

PAPER

Intelligent Multimedia Accessibility in Smart Environments Using IoT and Multi-Viewpoints Modeling

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ABSTRACT

Smart and mobile devices have become essential for all users, including individuals with physical disabilities such as deafness, blindness, or other impairments. This work proposes a novel approach that integrates two key technologies, the Internet of Things (IoT) and Multi-Viewpoints (MVP), to enhance and personalize the use of smart and mobile devices for people with physical disabilities. This approach enables real-time interaction and dynamic content adaptation. IoT is employed to enhance context-awareness, allowing smart devices to predict the user's current context and deliver appropriately adapted content. In parallel, the MVP framework supports the development of MVP Ontology, which enables multi-perspective content analysis and personalized adaptation based on user viewpoints. The proposed architecture is designed to be both flexible and intelligent. It ensures a versatile and inclusive multimedia delivery system that can adapt to diverse real-world scenarios through four layers of the architecture. We demonstrate the feasibility and effectiveness of this approach through a practical system optimized for both smart TV and Android platforms. A comparative analysis between mobile devices and smart TVs highlights the unique strengths of each in terms of performance and resource management.

KEYWORDS

interactive multimedia technique, intelligent accessibility, smart environments, Internet of Things (IoT), multi-viewpoints ontology, physical disabilities

1 INTRODUCTION

The rapid evolution of mobile computing technologies and the Internet of Things (IoT) has profoundly transformed the manner in which individuals interact with multimedia documents (MDs), which include videos, audios, images, and texts. These MDs have become essential in communication, education, and professional tasks. Furthermore, technological advancements have enhanced their

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accessibility across diverse platforms, including those run on laptops, tablets, smartphones, smartwatches, and smart TVs. However, ensuring equitable access remains a significant challenge, particularly for individuals with physical disabilities. Traditional access methods often fail to accommodate their needs, leading to digital exclusion. For instance, visually impaired users cannot perceive text or images, individuals with hearing impairments have difficulty accessing audio content, and individuals with motor impairments may struggle to manipulate mobile devices.

In pervasive computing environments, the retrieval and presentation of MDs are influenced by dynamic contextual factors, including user preferences, environmental conditions, and device capabilities [1]. Additionally, the needs of individuals with disabilities further complicate content adaptation, creating additional challenges. To address these accessibility barriers, we propose an integrated approach that combines IoT, MVP, and ontology-based reasoning to enhance MD adaptation and improve user interaction in pervasive computing environments.

In adapting multimedia content, the main challenges involve accurately identifying the user's context and choosing the most suitable type of adaptation. To tackle these issues, we have integrated the IoT, which offers effective solutions for managing critical situations, especially in sensitive areas. The number of IoT devices is growing quickly, driven by advances in wireless technologies and high-speed internet connectivity [2]. Large amounts of data are being produced through digitization across various IoT sectors, such as education [3]–[4] and learning [5], vehicular networks, and intrusion detection systems (IDSs) [6]. Forecasts suggest that by 2027, the number of IoT devices will reach about 41 billion, showing their increasing role in everyday life [7]. IoT involves the seamless connection of smart objects and devices, which enable real-time data sharing over the Internet. This interconnected ecosystem enhances automation, accessibility, and service efficiency across multiple domains. In agriculture, by way of illustration, IoT facilitates smart farming through systems for automated irrigation, precision crop monitoring [8]–[9], and fire detection and prevention, helping to improve resource efficiency and reduce risks [10]. In healthcare [11]–[14], for instance, wearable devices such as smartwatches and remote patient monitoring systems enable real-time health tracking, early disease detection, and telemedicine solutions. Smart cities use IoT for smart homes, utilizing IoT for security [15], which enables automation, predictive maintenance, and enhanced customer experiences.

The MVP approach is widely used across various fields to manage and analyze data from multiple perspectives. In the context of accessibility, it helps classify different types of disabilities and tailor digital interactions accordingly, ensuring that content adapts dynamically to user requirements. Furthermore, ontology-based frameworks serve as powerful tools for representing domain knowledge. They facilitate seamless information exchange and improve interoperability between systems, allowing for more adaptive and intelligent interaction with digital content.

The remainder of this paper is organized as follows. Section 2 reviews and discusses related work in semantic multimedia adaptation, the multi-viewpoint approach, and the IoT. Section 3 presents the proposed methodology, including the conceptual model, the context adaptation mechanism based on reasoning rules, and the overall system architecture. Section 4, implementation of a prototype for the proposed approach, including illustrative scenarios and the evaluation

model outcomes. Finally, the last section concludes the paper and outlines future research directions.

