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AFIN 2023

Forward

The Fifteenth International Conference on Advances in Future Internet (AFIN 2023), held on September 25-29, 2023, continued a series of events dealing with advances on future Internet mechanisms and services.

We are in the early stage of a revolution on what we call Internet now. Most of the design principles and deployments, as well as originally intended services, reached some technical limits and we can see a tremendous effort to correct this. Routing must be more intelligent, with quality of service consideration and 'on-demand' flavor, while the access control schemes should allow multiple technologies yet guarantying the privacy and integrity of the data. In a heavily distributed network resources, handling asset and resource for distributing computing (autonomic, cloud, on-demand) and addressing management in the next IPv6/IPv4 mixed networks require special effort for designers, equipment vendors, developers, and service providers.

The diversity of the Internet-based offered services requires a fair handling of transactions for financial applications, scalability for smart homes and ehealth/telemedicine, openness for web-based services, and protection of the private life. Different services have been developed and are going to grow based on future Internet mechanisms. Identifying the key issues and major challenges, as well as the potential solutions and the current results paves the way for future research.

We take here the opportunity to warmly thank all the members of the AFIN 2023 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to AFIN 2023.

We also thank the members of the AFIN 2023 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope that AFIN 2023 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the field of future Internet. We also hope that Porto provided a pleasant environment during the conference and everyone saved some time to enjoy the historic charm of the city.

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The Research on a Cloud Intelligence Communication Platform of Smart Edge Devices Supporting for Metaverse Spatial Reality

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***Abstract*—This paper would like to introduce a new Device Edge Computing (DEC) that connects wearable devices with multimodal sensor hubs (supersensitive cameras, supersonic complex sensors, etc.) and (B)5G public/private networks. This DEC has studied the function/performance requirements of metaverse devices that support super-reality and super space-reality eXtended reality (XR) services that directly feel the high-sensitivity sensing of remote virtual objects, and proposes a quality-guaranteed cloud intelligent network architecture platform to support advanced services of metaverse space reality content.**
Keywords-DEC; Metaverse Wearable Devices; Spatial-Reality.

I. INTRODUCTION

Recently, in the non-face-to-face era such as COVID-19, we are actively researching and developing the "metaverse daily service" era that can remotely control the real and virtual objects ((Non-)IIoT vs. Avatar) by remotely connecting to a metaverse communication platform without going to a smart factory or smart farm, etc [1]. In addition, the advanced Information & Communication Technology (ICT) countries in the metaverse research field of communication, media, and content are actively providing virtual and reality space due to the development of ultra-high-speed, ultra-low-latency mobile networks, ultra-real media User Interface (UI) / User eXperience (UX), and the advanced Cloud-based Software Defined Network (SDN) / Network Functions Virtualisation (NFV) / virtual Deep Packet Inspection (vDPI), 5G/6G & Multi-access Edge Computing (MEC), Virtual Reality (VR), Augmented Reality (AR) / Mixed Reality (MR) / XR media and their ultra-immersive contents technology.

Currently, the main characteristics of metaverse-supported physical communication, media, and content for hybrid Brain Computer Interface (BCI) & XR services would be required as follows:

1) Measure and analyze various willingness and sentiment with multi-modal sensor detection of smart wearable device [4].
2) Recognize and respond to the environment-surrounding risk factors in advance through Big-Data and AI analysis.
3) Enhance and apply the collective intelligence communication through {body intelligence (brainwave & willingness & emotion) + hydrology Convolutional Neural Network (CNN) / Reinforcement Neural Network (RNN) / Spiking Neural Network (SNN) + Internet Cloud intelligence},
4) Acquire the determining system of situation, inference, simulation for ensemble of global heterogeneous signals through a multi-modal signal hub

So, we believe that metaverse services will be provided in the following short-term period, mid-term period, and long-term period forms in terms of applying the following metaverse scenarios:

Short-term period: In the event of an emergency, rescue workers at a disaster site, wearing augmented reality (AR/XR) glasses receive the emergency evacuating information from a remote location to safely rescue the victims via AR Tele-Presence/Navigation.

Mid-term period: A healthy running emotional exercise between couples living apart from Seoul and Jeju Island while feeling friendly remote five senses through the immersive spatial-reality AR/XR glasses and human intelligence edge devices as shown below in Fig. 1.

Figure 1. Metaverse Running Healthy with Remote Virtual Partners [Mid-term period]

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Long-term period: Like Luc Besson's SF movie "Valerian: City of a Thousand Planets," a true metaverse service that connects to virtual space in a desert-like real space to experience the XR/hologram-type surroundings and main character movements

In the above service scenarios, the following specifications would be required for Metaverse Wearable UI/UX devices and their supporting DEC devices (Fig 2):

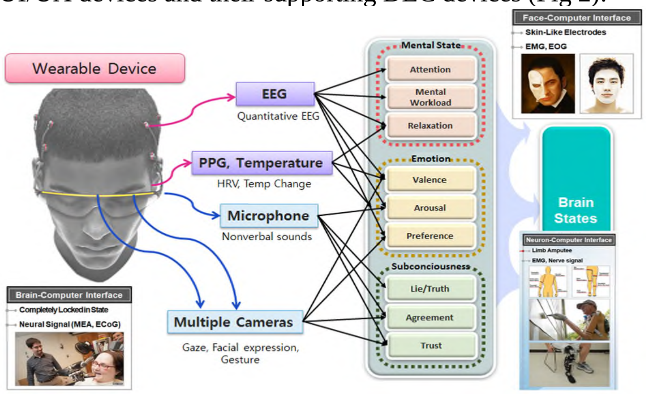


Figure 2. Metaverse Wearable XR Glasses

- Smart Thin-Client Wearable Device: {Social feed analysis (object feature point/area extraction accuracy: 65.0 APoks, Learning performance: 0.25sec) & AI-imaging (Cascaded R-CNN, Location/Area Detection Accuracy: 69.5/64.0%, 20fps, Similar Product Search Accuracy: 63.8%, Style Tag Extraction Accuracy: 73.85%)}, examples: UI/UX such as Electro Encephalo Graphy (EEG) helmet, AR glasses, XR goggles, AR interlocking ring/thimble, etc. [1]
- Smart Edge Devices: high-performance spatial scanning holographic camera/projection as an extension of WiFi-Access Point (AP) {Multi-View-Point 2D Web-Cam Scanner and ALG-motion (2+ people, up to 27 joints) motion recognition technology create 31.5-inch 8K glasses-free-3D Light Field (LF)-hologram realistic content}, Communication Intelligence On-device AI/Computing (AIoT), etc [1].

The remaining of the paper is structured as follows: The overall of Section 2 presents the Metaverse DEC Cloud Network Architecture and its required DEC's detail specifications in Section 2.A, 2.B, 2.C.

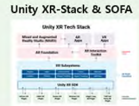
II. MAIN RESEARCH ISSUES

In section II, we would show the relationship of metaverse device and direction of cloud intelligence communication platform in II.A, and detailed research and developing direction of DEC cloud intelligence communication platform for Metaverse in II.B, and the future Metaverse services' challenges expecting functions & performances in II.C.

A. Relationship of Metaverse Device and Direction of Cloud Intelligence Communication Platform

In an ultra-low delay, high broadband, and ultra-connected intelligent communication environment under 5G/MEC [2] and 6G/DEC [6], the metaverse user devices would be advanced as listed in Table I.

TABLE I. MAIN CHARACTERISTICS OF METAVERSE USER DEVICES

Monitors (Notebook, Laptop etc.)	Smart Phones (Mobile)	Smart Glasses (VR-HMD Headsets) (AR/MR/XR-Glasses)	Vehicles (Automobile)	Metaverse Devices
Windows, MacOS	iOS, Android Studio	Unity, Unreal, ARcore etc (various contents SDKs)	ADAS studio	Meta-studio (digital hologram)
AR-Projection	AR-Tracking AR-Rendering AR-Mirroring	Unity XR-Stack & SOFA 	AR-Projection (AR-Navigation etc.)	Open Meta-OS (SOFA⁺⁺ digital twin)
		OpenXR (Open SmartGlasses-Device Standard I/F)	ADAS Device I/F	OpenMetaverse (Open 4GIR - standard device I/F)
WiFi connecting Tethered-Smartphones	WiFi/4G connecting (eMBB/mMTC/uRLLC slices) (Edge Cloud & Macro-Cell)	WiFi/5G connecting (eMBB/uRLLC slices) (Edge Cloud & Macro/Small-Cell)	5G communication (eMBB/uRLLC slices) (Edge Cloud)	6G/6E comm. (+bloackchain slices) (Device Cloud: DEC)

The AR/XR/hologram glasses, drone-attached intelligent five-sensory device edge computing (DEC) 4D, automatically adjusting 4D (3D+five senses) space size and visibility/light of indoor and outdoor environments, recognizing and identifying 4D (3D+five senses) metadata required to identify object information, we think that it is necessary to secure a new five-sense experience-type Spatial-Reality metaverse technology that connects virtual information about see-through objects reflected from remote locations by cluster control communication and synchronization only with gaze/speech/gesture-UI access.

