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Sentient Spaces: Intelligent Totem Use Case in the ECSEL FRACTAL Project

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Abstract— The objective of the FRACTAL project is to create a novel approach to reliable edge computing. The FRACTAL computing node will be the building block of scalable Internet of Things (from Low Computing to High Computing Edge Nodes). The node will also have the capability of learning how to improve its performance against the uncertainty of the environment. In such a context, this paper presents in detail one of the key use cases: an Internet-of-Things solution, represented by intelligent totems for advertisement and wayfinding services, within advanced ICT-based shopping malls conceived as a sentient space. The paper outlines the reference scenario and provides an overview of the architecture and the functionality of the demonstrator, as well as a roadmap for its development and evaluation.

Keywords- Edge computing, artificial intelligence, cognitive systems, Internet of Things, sentient spaces, intelligent Totems

I. INTRODUCTION

According to [1], "the global Artificial Intelligence in Retail Market size is expected to grow from USD 736.1 Million in 2016 to USD 5,034.0 Million by 2022, at a Compound Annual Growth Rate (CAGR) of 38.3%". User-experience enhancement is one of the most relevant needs that motivates this trend, together with several others, like for example improved productivity, *Return on Investment* (RoI), mainlining inventory accuracy, and supply chain optimization.

In the retail sector, where competition is fierce, customer satisfaction is a key issue for business growth. To improve sale processes, it is necessary to deliver a shopping experience that meets customer expectations. Digital Signage is the best option for trendy and appealing store layouts and engaging communication. In particular, interactive totems and touch screens enhance in-store customer experience by providing a wide range of added-value services, such as checking in-stock goods, their positioning within each department, advertise etc. Personalization in terms of tailored advertising according to personal customer data, is a prominent success factor in the retail industry.

Thanks to the methodologies and technologies developed in the FRACTAL project [2], and applied to the *Cooperative Intelligent Totems Use Case*, a great improvement will be possible in this direction. Advertisements will be specifically focused on the customer characteristics, thanks to AI-based video and audio analytics executed locally by implementing the FRACTAL methodology. In fact, interactive totems will integrate cameras and other heterogeneous sensors, which will allow to acquire and elaborate context awareness information in their proximity. For example, they will be able to estimate age and classify gender of customers, adapting consequently the advertisement displayed on the screen. The impact of personalized advertisements on retail business is forecasted to be dramatic. According to [3], "the 2017 online survey of 1,000 consumers ages 18-64, the appeal for personalization is high, with 80% of respondents indicating they are more likely to do business with a company if it offers personalized experiences and 90% indicating that they find personalization appealing".

The impact of the intelligent totem can be very relevant also from a societal point of view. In fact, other than adapt the informative content depending on the context, it will be possible also to adapt intelligent totem user interface so also improving totem usability. Not so rarely, looking for useful and interesting contents in these devices results to be quite unintuitive for the person who is doing the search, especially for elderly or "not so hi-tech" people. An intelligent totem will help the search for contents, by modifying its user interface and navigation mode and/or by highlighting certain contents rather than others. This involves facilitation in the navigation of the information contents themselves. The discriminating elements of this differentiation are the recognition of the gender and age range of the person who is conducting the search on the device. For example, in the case of an elderly person, the menu could be made more readable (increased characters' size) and the menu access mode simpler for a person unaccustomed to the use of technologically advanced objects. On the other hand, for a young person, the device could propose a smarter way to present the contents. Finally, it is worth noting that such an approach, once successfully validated, can be extended to other relevant devices as ticket machines or ATMs, so potentially extending in a dramatic way the possible impact on the society.

The rest of this paper is structured as follows: Section II provides an overview of the FRACTAL project, Section III describes the intelligent totem use case, and Section IV provides details about the 2nd year demonstrator. Finally, Section V draws out some conclusions and outlines the future works.