2 RELATED WORKS

Extensive research has been conducted on the adaptation of multimedia documents within context-aware pervasive systems. These approaches differ primarily in the methods used for context sensing and modeling, as well as in the strategies employed to respond to contextual changes. Table 1 summarizes relevant previous works, highlighting whether they use MVP, IoT, Intelligent Real-Time, or SWLR, as well as their limitations in the context of disability-friendly architecture. In addition, we indicate that the adaptation of Multimedia Documents to align with current constraints is directly driven by the influence of context. Recognizing the significance of context, it becomes imperative to tailor the content of MDs. In this regard, we present a proposition to leverage the IoT as a means of obtaining real-time user context. By harnessing IoT technologies, we can gather user context information in real time, thereby enhancing the accuracy and timeliness of MD adaptation.

Table 1. The comparison of MD adaptation approaches

Reference	Using MVP	Using IoT	Using Real-Time	Using SWLR	Adaptation MD	Disability-Friendly Approach
[16]	✗	✗	✗	✗	✓	✗
[17]	✗	✗	✓	✓	✓	✓ (limited use)
[20]	✗	✓ (limited)	✓	✗	✓	✗
[21]	✗	✓ (limited)	✓	✓	✓	✗
[22]	✗	✓ (limited)	✓	✓	✓	✗
[23]	✓	✗	✓	✗	✓	✗
[14]	✗	✗	✓	✗	✓	✗
Our Approach	✓	✓	✓	✓	✓	✓

Traditional approaches [16]–[20] primarily adapt the document to the same device, making them less effective for individuals with physical disabilities. Subsequently, a novel hybrid approach for multimedia document adaptation [21], which combines multiple adaptation categories, was proposed, but it does not consider the needs of persons with disabilities. In contrast, our approach leverages IoT technology to enable seamless adaptation and transfer across multiple devices, ensuring greater accessibility and usability. By leveraging these technologies, accessibility can be significantly improved, fostering inclusivity and enhancing the quality of life for individuals with disabilities in an increasingly digital world.

3 METHODOLOGY

In this paper, our primary focus lies in the utilization of viewpoints within ontology modeling to facilitate MD adaptation. Furthermore, we explore how the

integration of IoT technology enriches this process. It enables the prediction of the user's current context, facilitating dynamic adaptation of MDs and control over the state of connected devices.

3.1 Conceptual Model

We developed the Intelligent Adaptation Architecture for MD, as shown in Figure 1, based on IoT and MPV, to enhance multimedia accessibility for individuals with physical disabilities. This flexible and intelligent framework comprises four main layers: (1) a communication layer, (2) an IoT device layer, (3) the MVP-IoT ontology layer (as shown in Figure 2), and (4) an integrated cloud and connected services layer. The first layer is the interface of the communication between the user and our application. The second layer is used for detecting and connecting user devices. The third layer is implemented for identifying disability types and adaptation needs. The last helps ensure inclusive and context-aware multimedia delivery. Table 2 summarizes the roles of the components of each layer.

Table 2. Functional specification of the proposed architecture components

Type	Component	Component's Role
Communication	Interface	It transmits requests and receives MD adapted.
Analyzing	Request & Context Analyzer	It improves requests by including relevant contextual details.
	Conflict Analyzer	It is responsible for handling conflict management.
Sensing	User Context	It is a set of environmental factors, behaviors, and attributes that characterize a user's state at a particular moment when interacting with an application.
	Sensor Context	It senses changes in context values.
Adapting	MD Adapter	It returns an MD adapted.
	Application Web Service	It enables integration between different systems and platforms, facilitating interoperability and the exchange of data and functionality across diverse environments.

3.2 Context Adaptation Mechanism (Reasoning Rules)

In this particular section, we outline a selection of reasoning rules employed in our prototype. These rules play a critical role in enabling the dynamic exploration of adaptation services for both MDs and connected devices. Furthermore, this paper employs three distinct types of multimedia content adaptation services:

- **Transcoding:** It refers to the process of transforming the format of media content while preserving the media type.
- **Transmoding:** It is the process of transforming the type of media content into a different form.
- **Transforming:** It involves making modifications to the media content while preserving both the format and the type of the media.

