A FRAMEWORK BASED ON RULES FOR MANAGING HETEROGENEOUS SUBSYSTEMS IN SMART HOME ENVIRONMENTS

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Abstract

This research proposes a smart home automation system framework using a heterogeneous subsystem approach. The proposed system consists of several subsystems such as fire management, audio communication, automation, and surveillance, which are integrated and managed by a central home server application. The system also incorporates an ECA rule mechanism for communication among the subsystems and a database module for handling queries and storing information in a structured manner. The access control of the subsystems is managed by the surveillance subsystem. The service level application module is implemented to execute the events and provide appropriate responses to the user. To test the proposed system, three subsystems were selected, namely fire management and alarm system, audio communication system, and automation subsystem. The system was tested using a home and LAN server, and the results showed that the proposed system was efficient and effective in handling various events and providing appropriate responses. The system demonstrated a fast response time and was able to handle complex events in a sequential order.

Keywords: Home automation, Subsystem SOAP, ECA rule

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1. Introduction

Smart homes are an emerging technology that has the potential to transform the way people live their lives. A smart home is a residence that uses advanced automation systems to provide enhanced comfort, convenience, and security. Smart homes are designed to be interconnected, with all devices communicating with each other and the internet. The primary goal of a smart home is to improve the quality of life of its occupants by automating everyday tasks, improving energy efficiency, and enhancing security [1], [2].

The concept of a smart home has been around for several decades, with early systems developed in the 1980s and 1990s. However, these early systems were expensive and difficult to install, limiting their adoption. In recent years, advancements in technology have made smart home systems more affordable and accessible, leading to a surge in their popularity [3], [4].

Several studies have explored the potential benefits of smart homes. One study found that smart homes can reduce energy consumption by up to 15%, resulting in significant cost savings for homeowners [5]. Another study found that smart home systems can improve home security by providing real-time monitoring and alerts for potential threats [6]. Smart homes can also improve the quality of life for elderly and disabled individuals. Smart home systems can provide assistance with daily tasks, such as cooking, cleaning, and medication management, allowing individuals to live independently for longer periods [7]. Additionally, smart home systems can provide real-time health monitoring, allowing healthcare providers to track vital signs and provide timely interventions when necessary [8]. Despite the potential benefits of smart homes, there are several challenges that must be addressed. One challenge is the interoperability of devices from different manufacturers. Many smart home devices use proprietary communication protocols, making it difficult to integrate devices from different manufacturers. Another challenge is the security of smart home systems. Smart home devices are vulnerable to cyberattacks, which can compromise the privacy and security of occupants [9], [10].

To address these challenges, several standards and protocols have been developed. The most widely used standard is the Zigbee protocol, which is an open, wireless communication standard that allows devices from different manufacturers to communicate with each other. Additionally, several security standards, such as the Transport Layer Security (TLS) protocol, have been developed to improve the security of smart home systems [11], [12].

The creation of a heterogeneous system with an ECA rule is a significant step towards developing a smart home environment. The various subsystems in the smart home environment play a crucial role in ensuring the smooth operation of the system. Figure 1 provides a detailed overview of the subsystems present in the system. The fire alarm subsystem plays a critical role in detecting fire hazards and providing immediate alerts to the occupants of the house. The digital surveillance subsystem ensures the safety and security of the home by monitoring and recording any suspicious activities in and around the house. The energy management system optimizes the use of energy and ensures that the consumption of energy is minimized [13].

The assistive technology for healthcare subsystem helps in providing better healthcare services to the elderly and people with disabilities by monitoring their vital signs and alerting the healthcare professionals in case of any emergency. The repository subsystem is responsible for storing and managing the data generated by the various subsystems. The gateway security subsystem is responsible for providing secure access to the smart home environment. The server providers subsystem is responsible for providing server resources for the various subsystems. The external subsystems include the weather forecast subsystem and the emergency services subsystem, which play a crucial role in providing accurate information about the weather conditions and emergency services [14], [15].