It is necessary for supporting a complete thin-client communication structure between smart wearable devices [3][5] worn on the body and smart edge devices that support off-loading the insufficient network/computing /storage-caching performance of all-in-one wearable devices. It is thought that research on a "metaverse device communication platform that supports physical enhancement spatial-reality" that expands to five senses (such as visual/hearing/scent/ taste/touch) and cloud intelligence is needed.

Therefore, this basic study will be conducted in the following directions as the below of Fig. 3:

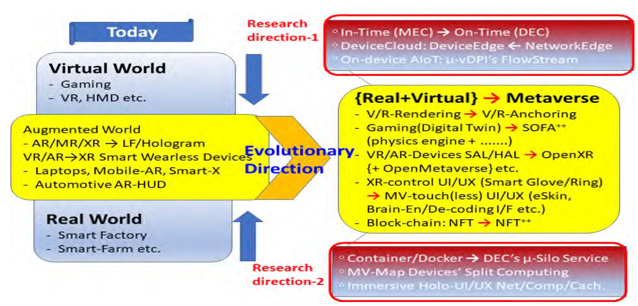


Figure 3. On-Premise DEC Study Direction (Red) according to Metaverse Evolution (Yellow)

- Research direction 1: The realistic immersive wearable device computing requires ultra-small, light-weight, and low-power AIoT(AI of Things) audio-visual intelligence that satisfies metaverse services: Indoor and outdoor real-world/object-cognitive and 3D-space correlation analysis/control method.
- Research direction 2: The real-time & time-sensitive deterministic multi-collaboration Visual Intelligent Device Edge Computing (DEC) with cloud intelligence communication platform structure that provides visual safety and visual work efficiency.

B. Detailed Research and Development Direction of DEC Cloud Intelligence Communication Platform for Metaverse

Prior to the metaverse era, VR/AR composite rendering support was simply a trend provided by Local Server (Thin-Client structure), but VR/AR support is gradually approaching MEC (Edge Cloud) in the 5G era. In the future, it is expected that it will be developed into a DEC for on-time provision of XR/Hologram next-generation XR contents beyond VR/AR. Therefore, the DEC concept is expressed in Device Cloud terms in 2021, and the establishment of the concept has not been clearly confirmed in international standardization. For the metaverse-support DEC R&D, this ETRI established domains in two directions for effective preemptive responses as in Fig. 4.

1) Cloud Intelligence Communication Edge Device Requirements & Specification based on Metaverse Service Characteristics: User Device Requirements & System Requirements - Definitions Established

2) The Platform of DEC Structure/Function/Performance of Cloud Intelligence Communication Edge Device based on Metaverse Service Quality Assurance

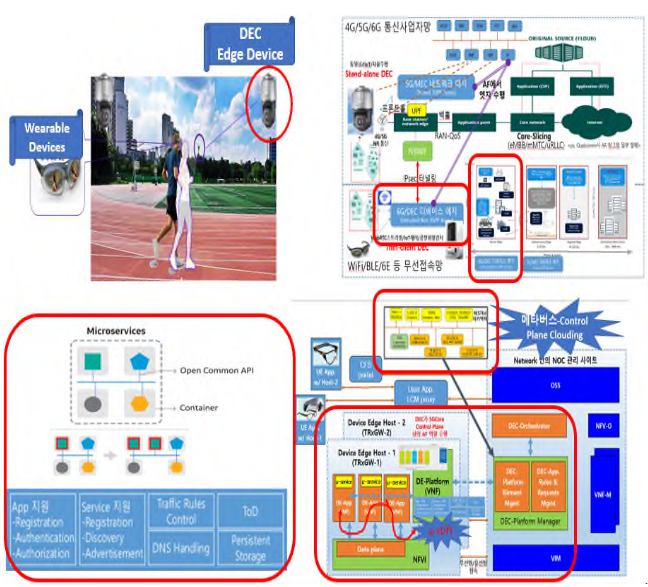


Figure 4. Cloud intelligence communication type DEC type of 5(6)G network application location/structure (red box)

C. Future Metaverse Services Expect Functional/ Performance Challenges

1) Edge Access-Point (AP) device requirements (Fig. 5)

- Visual Intelligent Edge Device-HardWare(HW)
  - 3D high-precision position/coordinate and size SLAM calculations, fixed/mobile/drone-attached variable-lightening, high-density resolution and motion-to-photon (HW-MTP), edge GPU/TPU/NPU (biological) chips & AP (Application Processor) boards
- Visual Intelligent Edge Device-SoftWare(SW)
  - Multi-Collaborative Virtual Space Infrastructure Dynamic Configuration, Real/Virtual Object Matching Precision, Eye-movement/Biological/Body-gesture Automatic Tracking and Situation Cognition, μ-Service Device-dedicated OS/SDK/IDE SW Development Environment
- Visual Intelligent Edge Device-AIoT
  - Real-object property correlation analysis, correlation matching with virtual objects, multi-collaboration spectrum optimization, real-time caching of device's location/gesture transformation content, real-time resource optimization, privacy of fixed/movement objects, etc
- Visual Intelligent Edge Device-Network Computing
  - Location/posture conversion Round Trip Time (RTT) ultra-low latency, Physical/Virtual/Container Network Function (PNF/VNF/CNF)-mixed micro-service silo structure with RESTful bus structure, DEC net computing virtualization with 5G-CorePlane AF(Application Function) and MEC standard model linkage, and Multicast/Broadcast support on XCF & XUF functional modules for multiple collaborations on 5G-CorePlane

2) Wearable Device Requirements Specifications (Fig 5)

Figure 5. ETRI Trustworthy AR Platform (an example)

- Analysis of the possibility of achieving 95% of the final metaverse (XR/SR) realistic recognition rate based on cognitive advancement (95%) in body (brain wave/biological) targets
  - Metaverse virtual space deployment time: 10 seconds → 1 second → 10ms or less
  - Metaverse {brain wave→real virtual object} directive response time: 1 second→10ms→1ms or less
  - Metaverse EEG-Intention/Emotional/Immersion Content: (Video) AR/XR→3D (real) Hologram→4D (feeling) Hologram
- (AR/VR/XR) Key features of wearable device requirements as Tele-Presence services evolve
  - Short-term period: Remote IoT-control Service in TR-Presence: Remote IoT access and cyan-tracking object-control based on Tele-Presence {Connected IoT access and simple gaze/voice reflected in mutual AR glasses between AR-DECs (Head Mounted Display (HMD) 100% already achieved)-Command control (HMD 100% already achieved) (HMD visualization RTT average 23ms achieved)
  - Mid-term period: Remote tactile (five senses) analysis/ transmission and fine-feeling (sense) object-control on Tele-Experience
  - Long-term period: Remote Thinking (intention, emotion) analysis and communication on Tele-Hologram and physical-AI-based all-thing (people/things)-control

III. CONCLUSIONS

Currently, this study is planning to establish a linkage structure between metaverse user devices, Device Cloud, 5G/MEC and 6G/DEC, derive a real/virtual-object content metaverse platform environment between 5G/6G Control Plane and wearable/edge devices, and identify metaverse content creation levels as shown in Fig. 6.