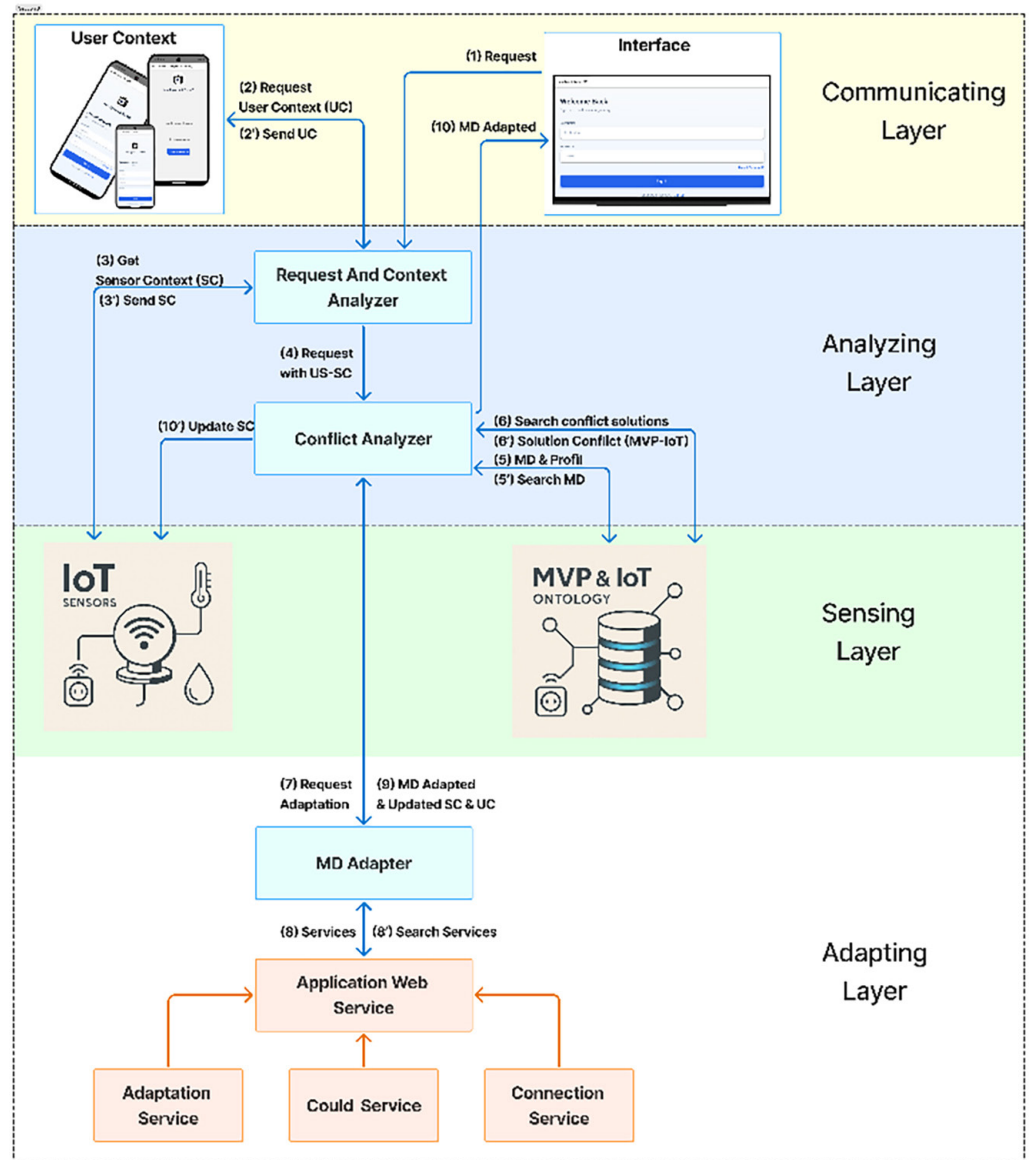


Fig. 1. Architecture of the proposed adaptation approach based on MVP-IoT

To enhance the expressiveness of the multi-viewpoint ontology enriched by IoT technology and enable the specification of if-then statements, we enriched the ontology defined in [18] by adding a set of new classes to better describe the user, their location, and the devices connected to them (see Figure 2). Two media types are associated with adaptation services: input media and output media. Each adaptation service is represented by a set of information detailing the necessary contextual constraints.

The Connected Devices class is a subclass of the Network Context class. It allows identifying all devices connected by the user to determine where the adaptation results can be displayed. Additionally, the Location class enables defining the correct location of the user. The semantic representation of the adaptation service allows for the comparison of services across various types. Semantic information about a service serves as a crucial criterion for selecting the appropriate service and enables its integration with other services to generate an adaptation process. For this reason, we introduce three types of services related to the adaptation services: MD adaptation service, cloud service, and connection.