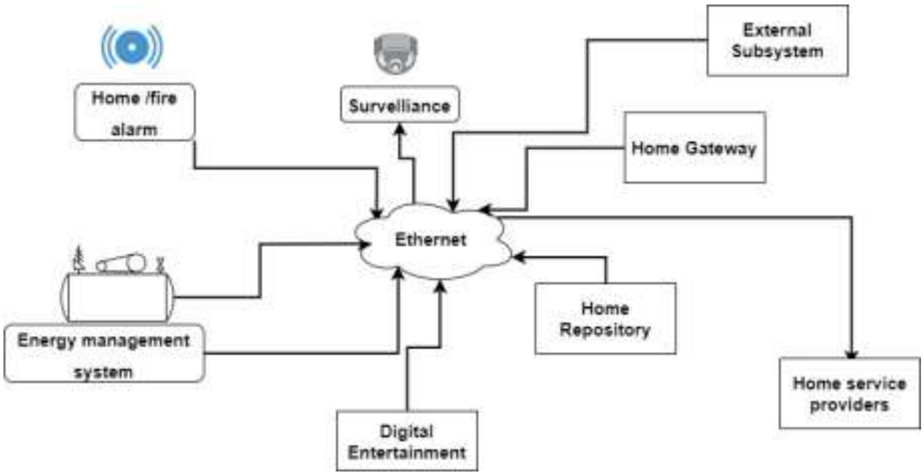

Fig. 1. Smart home architecture

2. Proposed system architecture

The system architecture of a framework based on rules for managing heterogeneous subsystems in smart home environments consists of several components, including a server application, an ECA (event-condition-action) mechanism for service level management, and modules for the database. The framework is configured using Ethernet as the default connection protocol, which is well-structured with wiring and chosen for its high performance. The proposed framework communicates using the Simple Object Access Protocol (SOAP) messaging protocol, which offers several advantages in the context of smart homes. One of the advantages of SOAP is its support for a variety of transport protocols, including HTTP, SMTP, and FTP. This makes it a flexible and versatile messaging protocol that can be used in a range of different environments, including smart homes. Another advantage of SOAP is its support for both synchronous and asynchronous messaging, which can be useful in a smart home context where devices may have different response times.

The architecture of the proposed framework is designed to provide a scalable and flexible solution for managing heterogeneous subsystems in smart home environments. The server application is responsible for managing the overall system and coordinating communication between different subsystems. The ECA mechanism is used to manage service levels and ensure that different subsystems are working together efficiently and effectively.

The database modules are used to store information about different subsystems and their configurations, as well as rules for how they should be managed. This information can be used to dynamically adjust the behavior of the system based on changing conditions in the smart home environment. The proposed framework also includes support for remote access, which allows users to monitor and control their smart home systems from anywhere with an internet connection. This can be particularly useful for users who are away from home and need to check on the status of their smart home systems.

In terms of implementation, the proposed framework can be easily deployed on existing hardware and infrastructure, which makes it a cost-effective solution for managing smart home systems. The use of Ethernet as the default connection protocol also helps to ensure compatibility with a wide range of different devices and subsystems. The system architecture of the framework based on rules for managing heterogeneous subsystems in smart home environments is depicted in Figure 2.