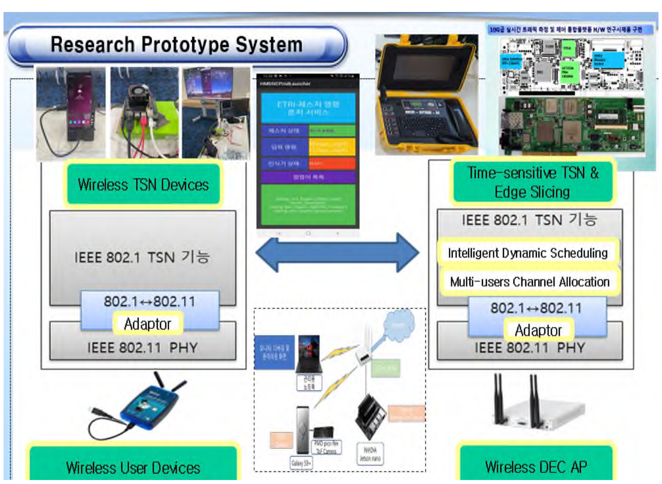


Figure 6. DEC Prototype Device & Server Platform (from ETRI & KoreaTech Univ.)

The results of this study will be a preemptive research opportunity in the development of intelligent edge device communication platforms that provide as follows (Fig. 7):

1) High angle, high precision, and xyz space coordinate 3D space risk detection and work efficiency in everyday life
2) A preemptive research opportunity for the development of an intelligent edge device communication platform that provides life safety audio/visual-moving_guide through recognition/ inference of the elderly/children's behavior observation.

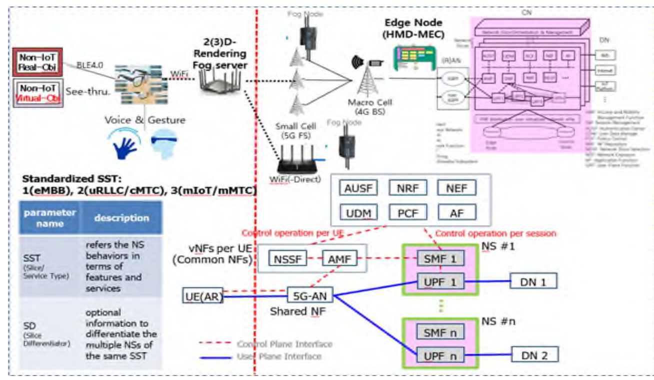


Figure 7. The DEC adapting to 5G Core Plane Prototype

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WrEx - Wrist Exercise Trainer a System for Monitoring Physical Therapy Exercises

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***Abstract*—Repetitive movements can be enough to cause joint damage. This is a problem that often arises, in particular on the hands and wrists, due to the intensive use of smartphones and computers. That is why it is important to have tools and apps that can help in some way, first in prevention and then in possible injury recovery exercises. It is very interesting to have the possibility to perform some types of prevention/treatment exercises continuously over time, and not only when in a clinic and in the presence of a healthcare professional. In this paper we present a physiotherapy exercise monitoring system for the wrist that can be used autonomously by patients. The system consists of an interactive mobile application and a set of devices that will be placed on the wrist and hand. The devices are able to detect movements made by the wrist joint and send this information to a mobile application. Through the application, the patient can access a set of exercises, previously defined by a physiotherapist, and have access to information collected in real time about the exercises and also if they are being done correctly. Our system also provides an application for physiotherapists where they can monitor and manage the exercises performed by their patients.**

Index Terms*—Wrist Movements; Motion Sensors; Wearable sensors; Mobile Computing; Interactive Mobile Application.

I. INTRODUCTION

Technological innovation has allowed the rise of new communication and information technologies which are increasingly replacing or extending in-person services with remote services, since these are powerful tools capable of breaking the barriers of time and space [1]. Telehealth services take advantage of communication technologies, allowing patient diagnosis to be made anywhere in the world and information to be accessed, evaluated, and delivered through wireless communication services.

Thus, the opportunity arises to explore new tools that aim to contribute to this area, in order to promote greater convenience and quality of health services. Through the integration of devices that use simple and easy-to-use sensors, it is possible to perform measurements automatically and outside the clinical environment, thus reducing the need for intervention by specialised personnel.

The system presented in this paper aims to develop an interactive mobile application that connects to a wearable motion-sensing prototype to monitor physiotherapy exercises, in particular musculoskeletal rehabilitation of the wrist. In order to assess wrist mobility, four physiotherapy exercises are evaluated: flexion and extension, as well as radial and ulnar deviation, which can be performed with or without load, and with the left or right hand. In these movements, the forearm is fixed on a surface, and only the wrist joint is rotated, as shown in Figure 1.

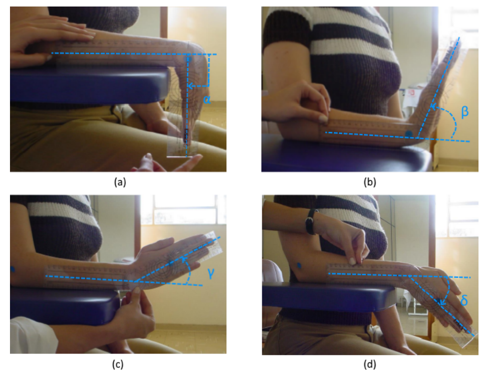

Figure 1. Measurement of physiotherapy movements of the wrist [3]. (a) Flexion. (b) Extension. (c) Radial deviation. (d) Ulnar deviation

The wrist flexion and extension movements occur in the sagittal plane at the radiocarpal and intercapal joints [2]. In these exercises, the arm should be in pronation and the elbow flexed to about 90° with the axis on the medial side of the wrist. The wrist flexion consists of moving the hand downward in a joint range between 0º-90º, the α angle illustrated in Figure 1(a). Alternatively, wrist extension is the opposite movement, in a joint amplitude between 0º-70º [3], angle β shown in Figure 1(b).

The movements of radial deviation (abduction) and ulnar deviation (adduction) of the wrist occur in the frontal plane. The elbow must be flexed and the forearm in neutral position, i.e., between supination and pronation with axis at the radiocarpal joint, where forearm supination consists of rotating it upwards, while pronation is the opposite movement, rotating the forearm downwards. The radial deviation occurs when the hand is moved upward, in a range of motion between 0º-20º, angle γ shown in Figure 1(c) while ulnar deviation is the opposite motion, with a range of motion between 0º and 45º [3], angle δ illustrated in Figure 1(d).

This paper presents the objectives and motivation that inspired its development in Section 1, while Section 2 covers an investigation of different projects and applications with the aim of particularly improving the condition of the wrist through physiotherapy exercises. Sections 3 and 4 describe the system and the evaluations conducted to validate the system's effectiveness and usefulness. Finally, Section 5 concludes and describes future work.

II. Related Work

The number of applications aimed at joint rehabilitation has been increasing, with the goal of encouraging the practice of physiotherapeutic movements in order to improve and make the rehabilitation process more effective and attractive. Sometimes these applications are only informative and for communication between the physiotherapist and the patient, with only a small percentage of these applications incorporating a sensor component that theoretically allows a more effective treatment [4]. Through monitored exercises, or even interactive games to capture the user's attention and interest over long periods of time, it is possible to enhance the patient's prevention and rehabilitation process.

The system presented in [5] integrates an Inertial Measurement Unit (IMU) sensor to evaluate the amplitude of various wrist movements, such as flexion, extension, ulnar and radial deviation, as well as pronation and supination. The system incorporates a micro-controller and an Android application to process and visualise, respectively, the data obtained by the sensors through Bluetooth communication. This work analysed different ways to perform the measurements of the different wrist movements, varying the positioning of the device on the back of the hand, with the best results being obtained when the device was placed at the central and end point of the back of the hand. The results obtained in [5] indicate that this device collected quite reasonable and acceptable data on the amplitude of wrist movements.

In the work [6], the focus is on finger rehabilitation. In this work, resistance-based sensors are used and compared with inertial measurement unit sensors. The device presented in this work was a glove consisting of three 6-axis IMU sensors and two 2.2-inch flex sensors to detect the movement of the finger joints. This system includes a graphical interface with a 3D visualisation of a rectangle that moves according to the movement made by the finger, which is very useful for the patient to better understand how the movement is being performed. In this study, they concluded that the IMU sensor is the most suitable due to its higher accuracy and efficiency in readings, as well as having a lower percentage of error compared to resistance-based sensors.

Another interesting study is the use of a combination of tele-rehabilitation technologies with advanced robotic technologies, allowing the development of semi-autonomous physiotherapy training with greater control and complicity between the professional and the patient [7]. The presented system motivates the patient to perform certain wrist movements through a rehabilitation robot controlled by a web application via Internet protocol. The therapist can modify the parameters, such as the limit of the angles of each movement, the speed and the number of repetitions, and can supervise the exercise in real time while the rehabilitation robot performs the desired movement.