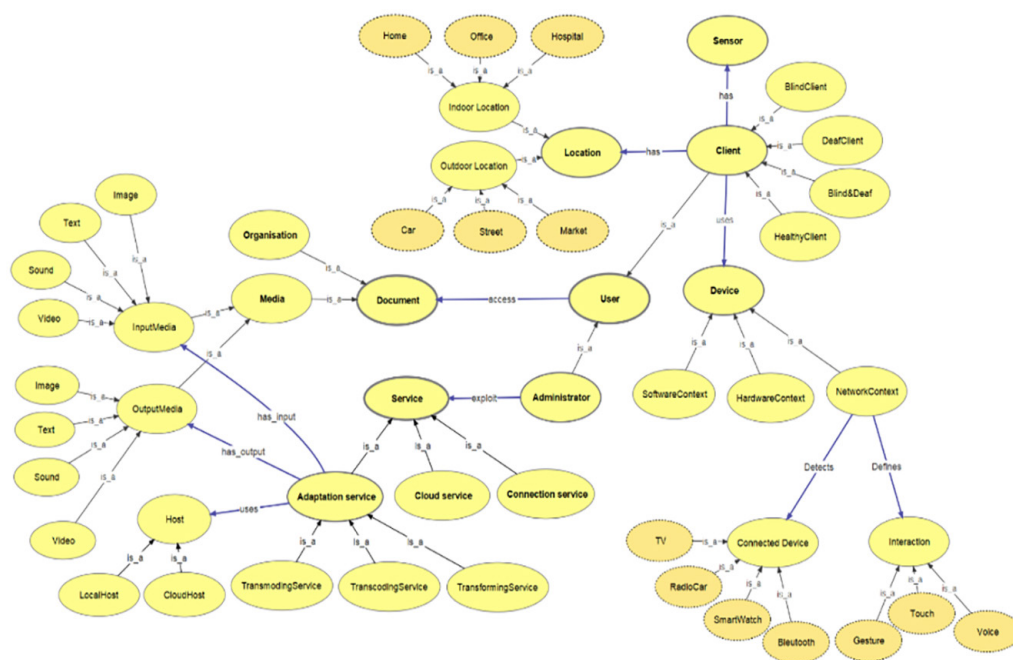


Fig. 2. A snapshot of adaptation service global ontology

We employed the Semantic Web Rule Language (SWRL) [24]. This choice allows us to utilize a rule-based formalism, which enables us to define logical rules and make inferences within the ontology. By employing SWRL, rules can be formulated to perform reasoning and derive new knowledge from existing IoT data descriptions available on the web. The incorporation of additional predicates augments RDF triples, enabling IoT applications to acquire more precise information and make improved decisions. We start by the following three rules.

- R1: $\text{Locatedin}(\text{?x,home}) \wedge \text{Activity}(\text{?x,watchTV}) \wedge \text{display}(\text{?x,video}) \Rightarrow \text{AdaptationService}(\text{transmoding,audio}) \wedge \text{Action}(\text{TV,exit-audio-TV})$
- R2: $\text{Locatedin}(\text{?x,minimarket}) \wedge \text{Activity}(\text{?x,takeshopping}) \wedge \text{display}(\text{?x,video}) \Rightarrow \text{AdaptationService}(\text{Transmoding,audio}) \wedge \text{Action}(\text{Bluetooth speaker,Activated})$
- R3: $\text{Locatedin}(\text{?x,car}) \wedge \text{Activity}(\text{?x,drawing}) \wedge \text{display}(\text{?x,Text}) \wedge \text{Activity}(\text{?x,lest ening-music}) \Rightarrow \text{AdaptationService}(\text{transmoding,Text}) \wedge \text{Action}(\text{Car-Radio,exit-audio}).$

The first rule exemplifies the use of SWRL formalism in reasoning. It suggests that an activated transmoding service can help users with motor disabilities receive video content when they are watching a connected television at home. In this case, the TV audio is automatically muted, which reveals the role of complex logical rules in enabling intelligent automation. The second rule provides a better shopping experience for visually impaired users via accessible content delivery and seamless communication. It specifies that smartwatches detect their interaction with products in minimarkets. With respect to this situation, a transmoding service is launched and Bluetooth is enabled. The third rule integrates both motor and visual impairments. It states that a transmoding service may be triggered when the user is engaged in multiple tasks simultaneously. Analogously, this applies to a driver who listens to music and receives textual content at the same time. In this scenario, the car radio would

be deactivated once the transmoding service is activated to reduce distractions and, hence, direct the driver's attention towards the road.

4 RESULTS AND DISCUSSION

4.1 Implementation of a Prototype for the Proposed Approach

The proposed model is initially tested and validated using a real prototype to demonstrate the feasibility of our approach. This prototype focuses on the adaptation of messages of the MD type and their notifications. However, since it is very challenging to provide the necessary hardware resources to scale for a large number of scenarios and types of disabilities, the system was prototyped in a hybrid simulated-real environment, and the overall performance is measured through simulation.