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II. FRACTAL PROJECT OVERVIEW

The objective of the FRACTAL project [2] is to create a novel approach to reliable edge computing (e.g., [14]). The *FRACTAL Computing Node* will be the building block of scalable cognitive *Internet of Things* (from *Low Computing to High Computing Edge Nodes*). The cognitive skill will be given by an internal and external architecture that allows forecasting its internal performance and the state of the surrounding world. The node will have the capability of learning how to improve its performance against the uncertainty of the environment. Cognitive advantages are brought to a resilient edge and a computing paradigm that lay down between the physical world and the cloud. However, to achieve industrial edge computing, new devices are required to satisfy a new set of challenging requirements such as time-predictability, dependability, energy-efficiency, and security. While these features are critically important, focusing only on them leaves aside the enhancement opportunities brought by the continuous emergence of more powerful solutions in the areas of *Cyber Physical Systems* (CPS), *Systems of Systems* (SoS) and *Internet of Things* (IoT), and more importantly will not be able to meet the stringent requirements for increased autonomy coming from the new application domains. For instance, opportunities coming from advanced microelectronics, high-performance computing, smart system integration, and improved cloud services have been traditionally mostly neglected. As a result of the integration of these cognitive systems into a FRACTAL network, there will be an intrinsic crucial advantage, a combination of safety, emergency, and adaptability. Therefore, new industrial functions will flourish through the created space of possibilities of FRACTAL cognitive systems. This complex network will transfer all those cognitive advantages to a resilient Edge, a computing paradigm that lay down between the physical world and the cloud. In summary, the strategic objectives of the FRACTAL project are the following:

- O1: to design and implement an open-safe-reliable platform to build cognitive nodes of variable complexity.
- O2: to guarantee FRACTAL nodes and systems extra-functional properties (dependability, security, timeliness, and energy-efficiency).
- O3: to evaluate and validate the analytics approach by means of AI to help the identification of the largest set of working conditions still preserving safety and security operational behaviors.
- O4: to integrate fractal communication properties (scale free networks) to FRACTAL nodes.

A. *FRACTAL Nodes*

The current architecture of this type of solutions can be seen in Figure 1. Basically, it is a Smart System Representation plus an IoT connectivity to the cloud. The smart system represented is a mere node where information is collected, processed, and sent upwards to the cloud.

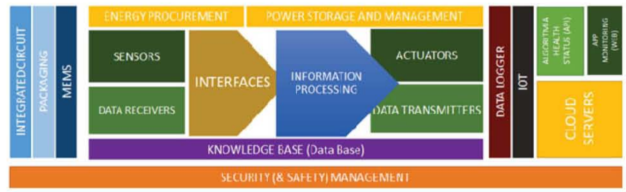

Figure 1. Traditional smart system representation

Instead, complex reality needs the adoption of cognitive systems at the edge [4]. In particular, Edge computing can be defined as "cloud computing systems that perform data processing at the edge of the network, near the source of the data", so that only aggregated data is sent to the cloud, reducing communication bandwidth requirements, and improving data transfer time [5]. Besides, the cloud will carry out edge controller functions for enabling condition awareness and node autonomy by storing and improving cognitive models. This approach provides the needed scalability, the so-called FRACTALITY, for arbitrarily large and complex systems, but it requires a node architecture that provides intelligence and computational power using limited energy, time, and space resources (Figure 2) [21].