In general, there are many interesting and well accomplished works for the intended purposes using different sensors, such as inertial measurement units, flexible sensors, and tactile sensors. The comparisons observed in these works regarding the efficiency of the different types of sensors are useful to understand and study the best options to implement our system. Some of the solutions presented have limitations due to not using enough or adequate sensors, or sometimes the system itself is not easy and convenient to be used autonomously by the patient, as well as does not present graphical and interactive interfaces in real time about the exercise that is being performed. Thus, the system presented in this paper intends to combine these features and present simple and intuitive interfaces for both patients and physiotherapists in order to promote better rehabilitation of the wrist joint. The system uses two 9-axis IMU sensors that work together to validate and correct the movement being performed.

III. System Description

WrEx trainer system consists of an interactive mobile application capable of measuring and monitoring wrist physiotherapy exercises through the use of a simple device with sensors. The exercises considered are: flexion, extension, ulnar deviation and radial deviation movements. The system can be used with the assistance of a physiotherapist, as well as autonomously and independently. In other words, this system can be used in everyday life and outside of a clinical setting. Supported exercises can be performed by both the right and left wrist, with or without load.

A. System Architecture

The system consists of three main components, which are: the wearable motion-sensing prototype component, the application component, and the server and database component (see Figure 2).

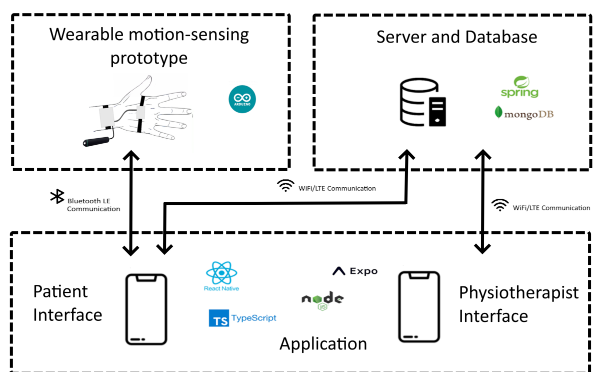

Figure 2. System architecture overview

The code that runs on the wearable prototype was developed in the Arduino IDE [8], the server in Spring Boot [9] and the database is a MongoDB [10] instance. The mobile application was developed in React Native [11], a framework that allows hybrid application development. Since a Bluetooth Low Energy (BLE) communication support is needed for the mobile device to communicate with the micro-controller, and a 3D animation support for the physiotherapy movement is also needed, the application was developed following a simple workflow. This way, it was possible to install the Expo animation libraries, as well as other native libraries, such as the React Native BLE library Manager [12], which supports BLE communication, that is essential for this application. In general, the application communicates with the wearable motion-sensing prototype component via BLE, as well as with the server and database component using the Wi-Fi communication protocol to establish bi-directional connections.

B. Wearable Motion-Sensing Prototype

The component device with sensors consists of two boxes and a powerbank, which supplies power to the system, as illustrated in Figure 3. Box number 1 contains an ESP32 micro-controller and an IMU MPU9250 sensor that has as the main function to assess whether there is movement of the forearm during physiotherapy exercises, and box number 2 contains an IMU MPU9250 sensor that will measure the wrist angles during all exercises.

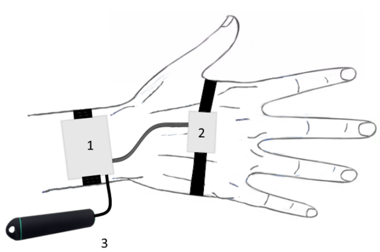

Figure 3. Schematic of the wearable motion-sensing prototype

The placement of the device must be as follows: the box number 1 should be in the area between the wrist and the forearm and the box number 2 on the back of the hand, by using elastic bands with velcro. This way the x-axis of the sensor in the box with the number 2 goes along the arm, the y-axis is perpendicular to the forearm, and the z-axis points upwards. The angles that are measured relative to the wrist movements correspond to the rotation about the y-axis. For the sensor in the box with the number 1, all the axes are considered, since it is necessary to detect when there is any movement of the forearm.

1) Communication Between the Micro-controller and the IMUs: Communication between the ESP32 and the two MPU9250 sensors is performed using a simple serial communication protocol called I2C, which is composed of serial data and serial clock signals [13]. In order to allow separate communications with the sensors, each MPU9250 has its own I2C address.

It is important to perform data fusion to get more reliable information after collecting the sensor values. This pre-processing of the data is done in the micro-controller, so there is no need for a connection between the prototype and the server application or component to read and process the data collected by the sensors. The library chosen to support the communication between the IMU MPU9250 sensors and the ESP32 micro-controller, as well as the processing of the data obtained when collecting and filtering the sensor signals to improve data quality, was created by hideakitai [14]. This library also allows to apply the Madgwick filter [15], which uses a quaternion representation of the orientation to describe the orientation estimates [16].

2) Communication Between the Micro-controller and the Application: The communication between the micro-controller of the wearable motion-sensing prototype and the mobile application is done through the BLE communication protocol. This communication protocol is widely used in the IoT world and in systems integrating sensors, as it transmits and receives small amounts of data, with low power consumption, so it can easily work for long periods of time [17]. In this communication, the ESP32 micro-controller acts as the server and the client is implemented in the mobile device application [18].

The composition of the data transmitted between the micro-controller and the mobile device consists of a quaternion value that is an average of about 63 readings performed by the sensors during a time interval of approximately 508ms, followed by the respective conversion to Euler angles. Therefore, the size of the data sent to the application is around 40 bytes. This data is used to visualize in the application the different angles performed in real time, but only the values collected during the validation time of the angle to be reached during the exercise are sent to the server and stored persistently in the database to be accessed by the physiotherapist, since the purpose of the system is to evaluate and verify that the exercise was well performed.

In this communication it was necessary to define an increase in the Maximum Transmission Unit (MTU). The method used to increase the MTU limit was through packet length extension (DLE) [19], introduced in Bluetooth 4.2.

The calibration of the accelerometer and gyroscope sensors that are part of the two IMUs is performed after the communication is established.

C. Mobile Patient Application

The patient application provides a set of core functionalities for the patient: (1) consult and begin a training plan and (2) perform the physiotherapy exercise.

1) Training Plans and Physiotherapy Exercises: The patient has access to the training plans and respective exercises proposed by the physiotherapist, as well as the interface to perform each exercise. A plan is a set of exercises, where for each exercise the type is defined, the angle to be reached, the number of repetitions and sets, the time intervals to perform each repetition and validate the objective angle, and also in which of the wrists the patient must equip the sensor component to perform the exercise. In the plan list interface, it is possible to see which plans are available, unavailable, completed and in progress, which means that a training plan has been started and can be resumed. A plan is unavailable

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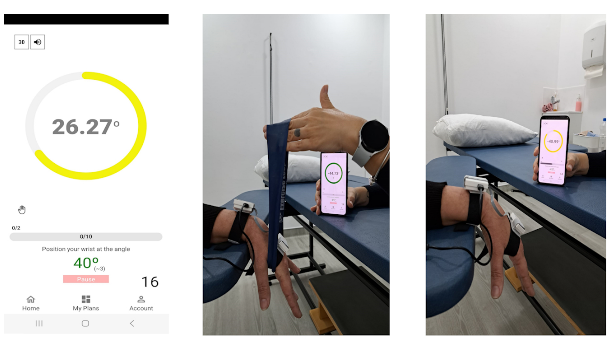
when the date set by the physiotherapist for its completion has not yet arrived. On the other hand, plans are available and can be performed when they have not yet been completed and the date set for their completion is the current or previous day. A completed plan cannot be repeated, which means that the patient has completed the proposed physiotherapy exercises and finished the plan. The physiotherapist can define different training plans according to the patient's physical condition and based on the evaluations of previous plans, i.e. whether the exercises previously performed by the patient were successfully completed or whether problems or disabilities occurred during their execution.

When a patient decides to perform a physiotherapy exercise, an interface is presented to establish the connection between the mobile device and the micro-controller, as well as to perform the calibration of the sensors. After a successful calibration, the patient's mobile app presents an interface where the 3D model of the wrist or an interactive graph showing the angle being performed is displayed, as well as all the information needed to perform the exercise (see Figure 4). In the interactive graphical interface, a circular graph is presented and filled according to the angle performed by the wrist. The colour of the graph changes from red, orange, yellow to green as the value of the angle performed with the wrist approaches the objective angle value. There is also other information, such as progress bars for repetitions and sets, the time required to perform each repetition, as well as coloured borders to indicate correct and incorrect movements. In addition, there are temporary messages that indicate the progress stages of the exercise, such as whether a repetition has been started or completed, or whether a movement is being validated or is incorrect, with these messages being followed by different sound effects that help alert the patient to these situations. There is also a button to enable or disable the sound effects.