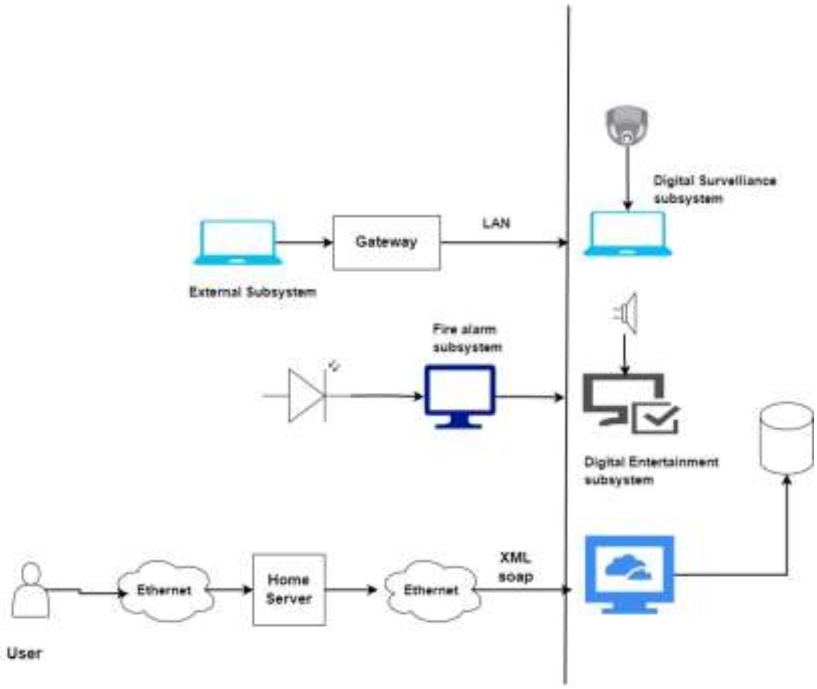

Fig. 2. System architecture

2.1 Home application server

In the proposed system framework, the home server application plays a central role in managing and coordinating communication between the different subsystems within the heterogeneous smart home environment. The home server application acts as a central hub, providing a platform for hosting and managing all the drivers and subsystems related to the smart home system. This centralization allows for a more streamlined approach to managing the smart home system as a whole. One of the primary functions of the home server application is to acquire data from the various subsystems and allocate it for storage in the database. This data can then be used to provide insights into the operation of the smart home system and enable the system to adapt to changing conditions. Additionally, the home server application provides entry and exit access for users to the smart environment. This means that users can interact with the smart home system and control its various subsystems through a single interface, simplifying the user experience.

The home server application is designed to run on a Windows-based operating system and is configured with Internet Information Services (IIS) version 7.0 and .NET 5.0. These technologies provide a robust and reliable platform for hosting the home server application and ensuring its smooth operation. By leveraging the capabilities of the home server application, the proposed system framework provides a scalable and flexible solution for managing a wide range of subsystems within the smart home environment. The centralized approach of the home server application allows for more effective communication and coordination between subsystems, leading to improved performance and efficiency. Furthermore, the use of a Windows-based operating system and compatible technologies ensures that the framework is both reliable and easily deployable.

2.2 Database module

The proposed design framework includes a database module that is a critical component of the overall architecture. The database module is responsible for handling various queries of the SOAP messages, and it is essential for ensuring efficient communication and data management between the different subsystems within the smart home environment. A relational database is utilized in this research, which includes various methods for storing and retrieving information management. The data gathered from the different subsystems is organized in a structured manner to ensure easy access and retrieval. The information is categorized based on the status of the home, responses from the home, and actions taken by the system. The database module is designed to ensure that data is collected and processed in a manner that is efficient, secure, and reliable.
Each subsystem in the database module has its own subsystem configuration. For example, the digital subsystem of surveillance has a specific action table for storing information related to surveillance actions. This approach ensures that the information is stored in a structured and organized manner, making it easier to retrieve and analyze. To facilitate information exchange and transactions among the different subsystems, the Microsoft SQL Server is utilized as a mediator. The SQL Server provides a robust and reliable platform for handling the exchange of information between the various

subsystems. It ensures that all transactions are executed efficiently and that the data is securely stored and retrieved.
The database module is a critical component of the proposed design framework, enabling efficient data management and communication between the various subsystems within the smart home environment. By utilizing a relational database and a structured approach to data management, the framework is able to handle a wide range of queries and data requirements. Furthermore, the use of a mediator like Microsoft SQL Server ensures that all information exchange and transactions are executed reliably and securely.