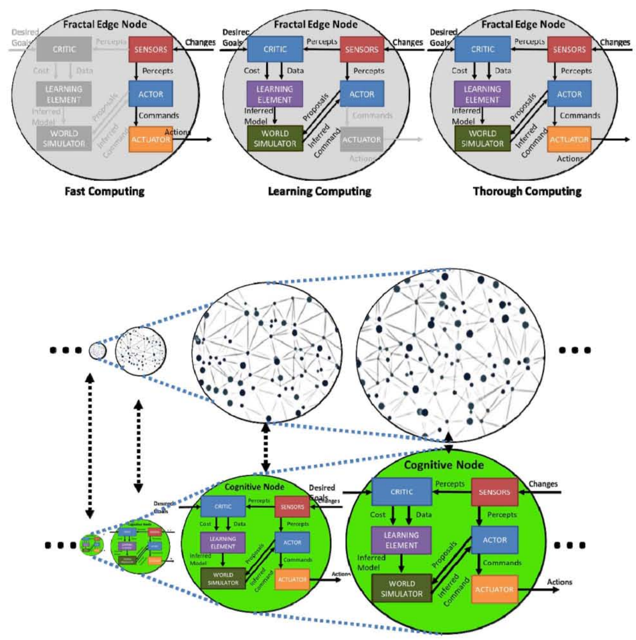

Figure 2. FRACTAL scalable architecture

In the context of the FRACTAL project, cognitive edge nodes will be presented in two flavors: (1) a partially constrained commercial node with low time-to-market based on the Xilinx VERSAL [6] (or, in alternative, the Xilinx Zynq Ultrascale+ [7]) computing platform and (2) a more research-oriented fully flexible customizable node based on RISC-V cores and accelerators for longer time-to-market exploration based on the open-source PULP (parallel ultra-low power) platform [8]. The aim of the former is offering soon a mature platform to end-users for the integration and assessment of their use cases already at the start of the project, as well as a relatively short path towards commercialization of the FRACTAL approach. This involves an extremely flexible FPGA-based development platform where resources in the node, as well as their organization, can be adapted as needed to enable a larger range of tradeoffs. Instead, the customizable node will be designed around the open RISC-V instruction set architecture (ISA) and based on the open-source PULP platform allowing FRACTAL partners a powerful and flexible starting point for the development of the custom node and a viable path for longer-term product development without an early commitment to a proprietary ISA and platform.

Figure 3. A typical totem in a shopping mall

III. INTELLIGENT TOTEM USE CASE

Shopping is one of the most important leisure activities in our life. Despite e-commerce is becoming a fast-growing area of business, shopping malls remain a relevant reference point above all [9]. Currently, indoor medium-large shopping malls are shopping areas from which traffic is excluded and, sometimes, distributed over several floors. Typically, in these buildings there are video-surveillance systems and informative totems which provide spatial type information, such as maps and advertising. Shopping malls are in general crowded and noisy environments, due to the presence of many shops. When looking for a specific shop, it can be difficult to locate and reach, especially when noise is loud and the space to move is limited by the presence of other people [10][16][28]. Another feature of those spaces is a good level of lighting. A typical totem in a shopping mall is depicted in Figure 3.

Here the goal is to transform the shopping mall into a sentient space, by embedding processing resources within the set physical environment [11][12][13][15]. Hence, this space can be seen as a network of interconnected nodes, each with its processing resources, such as smart cameras and advertising smart totems (equipped with cameras, microphones, and a large touch-screen display) located strategically inside the shopping mall (e.g., near entrances, in the hallways), able to provide support to the users uniquely tailored to their needs.

The above-described goal can be reached by applying the FRACTAL approach to develop an AI-based smart mobile totem, for advertisement and customer support inside shopping malls [23]. These totems could have a disruptive impact on retail and shopping mall business providing personalized advertisements and product recommendations and driving customers towards their selected destination/product (wayfinding service). The proposed platform could then evolve into anthropomorphic robots with more advanced capabilities creating an even more immersive user experience and enable their adoption not only in the retail sector but also in a smart city, providing service related to mobility, safety and security, logistics and goods delivery [27].

Considering the processing algorithms (based on advanced AI approaches) which will be developed and used to extract meaningful proximity information, edge computing is needed to elaborate data collected using heterogeneous technologies. In fact, such context-aware mobile totem will be equipped with heterogeneous sensors (like cameras, microphones, proximity sensors, etc.) and therefore are able to collect a huge amount of data that can be processed to better understand their surroundings. The output of such a processing will help also to select the most appropriated multimedia advertisements and will pilot customer movements [24]. Obtained information from totems can be shared with other elements in the same area (Figure 4) to exchange locally detected information, also including user feedback and content selected to improve the effectiveness of the advertisements they are providing. In this way, similar contents can be shown to the same group of people, in different locations, using different totems. Same sensors enable such autonomous objects to execute different tasks like patrolling and security monitoring during the night when the mall is closed.

In such a context, our aim is to make these devices more accessible and faster to use and understood [25], using Artificial Intelligence techniques. The totems part of the sentient space will be more accessible both to final users and content providers: to this end, we have kept into account different types of users (from buyers to retailers), and we are designing each totem exploiting both HCI

(Human Computer Interaction) and CPS (Cyber-Physical Systems) oriented design methodologies [19][20][22].