(a) (b) (c)

Figure 4. Patient's mobile application interface and performance of exercises with and without load. (a) Interactive graphic display while performing the first repetition. (b) Exercise with load. (c) Exercise without load

2) Perform a Physiotherapy Exercise: Every repetition of an exercise is started with the patient placing the hand that is wearing the wearable motion detection prototype in a position where the angle of inclination is 0° for a time interval of three seconds. Then the repetition is started, the patient must perform the exercise for a time interval determined by the physiotherapist until the objective angle is reached. For the repetition to be validated and successfully completed, when the proposed objective angle of the exercise is reached, the patient must hold the angle during a given time interval, defined by physiotherapist. During the angle validation time, an average of the angles performed with the wrist is calculated, which end up being minimally different from each other, since the patient has to keep the angle equal or very close to the objective angle, with a 3º deviation.

The correct position of the forearm position is defined at the beginning of each repetition, using the sensor placed on the forearm. Thus, if the forearm rotates up to 10° on either axis of the sensor, the movement is considered incorrect, so the repetition is stopped until the posture is corrected. The number of times the patient has been in an incorrect position is counted during the execution of the exercise.

D. Mobile Physiotherapist Application

The purpose of the physiotherapist application is to allow a more complete diagnosis of the patient's condition, so it provides a number of essential features for the physiotherapist: (1) search and view patient information (2) manage the patient's training plan and physiotherapy exercises (3) observe the patient's evolution.

The physiotherapist can check and evaluate the data and statistics of the exercises performed by patients during a session in the clinic, or afterwards, by accessing the management area in the mobile app. It is possible to view the specific angle values for each type of exercise, which means that it is possible to identify which angle values are reached during the movements and therefore check whether the target angle has been achieved. The execution times and the number of failures for each repetition of a given set performed by the patient are also displayed. Thus, the physiotherapist can carefully monitor patients, adapting new physiotherapy plans and exercises based on an analysis of the exercises already performed.

Each physiotherapist can access and observe any physiotherapy plans and exercises, but can only create, edit and delete physiotherapy exercises from plans created by themselves, as well as edit and delete plans of their own authorship.

The interface to observe a patient's progress during the physiotherapy exercises includes a bar graph with the different angles achieved during the various repetitions that can be filtered by a certain set to allow a more focused evaluation of the progress in that set, general statistics, and a list with detailed information about each repetition, such as the time used to complete the repetition, the angle reached, and the number of faults. The general statistics has information about the number of successfully completed repetitions, the total number of faults during the movements, the average of the angles performed in the repetitions, and also the average time interval for the execution of the movement.

The physiotherapist can also observe the movements made by the patient during the physiotherapy exercises through the animation of a 3D model of the wrist (see Figure 5). This model was provided by Hugo Colauto through the Sketchfab

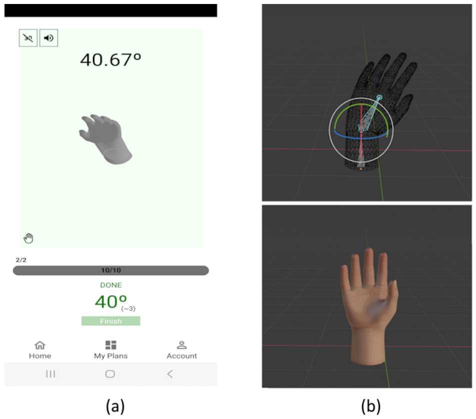


Figure 5. Wrist 3D model. (a) Interface when all repetitions and sets have been completed. (b) Wireframe and material preview

platform licensed under CC BY 4.0, which is imported into the Blender software to add a skeleton, which consists of two interconnected bones, where one bone is associated with all vertices of the hand region of the model, and the other bone to the remaining vertices of the model in order to deform the mesh.

IV. EVALUATION

Several tests were performed to find the best way to use and position the wearable motion-sensing prototype component on the wrist in order to obtain more accurate readings, as well as provide more comfort and less interference during physiotherapy movements. Also, an evaluation of the patient and physiotherapist mobile applications was performed to ensure that each component of the system was performing well, such as integration testing and usability testing.

1) Sensor Placement: The placement of the sensor located in the box with the number 2 (see Figure 3), which was used to measure the wrist angle values, was tested in 3 locations on the back of the hand: the central area, an area closer to the fingers, and another area closer to the wrist. The central region of the hand proved to be the most suitable for measuring the angles of the four physiotherapy exercises within their respective limits, which are the maximum angles that can be achieved in each exercise, without introducing significant errors. Some complications occurred during the flexion movement when the sensor was placed closer to the fingers, due to the fact that the sensor hardly made readings of angles above 70º. On the other hand, there were some problems during the ulnar deviation movement when the sensor was placed closer to the wrist, with the problem again being related to the sensor's inability to take readings from certain angles, in this case reaching angles above 30º. The sensor in box number 1, was placed between the wrist and forearm area, and proved to be able to perform its function of detecting any movement of the forearm.

A. Measurement Evaluation and Correction

Some experiments were conducted to determine if the wearable motion-sensing prototype component is collecting and processing the motion orientation data correctly. Three different angles were chosen for each physiotherapy exercise and ten repetitions were performed for each angle. The goal of these measurements is to evaluate whether the proposed angles were achieved correctly, that is, whether the values of the angles measured by the sensors correspond to the actual angle made by the wrist.

In general, the system proved to be both suitable and correct in reading the different values of the angles defined for each physiotherapy exercise, and the angles obtained oscillated very close to the objective angle and within the defined limit of 3º.

B. Usability Testing of Mobile Application

In order to evaluate the patient and physiotherapist application and obtain feedback from users, a set of user stories were described, consisting of descriptions of tasks with the information needed to accomplish them. An examiner was present during the test to note any difficulties or problems that the user might encounter. A questionnaire was conducted and the System Usability Scale (SUS) [20] was used, which is a reliable tool for measuring usability and provides an overview of subjective usability.

1) Patients: The tests were performed on twelve patients, aged between 21 and 60, and the results were positive.

Navigation and interaction with the different interfaces of the application were positive and all patients were able to easily access their plans and exercises, as well as start a physiotherapy plan and exercise without any difficulty. Overall, the wearable motion-sensing prototype was found to be comfortable and easy to use. The interactive graphical component was very well received and the sound effects were considered useful, as the patient did not have to be fully aware of the visual interface of the application to understand the status of the exercise while performing the movement.

Some questions were asked about the experience of using the system. The questions asked were as follows: (1) whether it was intuitive and easy to access the plan page and begin a physiotherapy exercise; (2) whether the wearable motion-sensing prototype was comfortable and easy to use; (3) whether the process of connecting the prototype wearable motion sensor to the mobile device and calibrating the sensors was easy; and (4) whether the exercise performance interface was useful and intuitive for completing the exercise successfully. Overall, as shown in the Figure 6, the responses ranged from 4 to 5 on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree), with only the opinion on the usefulness and intuition of the interface for performing one of the exercises having some responses with a less good rating (3 out of 5). This way, the evaluation was positive and most of the comments and observations were related to the design of the interface and the way the information is presented in the interface, and not to the performance of the functionalities of the system. Based on the feedback, some changes were made to the system to improve the user experience.

Regarding the System Usability Scale (SUS) questionnaire given to the patients, the score was 83.3%, which on that scale

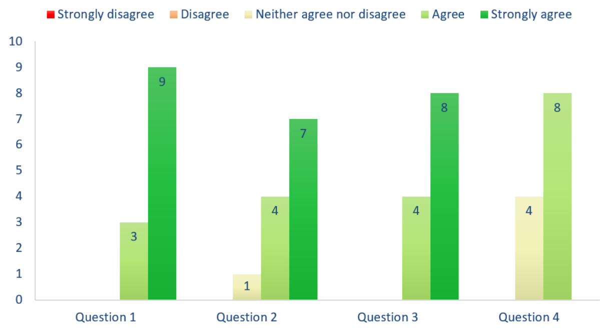


Figure 6. Patient evaluation graph

is equivalent to a good rating, being very close to excellent, which would be above 85.5%.