The tests are conducted through two scenarios, comparing the response times of adaptation processes with our adaptation approach proposed in this work. The performance is measured through case analysis, evaluating the scenarios. The experimental results indicate that our proposal could achieve significant improvements over related works. Overall, the outcomes obtained are promising and satisfactory, as they could achieve improvements over existing adaptation approaches based on different criteria related to the disabilities of the user.

```
useEffect(() => {
  let socket: Socket;
  if (token && isAudioEnabled) {
    setConnectionStatus('connecting');
    socket = io(BACKEND_ENDPOINT, {
      query: {token, device: 'tv'},});
    socket.on('connect', () => {console.log("TV Connected to WebSocket server");
    setConnectionStatus('connected');});
    socket.on('disconnect', () => {
    console.log("TV Disconnected from WebSocket server");
    setConnectionStatus('disconnected');});
    socket.on('notification', data => {
      console.log("TV Notification
      received: At", Date.now());
    setAudioBuffer(data.audioBuffer);}); }
  return () => {
    if (socket) {
      socket.disconnect(); } }; }, [token, isAudioEnabled]);
```

In this source code, we utilize the `useEffect` function, a fundamental feature in React, as shown below: `useEffect(() => { ... }, [token, isAudioEnabled]);`

In this source code, we utilize the `useEffect` function, a fundamental feature in React, as shown below: `useEffect(() => { ... }, [token, isAudioEnabled]);`

This function executes the enclosed logic whenever the values of the specified dependencies (`token` or `isAudioEnabled`) change. In this context, it enables the application to respond dynamically to changes in the authentication token or the audio state (enabling or disabling audio output). The primary objective of this effect is to manage the lifecycle of a `WebSocket` connection, which facilitates real-time communication.

When either the token or isAudioEnabled values change, the effort ensures that the appropriate connection or disconnection logic is triggered. Let socket: Socket;

We declare a variable socket of type Socket, which is used to manage the WebSocket connection instance (to control real-time connection). The first conditional block verifies that a valid authentication token is present and that audio is enabled.

setConnectionStatus('connecting'); This sets the connection status to 'connecting,' which may be used to reflect the current state in the User Interface (UI). This establishes a socket.IO connection to the specified backend endpoint. The token and device type ('TV') are passed as query parameters to identify the device and authorize the connection. These event listeners update the connection status based on the WebSocket's connection state. The console.log statements are used for development and debugging purposes to track the connection events. This listener responds to 'notification' events emitted by the server. It logs the reception time and updates the local audio buffer state with the received data.

```
return () => { if (socket) { socket.disconnect(); } }
```

This function runs when the component unmounts or before the effect reruns (e.g., if token or isAudioEnabled changes). It cleans up the socket connection to avoid memory leaks or duplicate connections.

The identification interface of our system is showcased in Figures 3 and 4, which serves as the gateway for users to access the system. This interface allows users to log into the system securely, typically by entering their credentials such as username and password. The design and functionality of this interface are crucial, as it sets the tone for the user's interaction with the system and ensures that only authorized individuals can gain access to sensitive information or functionalities. These interfaces are optimized for both smart TVs and Android platforms, ensuring seamless access and usability across different devices. By incorporating these interfaces into smart TV and Android environments, we ensure we provide users with a consistent and intuitive experience, regardless of the device they are using.