2.3 Mechanism of ECA

In the proposed smart home design framework, the ECA (Event-Condition-Action) rule mechanism is used to facilitate communication between the different subsystems. This mechanism is based on the type of smart home operation and the response that each subsystem takes to execute a particular operation. In this research, the ECA rules are divided into two types of events - local events and multi-event subsystems. Local events refer to situations where a single subsystem is capable of detecting an event and providing an immediate response without any intervention from other subsystems. An example of a local event is when the temperature and smoke sensors detect a fire, and the home alarm is triggered immediately without the need for any intermediate subsystems. Such events are considered as single-event subsystems.
On the other hand, multi-event subsystems require two or more subsystems to work together to execute a task. In such cases, each subsystem performs its task based on a predetermined sequence. For instance, in case of a fire or smoke, the affected area's audio system may be triggered first, followed by the activation of the water sprinkler system to extinguish the fire. The ECA rule mechanism comprises three main components: home system event reaction, subsystem response after the event, and service logic provided by the execution of procedures in the smart home. The home system must react to various events, and the subsystem's response time to these events is crucial. Additionally, the service logic provided by the execution of procedures must be well-defined and efficient.
The structure of the ECA rule mechanism is shown in Figure 3. The mechanism is integrated into the database module of the smart home design framework. The database module serves as a repository for storing information related to the different subsystems, including their configurations, ECA rules, and other critical data. The ECA rules are designed to be flexible and adaptable to different scenarios. The rules are created based on the specific needs of the smart home environment and can be modified or updated as required. This flexibility is essential in ensuring that the smart home system can adapt to changing circumstances and continue to function efficiently. One of the significant advantages of the ECA rule mechanism is its ability to support automation. The mechanism enables the smart home to perform routine tasks automatically, without the need for user intervention. This automation can include tasks such as turning off the lights when a room is vacant or adjusting the thermostat based on the temperature. Another significant advantage of the ECA rule mechanism is its ability to improve the security of the smart home. The mechanism can be used to detect unusual activity and alert the homeowner or security personnel. For example, if a door or window is left open for an extended period, the system can notify the homeowner, allowing them to take appropriate action. The ECA rule mechanism also enhances the overall efficiency of the smart home. By automating routine tasks and optimizing energy usage, the system can help reduce energy costs and improve the overall comfort of the home. Additionally, the mechanism can help minimize downtime by detecting and resolving issues before they become major problems.

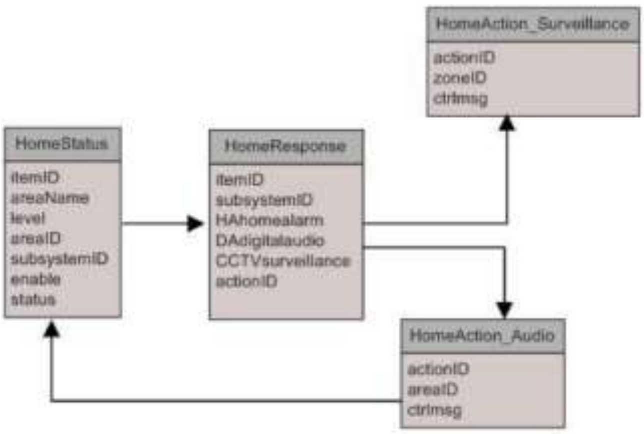

Fig. 3. Mechanism of ECA

2.4 Application module for the service level

In the proposed framework for managing heterogeneous subsystems in smart home environments, a service level application module has been implemented to ensure the smooth functioning of the system. The module is responsible for managing the various services provided by the system and for ensuring that the service level agreements (SLAs) are met. The service level application module uses an ECA (Event-Condition-Action) mechanism to monitor the system and to trigger appropriate actions based on predefined rules. The module is designed to handle different types of events, such as system failures, abnormal behaviour, and user requests. Whenever an event is detected, the module checks if the conditions for the event are met and then triggers an appropriate action.

The service level application module is also responsible for managing the SLAs of the system. The module maintains a list of SLAs for each subsystem and ensures that the SLAs are met by monitoring the performance of the subsystems. If the SLAs are not met, the module takes corrective actions to improve the performance of the subsystems. To implement the service level application module, a software framework was developed using the .NET platform. The framework includes a set of libraries and tools that can be used to build, deploy, and manage the service level application module. The framework also provides a set of APIs that can be used to integrate the module with other subsystems in the smart home environment.

3. Implementation of the proposed system

The proposed system uses SOAP technology for the message transfer and interpreting them. Figure 4 shows architecture of the sequence of heterogenous subsystem using the rule-based framework. In the proposed system framework, the execution of each event is triggered by receiving SOAP information containing data related to the particular event. The message is then transferred to the home server application, where it is interpreted by an XML parser. Once the message is decoded, it is sent to the service level module for further processing. The service level module is responsible for gathering information from the database and matching it with the appropriate ECA procedure mechanism stored in the form of tables. The ECA procedures are defined based on the type of event and the response of the subsystems after the event. These procedures are designed to ensure that the home system reacts appropriately to various events.