2) Physiotherapist: The tests were performed with a specialist at a clinic that provides specialised, individual and personalised physical therapy treatments.

The physiotherapist was able to easily access and manage the physiotherapy plans and exercises for a given patient, as well as identify and access the page showing the patient's progress throughout a given exercise. The creation of both the plans and exercises was successfully performed, and there was no difficulty in filling out the fields on the forms. Overall, the results were positive.

The physiotherapist suggested that it would be interesting to extend the system to also work with closed kinetic chain exercises, since currently the system only supports open chain exercises for the wrist, which consist of moving the distal part of the body, such as the hands.

Finally, the physiotherapist was also asked to answer the questionnaire presented by SUS, and the result was 75%, which on the scale is equivalent to a good.

V. Conclusion

The system allows a patient to perform physiotherapy exercises in a more controlled and correct way, using the application together with the sensor prototype at any time, autonomously and without any restriction. On the other hand, the physiotherapist can evaluate and follow the evolution of the patients during the rehabilitation process.

The sensor component is affordable so that it can be accessible and used by any physiotherapist and patient, and overall it is easy to use, with reduced volume and weight, in order to not limit or constrain any of the physiotherapy movements. The system performed well during the testing phase, being able to correctly reach and measure the angle values during physiotherapy exercises, and the results obtained in the tests performed with patients and physiotherapist were positive. The patient has all the information needed to complete the exercises, and the physiotherapist has access to an interface that provides the results of the patient's progress immediately upon its completion.

In the future, it would be interesting to include new physiotherapy exercises for the wrist and integrate new sensor devices to detect bad postures while performing movements.

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Design of an Intelligent Location-Aware Architecture for Mobile Computing Environments

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***Abstract*—Mobile devices have become ubiquitous in daily lives, especially for people who use their smartphones throughout the day while visiting different places in the real world. Providing valuable services and information that are tailored to a specific area or environment can make user interactions more seamless, personalized, and convenient. This paper proposes an intelligent location-aware architecture for mobile computing environments that interacts with individual mobile users by automatically providing appropriate local services, information, and personalized recommendations based on their current location and profiles while tracking their position and movement. Experimental results show that the proposed architecture is intelligent, scalable, reliable, and can be efficiently deployed in various real-world environments.**

Keywords—Location awareness; Personalized recommendations; User interactions; Mobile computing environments

I. Introduction

The emergence of mobile technologies and advancements in wireless networking technologies have significantly transformed the natural way for users to access and search for information, interact with digital services, and navigate surrounding environments anytime and anywhere [1]–[3]. The convergence of these technologies has shifted the trend towards Location-Aware Systems (LASs) that provide users with personalized and contextually relevant information based on their current geographical position within mobile computing environments [4] [5].

The development of location-aware systems typically resides on a backend server as a web application that operates using a client-server architecture [6], enabling interaction, communication, and data exchange between clients and servers. It consists of various technologies and components to provide convenient services and information for users. In this architecture, a client, a computer, or other device uses a web browser to request data or services through the Internet, while a server then performs the request, generates the result of the requested task, and serves the task results to the client, which are then displayed in the web browser.

Based on their previous research [7]–[9], Santipong et al. introduced a conceptual framework for the future web that helped local mobile users directly access and contribute web content and services on the local and global webs without needing centralized servers through their mobile devices. Moreover, it automatically provided mobile users with tailored local information and personalized services in environmental contexts, which could address the issues of information overload, centralization, and data privacy. However, it needs a complete description of the communication and interaction with local services hosted on a local sandbox server within a given environment, enhancing user experiences and enabling seamless integration with real-world environments.

To bridge the gap, this paper proposes an intelligent location-aware architecture for mobile computing environments. The proposed architecture aims to enhance the overall user experience by providing personalized and relevant services, information, and suggestions tailored to their needs and preferences based on their current location. The use of location-based services and user profiles ensures that individual mobile users receive valuable real-time information about nearby businesses, events or attractions. Moreover, through push or pull mechanisms, mobile users can receive potential interests related to an environment so that they can actively engage with their surroundings and discover new opportunities that match their interests. Furthermore, the proposed architecture is designed as a client-side mobile application that gives mobile users more control and ownership over their personal data, with a focus on maintaining privacy and allowing mobile users to fully manage their data.

The contributions of this paper are summarized as follows:

- This paper provides valuable insights into the challenges and opportunities of designing an intelligent location-aware architecture in mobile computing environments based on the current location and user profiles.
- Extensive experiments are conducted to validate the robustness and effectiveness of the proposed architecture.

The structure of the rest of this paper is as follows: In Section II, a literature review and related work are conducted. In Section III, an architecture is proposed. Experimental details are presented in Section IV. Section V contains a discussion of experimental results. Section VI gives an example of a use-case scenario. Section VII presents opportunities and challenges. Finally, a conclusion and suggestions for future work are presented.

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II. Literature Review and Related Work

In the last decade, various research studies have explored several application areas for location-aware systems. For example, Damianos et al. [10] focused on developing context-aware recommendation systems within intelligent location-aware platforms. Their study demonstrated that by considering user location and context, recommendation algorithms could provide highly personalized suggestions for nearby restaurants, shops, and attractions. Importantly, integrating machine learning techniques enabled the continuous refinement of recommendations based on user feedback and preferences. Building on this, Knijnenburg et al. [11] tackled the security and privacy issues inherent in location-aware platforms. Their research proposed a secure, privacy-preserving framework that robustly protected sensitive user location data against unauthorized access. Lastly, Shini et al. [12] presented a context-aware recommendation system for mobile users that leveraged location data and user preferences to provide personalized suggestions for nearby points of interest. Their research showed the capacity of intelligent location-aware platforms to enhance user experiences and decision-making processes.

Despite these significant advancements, there still needs to be a gap in designing a comprehensive location-aware system for mobile computing environments. Existing solutions regularly face challenges in accuracy, power consumption, privacy protection, scalability, and user experience. Therefore, the purpose of this paper is to address these limitations by designing an intelligent location-aware architecture that is optimized for mobile computing environments.

III. Architecture

This section describes the design of an intelligent, location-aware architecture for mobile computing environments. The main idea is to automatically provide individual mobile users in different environments with specific local services, information, and recommendations based on their current location and profile that meet the needs and preferences of the right users at the right time in an appropriate environment [13]. The proposed architecture is a computing model that divides tasks between a sandbox server and a mobile device, allowing mobile users to directly and securely access and contribute information and services through their mobile devices connected to a local Wi-Fi network. The sandbox server is responsible for hosting, managing, executing, and contributing services and information to the mobile device. The mobile device provides a user interface through which a mobile user can initiate requests for content or services and display results from the sandbox server. On the other hand, the sandbox server allows service providers to participate by developing their own services and applications, which they can then upload to the sandbox server. By uploading these services and applications to the sandbox server, service providers can extend the functionality and capabilities available to mobile users. This enables a dynamic and customizable user experience and the ability to access a wider variety of content and services through mobile devices. An architectural overview is given in Figure 1.

The proposed architecture also provides a solution to privacy and data protection issues by independently separating personal data stored on mobile devices from local services on a sandbox server. Each mobile user can control their own data through their mobile device, enabling direct interaction between mobile users and their local server without intermediaries. Additionally, mobile users can grant or revoke access to their personal data as needed and authorize external services, applications, or users to access it.

The proposed architecture consists of two main components: (1) a mobile device and (2) a sandbox server. This architecture plays important roles in serving a specific purpose, seamless communication, and engagement within a specific environment. Each part is explained, which describes how the sandbox server shares services and information and interacts with mobile users.

A. A Mobile Device

A mobile device includes the hardware and software components necessary for running applications. This includes the processor, memory, operating system, and any additional features or sensors present on the device. This mobile device is designed to support the execution of various applications while providing a user-friendly interface for interacting with them. Additionally, it ensures that the mobile device is capable of securely connecting to a sandbox server and transferring data between the two entities. Figure 2 shows a data flow diagram representing the flow of data through several processes between a mobile device and a mobile user.