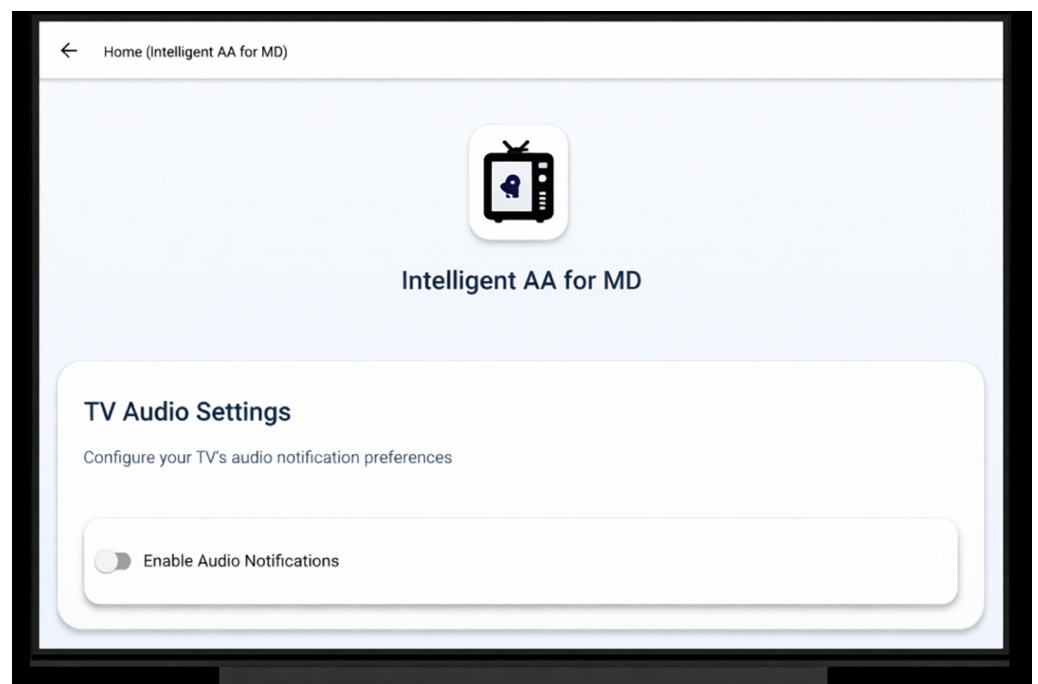


Fig. 3. Home screen for smartTV

This system checks the first connected devices for a user (if the user uses the TV or mobile). The system collects data from the device sensors and modules (acceleration, connected audio devices):

- If the TV device is connected, the system puts the user in the watchingTV state, it collects the notifications from the mobile device, and sends them to the TV device
- If the acceleration of the mobile phone is more than a predefined value (threshold), the system puts the user in the Walking state.
- The acceleration is calculated using the x, y, z positions each 500ms

```
let acceleration = Math.abs(
  Math.sqrt(x * x + y * y + z * z) -
  Math.sqrt(pX * pX + pY * pY + pZ * pZ),    );
```

pX, pY, pZ are the previous positions (500ms ago)

- If an audio device is connected (earphones or wired headphones) the system puts the user in the Listening state
- If the user is Walking and Listening, the system will collect notifications and send audio buffer to the mobile device, and then play the notification on the audio device.

4.2 Illustrative Scenarios

For our use case, we have identified two distinct types of handicaps, which are elaborated upon in the upcoming scenarios. These scenarios illustrate the situations and challenges, as well as, the needs for using the MD associated with each type of handicap. Besides, we explain how our system reacts.

Scenario 01: Lina is an individual with a mobility impairment that affects her legs, preventing her from walking. While her phone is placed at a distance for charging, she cannot remain near it or approach it every time a new message arrives. To address this challenge, our innovative system allows Lina to stay informed without needing to physically access her phone. By interacting with a smart TV, she can receive notifications directly on the television screen in either textual or auditory format. The system also includes an automated feature that temporarily pauses the TV's audio output to ensure that notifications are delivered clearly and without interference, thereby enhancing accessibility and convenience in her daily life.

Scenario 02: Lina experiences visual impairment or may find herself in situations where physical interaction with her phone is limited, such as while performing hands-on tasks, driving, or participating in meetings. In such contexts, our innovative system automatically activates Bluetooth functionality and connects to available audio devices such as AirPods. Notifications are then converted into auditory messages and delivered through the Bluetooth-enabled device. This ensures that Lina can receive important information in real time without needing to look at or handle her phone, thereby enhancing accessibility, safety, and responsiveness in dynamic or visually restrictive environments.

