Fuzzy processing applied to improve multimodal sensor data fusion to discover frequent behavioral patterns for smart healthcare

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***Abstract*—This work summarizes the proposal entitled "Fuzzy processing applied to improve multimodal sensor data fusion to discover frequent behavioral patterns for smart healthcare", which introduces an automatic methodology for the fusion and fuzzification of multisource sensor data. This fuzzy logic-based method enhances the interpretability and interoperability of complex datasets and has been validated in sensorized homes of Type II diabetic patients located in Cabra (Spain). The proposed system enables the identification of behavioral patterns and the optimization of clinical monitoring, demonstrating high potential to improve healthcare delivery through advanced data fusion techniques.**

***Index Terms*—Data fusion, Sensor data, Sensor fuzzification, Smart healthcare**

I. Introduction

The use of sensor technologies in healthcare environments, such as hospitals, nursing homes, and domestic settings, generates large volumes of data with high potential to provide valuable insights into patients' habits and behaviors. The increasing interest in exploiting such information has driven the development of advanced processing and analysis methods, particularly through data mining techniques aimed at detecting behavioral patterns that may support clinical decision-making.

In this context, systems based on the Internet of Medical Things (IoMT) enable continuous data acquisition through multimodal sensors. However, the heterogeneity and volume of the data, together with their continuous and fine-grained nature, make direct analysis challenging. Therefore, it is necessary to implement data fusion and transformation processes that produce more compact and interpretable representations. In this regard, fuzzy logic constitutes an effective tool for modeling the uncertainty inherent in sensory data, facilitating its interpretation through linguistic labels.

The work entitled "Fuzzy processing applied to improve multimodal sensor data fusion to discover frequent behavioral patterns for smart healthcare" [1] presents an automatic methodology that combines multisensor data fusion with a fuzzification process that does not require expert knowledge. Its aim is to extract association rules that describe behavioral routines relevant to healthcare professionals. The proposal has been validated in a real-world scenario: sensorized homes of patients with type II diabetes, demonstrating its practical applicability in smart healthcare systems oriented toward the monitoring and improvement of daily habits.

The document is structured as follows. Section II presents the fuzzy logic-based rule extraction process. Section 1 introduces the use case in which the proposed methodology has been applied. Finally, Section IV outlines the conclusions and future work.

II. A fuzzy-based system for pattern mining in big data

The proposal presented in this work is based on an intelligent system designed to detect behavioral patterns in older people from data collected by multimodal sensors deployed in real home environments. The system is structured into four main phases: data acquisition, pre-processing and fusion, fuzzification, and pattern mining through fuzzy association rules.

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First, data acquisition is carried out using sensors that capture physical activity, indoor location, and environmental conditions, integrated within an edge–fog–cloud architecture and protected through secure communication protocols. In the pre-processing phase, data are temporally normalized into one-minute intervals, and outliers or irrelevant transactions are discarded. Subsequently, during the fusion phase, contextual information is enriched by associating sensors with the user's position in the home using spatial anchors and proximity-based membership functions. This information is transformed through a fuzzification process that generates automatic linguistic labels, enabling the intuitive interpretation of continuous data and facilitating further analysis through data mining algorithms. Finally, fuzzy association rules are applied within a Big Data environment using Apache Spark, allowing the extraction of frequent behavioral patterns.

Experimental results demonstrate the system's scalability, computational efficiency, and ability to produce interpretable outcomes for healthcare professionals. The combination of data fusion techniques with fuzzy logic not only enhances the quality of the dataset, but also enables the discovery of relevant routines, such as hygiene habits or treatment adherence, key elements for monitoring in smart healthcare environments.

III. Use case: Smart home

To validate the effectiveness of the system, it was integrated into a real home (see Figure 1) inhabited by an older person, where a sensor network was deployed to monitor the user's daily routines.

For this purpose, the following devices were installed across all key areas of the home, including the user through wearable technologies:

- Motion sensors
- Environmental sensors
- Open/close sensors
- Fixed location devices (Raspberry Pi)
- Activity wristband
- Central node (Raspberry Pi)

This infrastructure enables the detection of daily activities related to hygiene, meals, rest, medication intake, and user localization, even in multi-occupant settings, thanks to the integration of indoor positioning technologies based on Bluetooth Low Energy.

In this case, the application of the fuzzy association rule algorithm enabled the identification of meaningful relationships between behaviors and time slots. For example, routines such as tooth brushing followed by medication intake in the early morning were discovered, as well as shower usage prior to that same activity.

$$\{teeth = using, Medication = open\} \rightarrow \{time = earlyMorning\}$$

The proposed approach, based on contextual data fusion and the use of fuzzy linguistic labels, significantly reduced the generation of irrelevant rules compared to traditional methods,

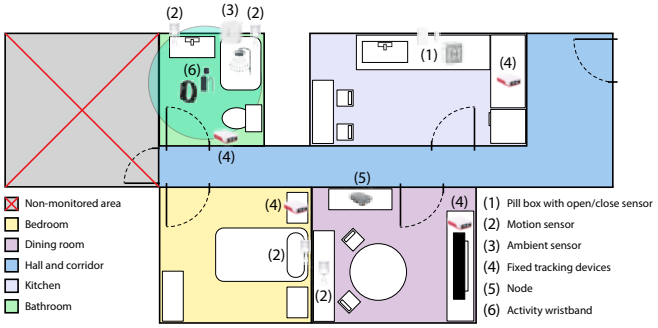

Fig. 1. Distribution of the dwelling used in the case study, location of the devices used and example of the activation range of the monitored elderly person obtained based on the proximity of these devices

thereby enhancing the interpretability and practical usefulness of the results for healthcare professionals.

Moreover, a substantial improvement in performance and scalability was observed when applied to scenarios involving large volumes of data. The reduction in dataset size, achieved by filtering out non-relevant information, combined with distributed processing in Big Data environments, enabled faster pattern extraction and optimized the use of computational resources.

IV. Conclusions and future work

In this work, a data mining system was developed and applied to a real-world setting, specifically in a home located in Cabra, Spain, with the objective of discovering behavioral patterns through the integration of data fusion techniques and fuzzy logic. The proposed system demonstrated significant improvements in computational efficiency and interpretability, due to the reduction in data volume and the use of linguistic labels that facilitate the understanding of results by end users, such as medical professionals.

Furthermore, the system has proven to be scalable and adaptable to other contexts, including hospitals and nursing homes, as well as to different population profiles, such as patients with chronic diseases. The extraction of patterns, such as hygiene routines or treatment adherence, shows great potential for anticipating behavioral deviations and enabling early interventions. Future work will focus on increasing the number of sensors, improving result visualization, and strengthening security mechanisms through techniques such as federated learning, in addition to conducting a qualitative and quantitative evaluation of the system's impact in clinical practice.

References

[1] C. Fernandez-Basso, D. Díaz-Jimenez, J. L. López, and M. Espinilla, "Fuzzy processing applied to improve multimodal sensor data fusion to discover frequent behavioral patterns for smart healthcare," Inf. Fusion, vol. 123, p. 103307, Nov. 2025.