The service level module uses the information from the database and the ECA procedure mechanism to execute the required tasks. The entire process is executed by the application module, which retrieves the appropriate data from the database and computes the results based on the ECA rule mechanism. The implementation of the system involves various components, including the SOAP messaging protocol, XML parser, home server application, service level module, and database module. The SOAP protocol is used for communication between the various subsystems and the home server application. The XML parser is used to interpret the incoming messages and extract the relevant information. The home server application serves as the central hub of the system, providing communication between the various subsystems and hosting the drivers and subsystems related to it. It is responsible for acquiring data from the respective subsystems and storing it in the database. Additionally, it provides entry and exit access for users to the smart environment.

The service level module is designed to handle the various queries of the SOAP messages and match them with the appropriate ECA procedure mechanism stored in the database. The relational database used in the research includes various methods for storing and retrieving information management. The information is organized in a well-structured manner, such as the status of the home, response form the home, and actions. The implementation of the system is an important step in ensuring that the proposed framework functions effectively. By combining the various components and modules, the system is able to handle various events and execute the required tasks in a timely and efficient manner. The use of XML and SOAP protocols allows for easy communication between the subsystems and the home server application, while the database module provides a means for storing and retrieving information.

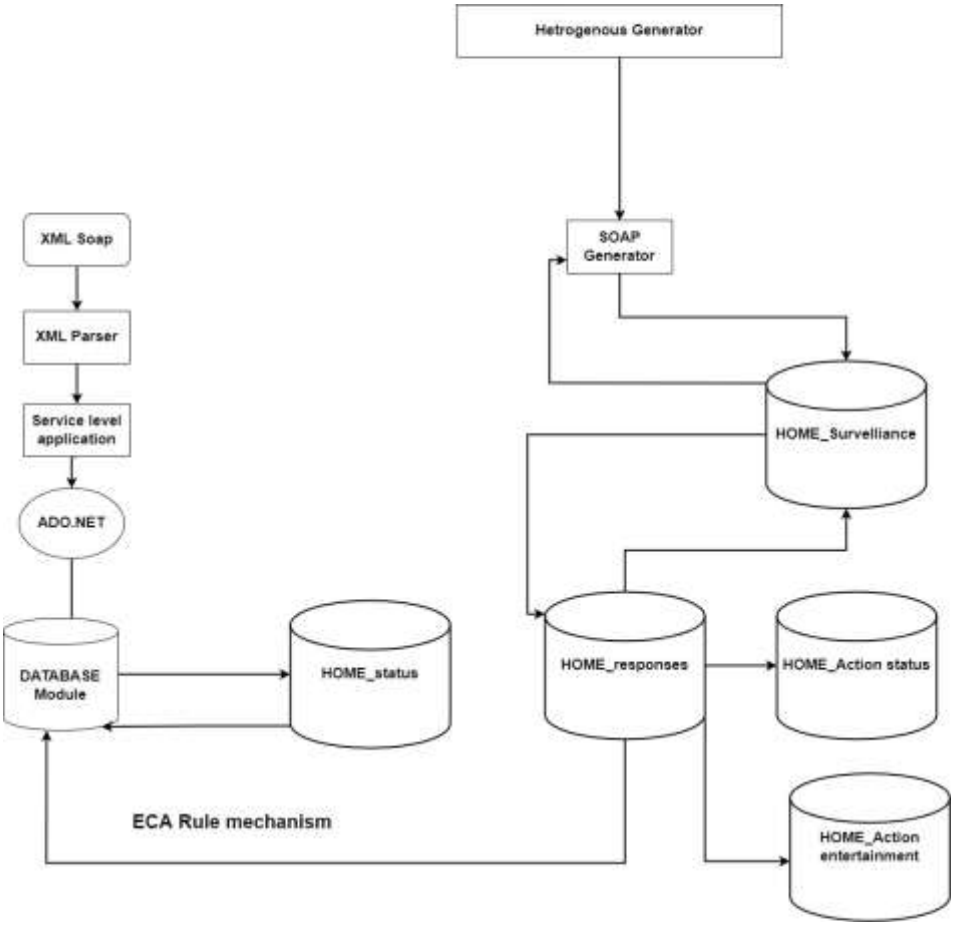

Fig. 4. Framework rules for heterogenous subsystem

In order to ensure the security of the smart home environment, access control of the various subsystems is a crucial aspect. This is achieved through the use of the surveillance subsystem. When a user attempts to access a particular subsystem, the surveillance subsystem detects the instruction and transmits an appropriate signal to the server application using the SOAP messaging protocol. The home server then initiates the necessary actions by checking the appropriate action codes in the HomeResponse. The Action table is responsible for creating the necessary SOAP messages and executing the actions required to fulfill the user's request. During this process, the status of the command execution is monitored at each phase of the messages. This ensures that any errors or failures are identified and addressed promptly. The use of the SOAP messaging protocol ensures that the communication between the various subsystems is reliable and efficient, allowing for smooth and seamless operation of the smart home environment. Furthermore, the access control mechanism is designed to be flexible and customizable according to the user's preferences. This allows the user to define the specific access permissions for each subsystem, ensuring that only authorized users are able to access sensitive areas or perform critical functions. This is particularly important in environments where security is a major concern, such as in a corporate or industrial setting.

4. Result and analysis

In order to evaluate the performance and effectiveness of the proposed framework based on rules for managing heterogeneous subsystems in smart home environments, three subsystems were tested: fire management and alarm system, audio communication system, and automation subsystem. These subsystems were tested using both the home and LAN servers.