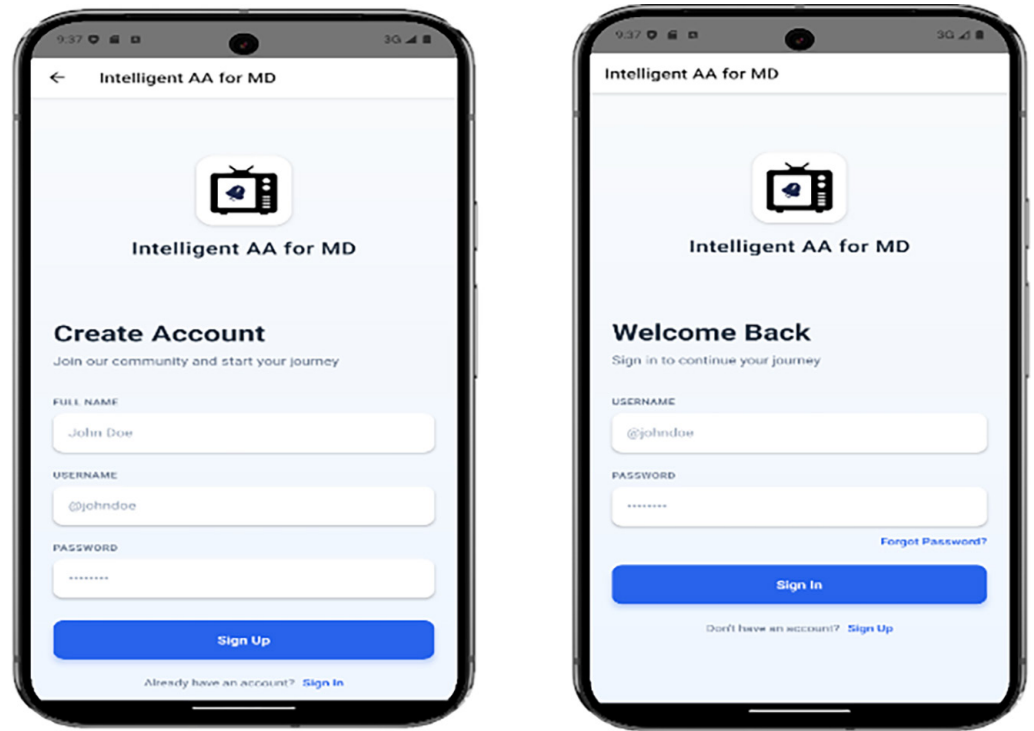


Fig. 4. Login and sign-up screen

4.3 Evaluation Model Results

To develop the Intelligent Adaptation Architecture for MD, a prototype was implemented using JavaScript, TypeScript, Protégé (for the creation of ontology), and Pellet reasoner (for SWRL rules). A Node.js backend was also chosen to enhance efficiency, while Express.js and Socket.IO was used to facilitate real-time communication. React Native powered the mobile front end, offering seamless integration with various smart TVs and Bluetooth speaker systems. As indicated in Figure 3, the system provides a robust authentication framework that allows for credential-based user access. Moreover, it supports the reception and relay of notifications regardless of whether the phone is off or operating with a low battery level. The system also tracks events like device activation and TV wake-up to deliver MD content in response (see Figure 3).

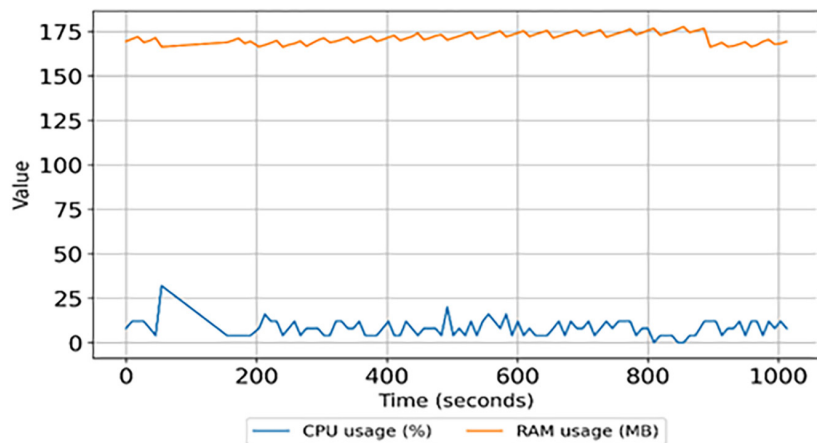


Fig. 5. TV performance metrics over time

Figures 5, 6, and 7 illustrate the performance metrics for the Android TV, text-to-speech (TTS) engine, and mobile device components, respectively. In Figure 5, the Android TV shows stable RAM usage around 170–180 MB, with CPU usage remaining consistently low, generally below 25%, indicating efficient resource utilization during runtime. Figure 6 demonstrates the linear growth in TTS audio output size (KB) relative to input text length, confirming the expected scalability of the TTS engine. The processing time remains statistically stable across increasing text lengths, suggesting the use of optimized TTS algorithms or hardware acceleration. In Figure 6, the mobile device shows more variability in CPU usage, ranging from 5% to over 80%, reflecting the real-time sensor data handling and communication overhead. RAM usage, however, stays relatively stable between 210–250 MB. These results confirm the system’s ability to operate with minimal computational load, even on resource-constrained devices, making it suitable for real-world deployment or further expansion.