Information can be detected in terms of customers' gender and age range, effectiveness of marketing campaigns inside the store determining customers attention time for each content promoted. Not only video but also audio processing will be used to detect meaningful data that can be further elaborated providing useful support for targeted advertisement and a personalized marketing strategy. Moreover, audio processing algorithms for in store context awareness exploit audio signal collected to provide user tailored information, contents, and services, delivering shopping experience that meets consumer expectations. Both audio processing and video content analysis are based on innovative AI approaches that can be deployed on edge devices without requiring to upload data collected (i.e., video streams and audio signals) to a centralized cloud infrastructure. The inference related to such AI approaches is provided by a neural network and ruled based approaches, optimized for running on the embedded device installed in the intelligent totem. Different embedded technologies will be investigated and compared by following the FRACTAL approach and platforms (i.e., Xilinx VERSAL or Xilinx Zynq UltraScale+).

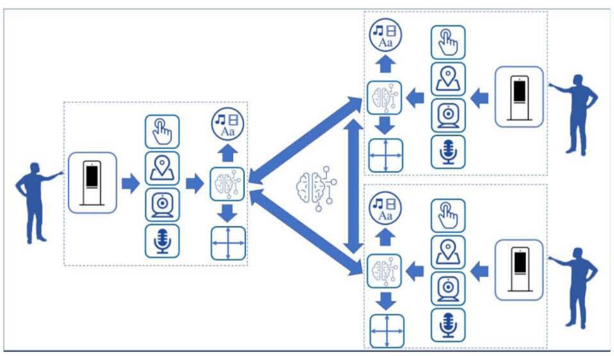

Figure 4. Cooperative intelligent totems

IV. 2ND YEAR DEMONSTRATOR

This section reports the preliminary results obtained in developing the use case described in the previous section by following the FRACTAL approach. The focus is on the description of the main features of the demonstrator that will be used to validate part of the results of the second year of the project. In particular, the following subsections describe the demonstrator system architecture and functional specification related to an ideal scenario. Further improvements expected towards the end of the project are described in the conclusive section.

A. *System Architecture*

Figure 5 shows the HW and SW architecture of the demonstrator system. The HW architecture is made of the following elements:

- Roof Node
  - Xilinx Zynq Ultrascale+ connected via ethernet to IPCAM and MQTT node
  - IPCAM (with quad-core ARM processor)
- Totem Node
  - Xilinx Zynq Ultrascale+ connected via ethernet to IPCAM and MQTT Node and, via USB/HDMI to Touchscreen, Microphone and Speakers
  - IPCAM (with quad-core ARM processor)
  - Touchscreen
  - Speakers
  - Microphone
- MQTT Node
  - Raspberry-like (with quad-core ARM processor)

It is worth noting that the Xilinx Zynq Ultrascale+ contains some accelerators targeted to AI-based workloads, plus some bandwidth regulators [17][18] to provide a bound to the response time of different tasks accessing the same external memory.

The demonstrator system SW architecture is made of the following elements:

- Roof Node
  - Xilinx Zynq Ultrascale+
    - ARM
      - System SW: PetaLinux, Client MQTT
      - Application SW: Runtime Management
    - FPGA
      - Application SW: Density Estimation
    - IPCAM
      - System SW: OS
      - Application SW: People Detection
- Totem Node
  - IPCAM
    - System SW: OS
  - Xilinx Zynq Ultrascale+
    - ARM
      - System SW: PetaLinux, Client MQTT
      - Application SW: Runtime Management, Content Selection, Face Detection, Idiom Recognition, Rule-Based Recommendation
    - FPGA
      - Application SW: Age Estimation, Gender Classification
- MQTT Node
  - System SW: Linux, Broker MQTT

B. *Functional Specification*

With reference to the system architecture described in the previous section, the 2nd year demonstrator will focus on an ideal scenario that can be summarized as follows: a person enters in the totem area, goes in the totem proximity, stays correctly in front of its camera, speaks for at least 3 seconds, interacts with the totem as needed, go away from its proximity, and exit from the totem area. Meanwhile, no other persons enter in the totem area. The starting functional specification of such a scenario has been provided by means of a UML Use Case Diagram (Figure 6).