Mobile users obtain a set of services and menus, depending on where they are, represented by local workflows through dialogues. These local workflows allow mobile users to easily navigate through various menus and access the services they need based on their location. As a whole, a mobile device can be divided into four primary layers:

1) Presentation Layer: This layer runs on a front-end device as a client-side system. A mobile user and a sandbox server interact and communicate primarily through a Graphical User Interface (GUI) with a compatible mobile application. A GUI consists of user interfaces and graphical elements, such as icons, buttons, and menus that allow mobile users to interact with them on dialogues. These dialogues are a communication process for exchanging data between a mobile user and a sandbox server that receives user input and displays information in response to user actions with dynamically updated content from the sandbox server, making them come alive with interactivity and adaptability. In a GUI, the visuals displayed in the user interface convey information relevant to the user and actions they can take. Users can usually interact with GUI elements by tapping a touch screen.

2) Business Layer: The layer is responsible for processing and managing the data received from the user interface. It handles the logic and rules of the application, ensuring that data is validated and processed correctly. Additionally, the business layer communicates with the data layer to retrieve and update information from databases. This layer plays a crucial

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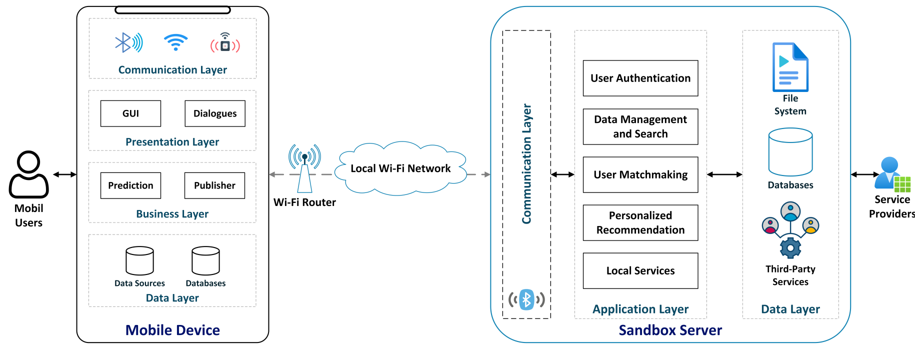

Figure 1. An architectural overview of the communication among a mobile device, a sandbox server, and service providers via a local Wi-Fi network

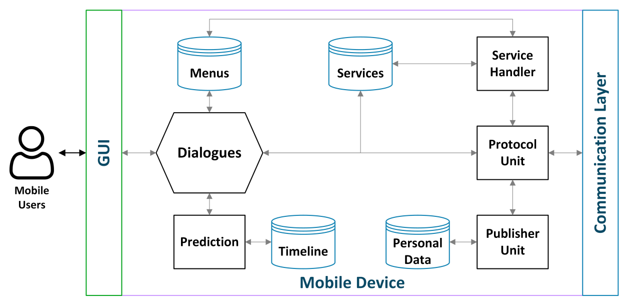

Figure 2. A data flow diagram of a mobile device

role in ensuring that the application functions properly and delivers the desired functionality to mobile users.

a) Service Handler: This is an instance that is responsible for downloading and uploading services and menus from local databases on a sandbox server. This instance ensures that the downloaded services and information are up-to-date by regularly checking for updates on the sandbox server. It also handles any errors or issues that may happen during the downloading or uploading process to ensure a smooth and uninterrupted flow of data.

b) Prediction Unit: The process attempts to automatically predict what a mobile user is doing next by learning sequential patterns from their local timeline or calendar. This is done using the Markov chain technique, which is a probabilistic model that has low computational resource requirements and can rapidly adapt to changing user behavior. This helps to optimize the overall efficiency and effectiveness of mobile applications and services. Additionally, it can be used to determine the possible next place or environment, which can help mobile users make better decisions on a daily basis.

c) Publisher Unit: This is responsible for automatically constructing a research-related profile with details that highlight their work, interests, and achievements from public academic databases. This profiling also includes extracting key information, such as authors, affiliations, abstracts, and keywords. This unit could be web crawlers or Application Programming Interfaces (APIs) to harvest the bibliographic data of a mobile user and store it in the personal database for further processing and analysis. It can then extract and share the required information with a sandbox server. For example, suppose mobile users have access to a conference. Then the publisher unit automatically shares their data and makes it accessible to the public on a sandbox server to make the conference location visible to other users.

d) Protocol Unit: This unit contains several custom protocols that are designed and implemented for particular applications or services to fit their specific needs. It is a set of rules, syntax, commands, and conventions that govern how different components within the application or service communicate and exchange information with each other.

3) Data Layer: This layer is responsible for storing and retrieving data from databases. It provides the necessary functionality for the business layer to access and manipulate data. This layer contains the following databases:

a) Personal Data: This database stores personal data that specifically identifies an individual mobile user, such as name, age, gender, education, contact details, expertise, biographies, and any other relevant data required for identification purposes. Additionally, it may include user preferences and settings to enhance the personalized recommendations.

b) Timeline Data: This database stores data related to the activities and interactions of mobile users, such as their browsing history, app usage, search queries, and social media interactions. This data is used to analyze user behavior, make personalized recommendations, provide next-item recommendations, and improve the overall user experience.

4) Communication Layer: This layer facilitates the secure exchange of data between a mobile device and a sandbox server. It acts as the first interface to manage the network connectivity of the mobile device, including incoming requests, validate them, and forward them to the appropriate components for processing, which enables a mobile user to directly and safely access information and services on the sandbox server through a local area network. There are a variety of communication technologies that enable a mobile device to establish connections with other devices or servers.

a) Bluetooth: Bluetooth is a short-range wireless transmission technology that is used for exchanging data between two different Bluetooth devices within a short distance using radio waves to communicate wirelessly. This Bluetooth technology is utilized for detecting the location information

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of mobile users, whether they are in radio coverage or not, and communicating with a sandbox server to request a Wi-Fi password before gaining access to resources or services on a local Wi-Fi network.

b) Wi-Fi: Wi-Fi is a wireless networking technology that allows mobile devices held by users to connect to a sandbox server. A Wi-Fi router assigns local IP addresses to connected devices, allowing them to communicate and exchange data with one another on a local Wi-Fi network. In addition, it uses the radio signal that the Wi-Fi router transmits to detect and identify the position and movements of a mobile user.

B. A Sandbox Server

A sandbox server, also referred to as a local server, runs on the backend system as a server-side component. It can be a physical or virtual machine operating on a powerful computer connected to a local area network within a specific environment. The sandbox server is responsible for receiving requests from mobile users. It processes these requests and returns the corresponding responses. A data flow diagram of a sandbox server is illustrated in Figure 3.

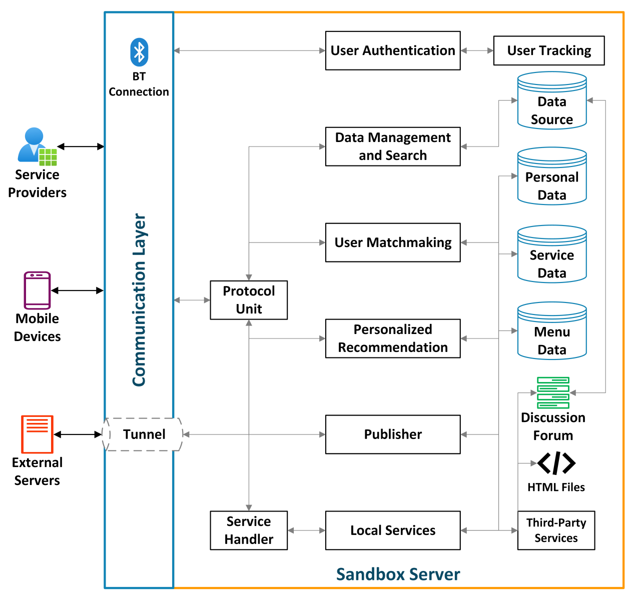

Figure 3. A data flow diagram of a sandbox server

A mobile device held by a user can request any services and information offered by a sandbox server and service providers. The sandbox server also creates a dynamic ecosystem where the service providers can continuously enhance and expand the range of information and services available on mobile devices. In addition, this sandbox server offers a direct connection to other local servers via a tunneling network, so that data transmitted across this network is encrypted and encapsulated within a secure communication channel. Overall, a sandbox server contains three fundamental layers:

1) Application Layer: This layer runs on a sandbox server that manages the logic and functionality of the proposed architecture. It processes user requests, performs necessary calculations or operations, and communicates with the data layer to retrieve or store information. Additionally, it handles user authentication and security measures to protect sensitive information. This layer facilitates the integration of local services, personalized recommendation services, and APIs, allowing for additional functionality and features to be incorporated into the proposed architecture. This application layer also communicates with the presentation layer to receive user input and deliver appropriate responses.

