that the child is very agitated. Different levels of restlessness are represented by color grades between these two colors. The level of restlessness is determined by available sensor nodes such as pressure sensor mat, microphones and cameras.

## Communication

In order to exchange safety events and data flows, the Universal Plug and Play (UPnP) concept was selected as preferred communication mechanism. UPnP offers seamless device-to-device communication and allows automated device discovery and configuration. A UPnP device can be any entity on the network that implements the protocols required by the UPnP architecture. Devices in a UPnP network announce their presence and defined services to control points present in the network. A control point is an entity in the network that works with the services provided by a device [8]. In GUARANTEE, the different sensor nodes are modeled as UPnP devices, whereas decision making and actuator entities are modeled as UPnP control points.

## Conclusions and future work

We present the architecture of an automated system to enhance the safety of infants in the home environment. Behavior analysis and decision making are the key technologies in the proposed architecture. The behavior of the infant and other individuals, e.g. children and adults which are not necessary directly interact with the infant, is monitored by means of a multimodal sensing platform. In order to minimize the false alarm rate, sensor fusion is performed to obtain a robust estimation of the infant's emotion and identity of individuals approaching the child. Based on the high level safety events extracted from the raw measurement data, reasoning is performed to define the situation context. The reasoning process takes into account aspects such as: infant's sleeping position, sleeping status, anxious and type of anxiety and pattern thereof. The output of the decision-making process offers to the end-user good situational awareness of the infant's behavior and current situation in its room which are potentially insecure. The proposed system mainly focuses on observing and mining the behavior of the infant and other occupants in the infant's room. No direct interaction is performed between the infant and the system; therefore it primarily enhances the role of the parent or caregiver as opposed to other concepts like robot nannies which ultimately functions as a child's caregiver [9]. Although many commonalities exist between our proposed system and robot nannies, especially from a sensory, context awareness and reasoning point of view, the later approach poses significant ethical issues (e.g. emotional attachment and connection with the caregiver) as a robot would mainly substitute the primary caregiver instead of improving its role [10].

In a domestic AmI environment, respecting the privacy of individuals interacting is an important aspect. During the design process of the system, a proper balance between the benefits of an automatic monitoring and invasion of privacy was taken into account. Privacy of individuals is preserved as the reasoning is based on high level sensor events which do not contain personal data. For future work we planned to verify the proposed system from a user perspective. This could be for instance by exposing groups of users to test usage (parts of) the system.

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