Such a reference ideal scenario will be used to implement the first working demonstrator as it will allow to evaluate the next steps with respect to the introduction of full wireless connectivity [26] and an increasingly complex interactions with users and environment (e.g., more people in the totem area, multi-touchscreen totems). Moreover, it will be used to evaluate when the FRACTALITY features will be required to provide the processing power needed to manage more complex scenarios, i.e., to allow a totem to offload some of the processing to other nodes in the FRACTAL network.

V. CONCLUSIONS

The objective of the FRACTAL project is to create a new approach to reliable edge computing. The FRACTAL cognitive computing node will be the building block of scalable Internet of Things. In such a context, this paper has presented in detail the intelligent totem use case within advanced ICT-based shopping malls, which are conceived as a sentient space. The paper has described the reference scenario and provided an overview of the architecture, and the functionality, of the 2nd year demonstrator. Future works will focus on the introduction of full wireless connectivity and the management of increasingly complex interactions with users and environment.

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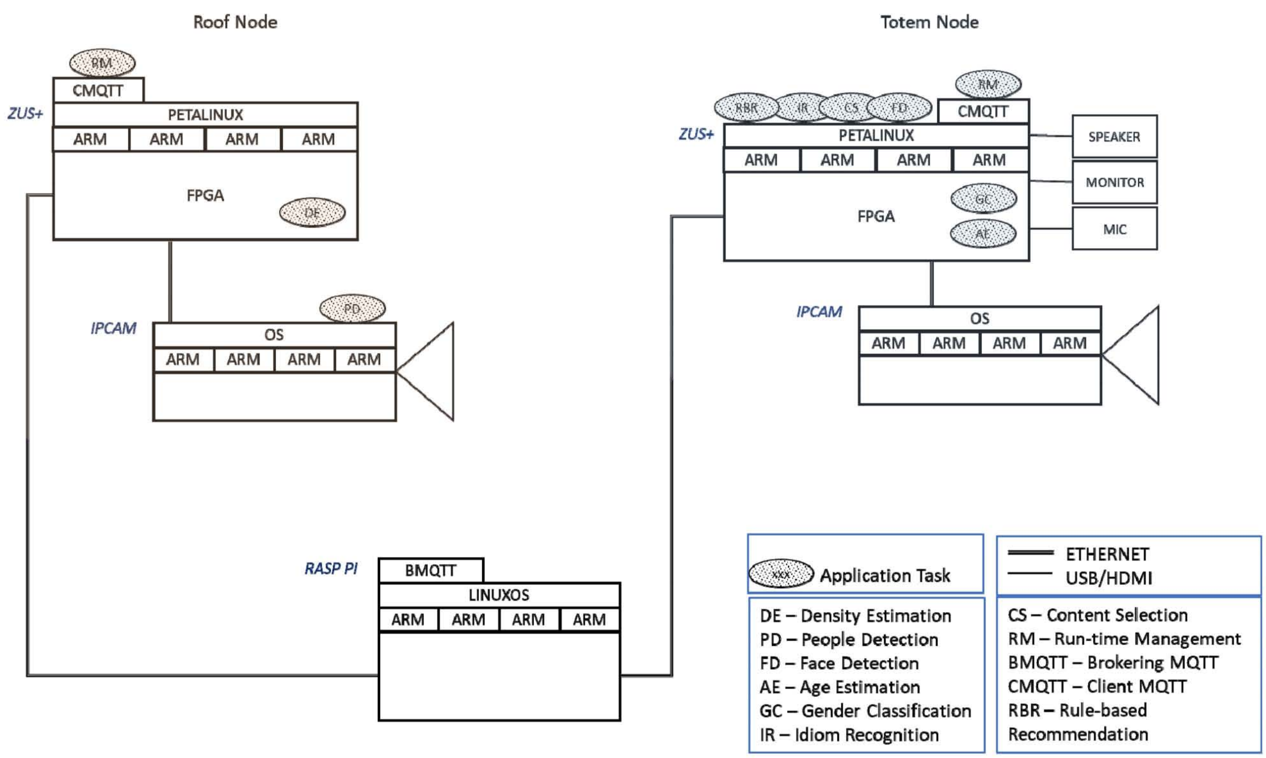