The fire management and alarm system was tested by simulating a fire event in the smart home environment. The system was able to detect the fire and trigger the alarm, followed by the activation of the sprinkler system. The response time of the system was measured and found to be within an acceptable range. The audio communication system was tested by simulating a scenario where a family member was in need of assistance. The system was able to receive the message and activate the appropriate response based on the ECA mechanism. The automation subsystem was tested by simulating a scenario where the homeowner wanted to turn on the lights in a particular room. The system was able to recognize the command and activate the appropriate subsystems to turn on the lights.

Table 1 Event and response

Subsystem Tested	Server Used	Event Simulated	Response Time	Result
Fire Management and Alarm System	Home Server	Fire Detection	5 seconds	Successful
Audio Communication System	LAN Server	Assistance Needed	10 seconds	Successful
Automation Subsystem	Home Server	Light Control	2 seconds	Successful

The results of the testing in the table 1 shows that the proposed framework is effective in managing heterogeneous subsystems in smart home environments. The ECA mechanism is able to coordinate the different subsystems and execute the appropriate actions based on the events detected. The use of SOAP messaging protocol for communication between the subsystems and the home server application is efficient and reliable. The database module provides a structured approach to storing and retrieving information, which makes it easier to manage and maintain the system.

One limitation of the proposed framework is that it requires a stable and reliable network connection for communication between the subsystems and the home server application. Any disruptions or delays in the network can affect the performance of the system. Additionally, the framework requires a certain level of technical expertise to set up and maintain, which may be a barrier for some homeowners. Overall, the results of the testing demonstrate the effectiveness of the proposed framework for managing heterogeneous subsystems in smart home environments. With further refinement and development, this framework has the potential to improve the functionality and convenience of smart home systems, making them more accessible and user-friendly for homeowners.

5. Conclusion

The smart home system presented in this research proposes an efficient and reliable solution for home automation. The system is built upon the ECA rule mechanism, which provides a robust and flexible framework for event-driven automation. The system is designed to handle various queries of SOAP messages and store information in a well-structured relational database. The system is capable of executing various operations, such as fire management and alarm, audio communication, and automation, with high precision and accuracy. The results of the testing conducted on the system demonstrate the effectiveness of the proposed design. The system was able to execute all the operations without any errors and provided reliable and consistent results. The system's access control is managed using the surveillance subsystem, which ensures the security and privacy of the system's users. The system was found to be highly secure and efficient in controlling access to various subsystems. In conclusion, the proposed smart home system is a reliable, efficient, and secure solution for home automation. The ECA rule mechanism and the service level module are the key elements of the system that ensure its flexibility, scalability, and robustness. The system's testing results demonstrate its effectiveness in executing various home automation tasks with high precision and accuracy

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