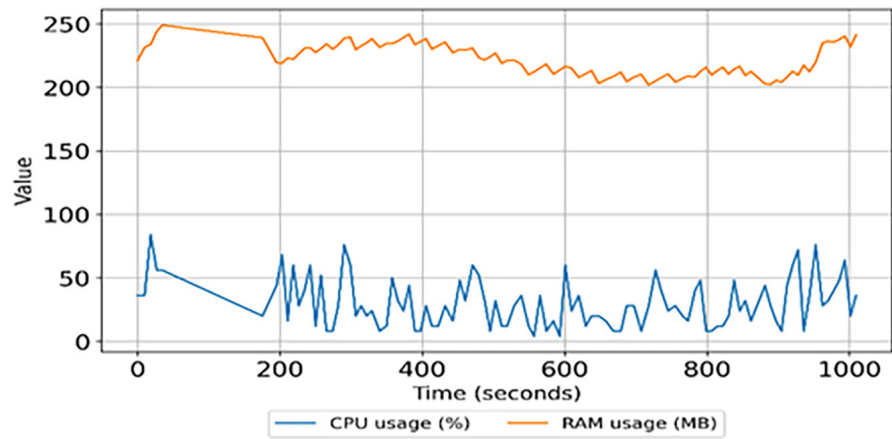


Fig. 6. Mobile performance metrics over time

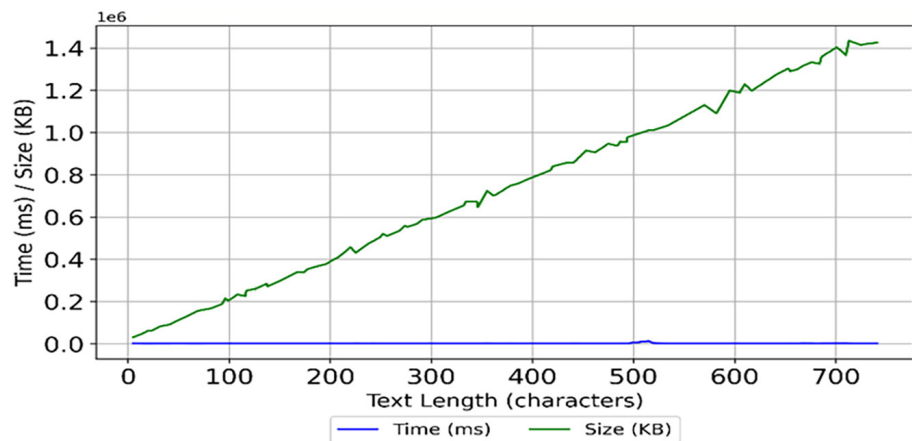


Fig. 7. TTS processing time, audio size, and text length

Lastly, Figure 7 reveals that audio size correlates with text length (as text length increases, so does the audio size), while our optimized TTS algorithm ensures consistent processing time, confirming the system’s effectiveness and scalability for longer inputs. The significance of this result lies in evaluating the scalability and responsiveness of the TTS module, which is central to user interaction in our system. The data

shows that while the audio size increases linearly with the text length, as expected, the processing time remains statistically stable, even for texts exceeding 700 characters. This indicates that the TTS engine maintains consistent performance, with no significant delays introduced by longer text inputs. This is particularly important for real-time systems, as it demonstrates that dynamic audio generation can scale without compromising responsiveness, ensuring a smooth user experience.

5 CONCLUSION

This paper focuses on improving multimedia accessibility for individuals with physical disabilities through a multi-viewpoint ontology approach that considers user context, using IoT technology. The aim is to enhance the adaptation of MDs by considering various viewpoints and leveraging IoT capabilities to capture and utilize user context information.

The challenge of adapting MDs to align with user context and needs has been further complicated by the diversity of devices and the needs of individuals with physical disabilities. To tackle this challenge, the authors of this paper have introduced a semantic MVP approach to address MDs and their adaptation. This approach enables user-device interaction through IoT techniques, thereby satisfying user needs based on their context. The proposed approach is represented in ontology format, incorporating viewpoints enriched with concepts from the IoT. This integration with IoT technologies enhances the efficiency and precision of the adaptation process, allowing for faster and more accurate adaptations of MDs.

In our proposal, we have introduced a comprehensive ontological model that encompasses an IoT system, taking into account multiple users within a single multi-viewpoint ontology. This ontology is designed to be generic, allowing for the incorporation of specific concepts relevant to the user's context as extensions. The motivation to build a generic ontology arises from the needs for:

- The avoidance of overwhelming the IoT system with an additional ontology.
- The alteration of the states of devices using the available IoT ontology to the fullest extent possible.

Therefore, our approach focuses on utilizing the existing viewpoints within an ontology through a targeted selection of the necessary concepts. Moreover, it prevents unnecessary complexity and streamlines the integration process for more efficient use of resources.

The article has presented a detailed MD adaptation Architecture based on the viewpoints' ontology, which is enriched by the IoT technique. However, there is a considerable amount of work remaining to comprehensively address all aspects of MD adaptation. We must also focus on improving our semantic and multi-viewpoint approach by integrating deep learning. Furthermore, there is another project in the works that aims to create a context-based deep learning adaptation architecture.

In future work, we plan to integrate an AI model and deep learning techniques to enhance the system's ability to determine optimal adaptation strategies. Furthermore, we aim to extend the use of mobile devices and smart TVs beyond individuals with physical disabilities to also support users with cognitive impairments. This approach seeks to provide personalized solutions by addressing the specific needs of individuals with cognitive limitations, thereby enhancing accessibility and overall user experience.

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