Figure 5. System Architecture

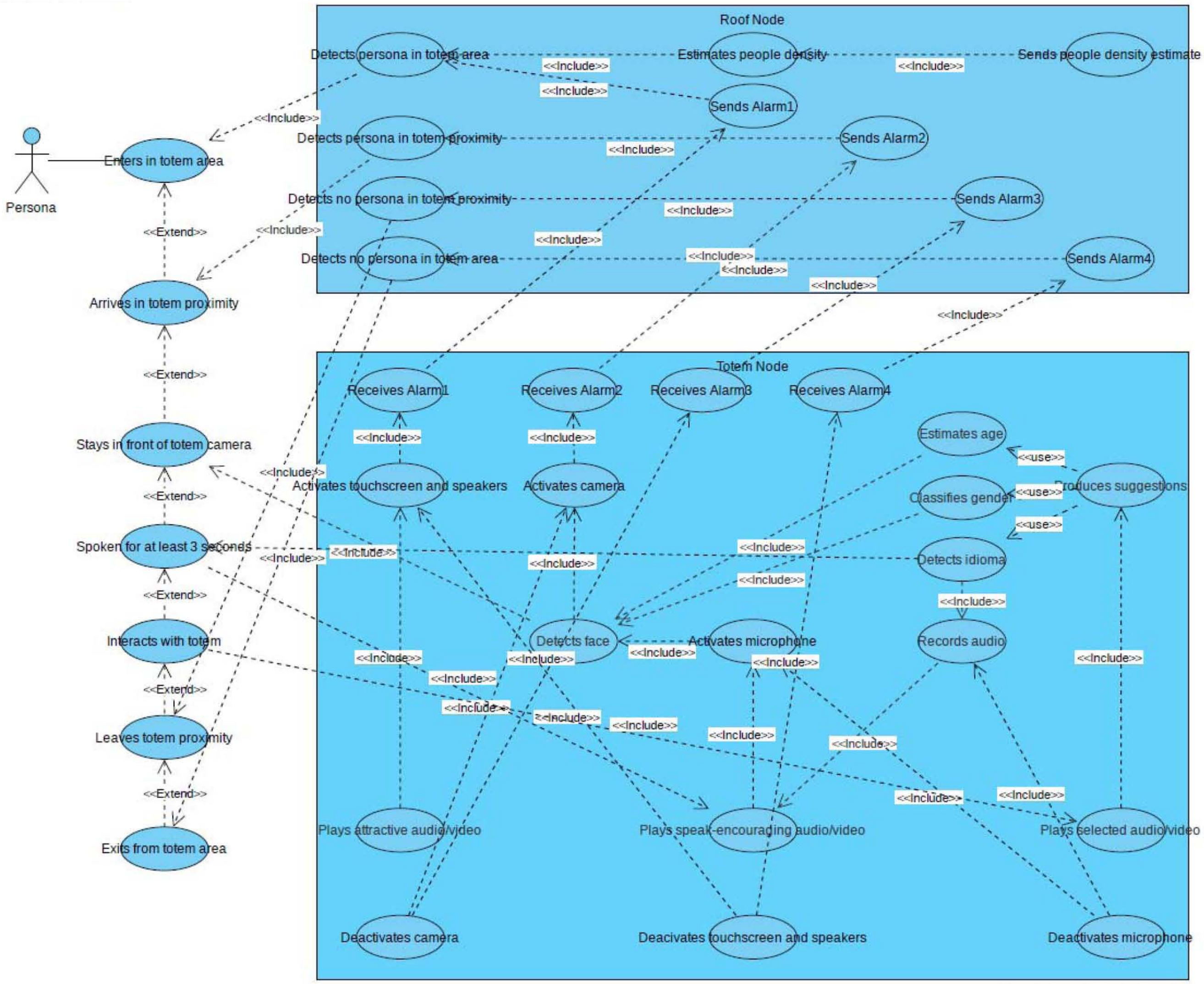

Figure 6. Ideal scenario Use Case Diagram

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