a) User Authentication: This is a security process to verify the identity of a mobile user attempting to access a local Wi-Fi network that prevents unauthorized users from accessing sensitive information. This can be accomplished through Wi-Fi authentication based on their presence or proximity. The proximity-based Wi-Fi authentication uses location-based BLE technology, enabling mobile users to authenticate using their mobile devices via Bluetooth connection. This means that it uses the distance between a mobile device and a sandbox server as a key measurement to verify the identity and determine that the mobile user is in close proximity to the sandbox server on a trusted mobile device. A mobile user needs to make a registration or check in by providing a phone number via Bluetooth connection to receive a Wi-Fi password according to the registered mobile phone via a Short Message Service (SMS). It makes sure that mobile users who access the local Wi-Fi network are authorized by the owner of the phone. By implementing this authentication process, the local Wi-Fi network can prevent unauthorized access and maintain a secure environment for its users. Additionally, this method allows the owner of the phone to have control over who can access their network, ensuring that only trusted individuals are granted access.

b) Data Management and Search: This offers efficient data management and search capabilities. Mobile users can easily find specific files or information from a database or data storage system when needed. Meanwhile, a sandbox server can manage and store their data.

c) User Matchmaking: The main objective of this application service is to produce a list of potential friends with similar interests, ranked according to a similarity score based on their personal information. The matchmaking algorithm compares a user profile with other profiles using a text similarity technique and suggests a suitable list of similar users. User interests, expertise, and biographies are combined to improve the accuracy of recommending similar users. The text similarity technique measures the similarity score between two pieces of personal information based on lexical and semantic similarity, covering both word level and context level using Natural Language Processing (NLP) techniques, word embeddings, and cosine similarity. Each user profile is cleaned up and transformed from unstructured textual data into an appreciable format. A word embedding technique encodes and converts textual data into a numeric format as a vector representation. Two vectors are compared using cosine similarity to extract semantically similar text from user profiles and return a similarity score.

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d) Personalized Recommendation: This is personalized features that suggest relevant information or services based on the current situations and preferences of mobile users. The main task is to provide tailored recommendations, including related items and friends. By offering personalized suggestions, recommendation services aim to improve user satisfaction and engagement with the mobile application. The recommendation services utilize NLP and Machine Learning (ML) techniques to analyze and understand the contextual data of mobile users and generate accurate recommendations. They take into account factors, such as user preferences, browsing history, location history, purchase patterns, and social connections to deliver highly relevant suggestions.

e) Publisher Unit: This unit is responsible for managing scholarly profile information from mobile users so that they can share it with other individuals. In this way, they can increase the impact of their research by, for example, gaining opportunities to create connections, associations, and interactions with others.

f) Local Services: These services provide adaptation information and services to mobile users depending on their current location. This is responsible for hosting the services offered to be downloaded from mobile devices. Mobile users can move to a specific environment to get more services and information relating to the environment. It consists of two main categories: (1) standard services and (2) additional services. The standard services are a set of basic requirements that interact with users in order to meet their expectations of mobile users. Ideally, the standard services include discussion forums, chat, local web pages, announcements, games or puzzles, advertisements, campaigns, promotions, and useful information defined by service providers. The discussion forum enables users to write and share content and images with their community in real time. The additional services are specific services offered to mobile users according to their profiles or historical behaviors. These additional services can include alternative features by integrating with third-party applications. A local service can be conceptualized as a local navigational workflow comprising a series of sequential processes defining how a service flows or moves from one state to another to accomplish a task or make a decision within a given environment. A local workflow consists of a series of processes that need to be accomplished to complete a task step-by-step, from initiation to completion. It is also useful for users to understand their particular roles in a specific environment by visualizing the processes involved in a service. This means that a local workflow serves as a user guide, enabling smooth navigation through the processes of each service. Consequently, a well-defined local workflow reduces user effort, enhances user satisfaction, and supports service providers in achieving long-term loyalty.

2) Data Layer: This layer stores and manages all relevant information exchanged between a sandbox server and mobile devices. This includes user profiles, preferences, and any other data necessary for the functioning of the proposed architecture. This data layer ensures that the information is securely stored and can be accessed by the sandbox server when needed for processing user requests.

3) Communication Layer: This layer handles incoming requests from mobile users and manages the transmission of data between a sandbox server and mobile devices, ensuring that data is returned to mobile users in a timely manner. It provides secure and efficient communication via a local Wi-Fi network by implementing protocols that ensure all communications are encrypted, protected from unauthorized access, and properly protected during transmission. These protocols include Hypertext Transfer Protocol (HTTP), Hypertext Transfer Protocol Secure (HTTPS), and WebSocket, which are utilized to send requests from the mobile user to the sandbox server and responses from the sandbox server to the mobile user. The WebSocket protocol especially provides a powerful, persistent connection for establishing bidirectional, real-time, and event-based communication channels between a mobile user, typically a web browser, and a sandbox server using WebSockets over a single Transmission Control Protocol (TCP) connection. It allows for frequent data updates and instant interaction. With this connection, the sandbox server can push data to the mobile user in real time while simultaneously receiving data from the mobile user. It eliminates the need for continuous polling or long-polling techniques commonly used in traditional HTTP-based communication. As a result, it significantly achieves scalability by reducing the overhead of HTTP requests and responses, facilitating low-latency data transfer, and improving the efficiency and speed of data transmission. This capability is particularly beneficial for applications that require real-time updates, such as chat applications, notification platforms, and multiplayer games. Additionally, it facilitates real-time synchronization of data between the mobile device and the sandbox server, ensuring that both systems stay updated with the latest information.

The sandbox server provides access over a local Wi-Fi network, allowing mobile users to interact with the application services from a specific area. This can help reduce the spread of misinformation and disinformation, as mobile users can access credible and relevant information specific to their locations and contexts.

In a typical scenario, when a mobile user comes within range of a sandbox server environment, the mobile user needs to authenticate before allowing them to establish the connection through a local Wi-Fi network. The mobile user initially verifies their identity by checking in to the sandbox server within the targeted environment using Bluetooth proximity to receive a Wi-Fi password directly sent to the registered mobile number via SMS. The mobile user then enters the received password to gain access to the resources and services through the local Wi-Fi network. The mobile user can set up profiles with some basic information that allows the sandbox server to provide them with more personalized recommendations and information. Once the mobile user has completed their profile settings, the sandbox server interacts with the mobile user by offering standard services. These standard services enable the mobile user to obtain useful information and communicate with others who share their interests, questions, and discussions. The mobile user can also access additional services. Then, specific services, personalization recommendations, and information will be integrated based on their profile and current situation in the form of user interfaces and dialogues. The mobile user utilizes a local workflow, which displays the navigational paths the mobile user takes in the environment from their entry point through a set of processes to reach a successful outcome or final interaction. In the situation where a new mobile user lacks historical and personal data, the proposed architecture initially suggests related information and services based on the current community, such as recently viewed items, frequently purchased items, best sellers, trending items, most viewed items, popular items, and featured items. When mobile users exist in the environment, their personal and behavioral data are automatically recorded since they started interacting in the recent environment. These data are saved as a daily schedule in a highly secure database in order to protect user privacy while working on the proposed architecture. It can also help the proposed architecture deeply understand the habits and preferences of mobile users and accurately tailor more personalized information and recommendations to them.

IV. Experiments

In this section, a series of experiments are conducted to validate the robustness and effectiveness of the proposed architecture, ensure that it can support the expected number of concurrent users, and work smoothly in real-world environments. In general, the experiments conducted aim to answer the following Research Questions (RQs):

- **RQ1**: Can the web pages hosted on a sandbox server handle a large number of concurrent users?
- **RQ2**: What maximum user load can web pages handle before the response time exceeds an acceptable threshold?
- **RQ3**: Can the APIs hosted on a sandbox server support a certain number of requests per second?
- **RQ4**: What is the maximum request rate that APIs can handle before the response time exceeds an acceptable threshold?

The detailed experimental procedures are shown in the following subsections:

A. *Experimental Strategies*

The experimental strategies aim to create a realistic simulation of user behavior under various load conditions, divided into two categories: (1) Web page load testing and (2) API load testing. The following strategies are explained below.

1) Web Page Load Testing: This strategy involves testing the load and performance of individual web pages under various scenarios to ensure smooth flow and an optimal user experience. The experiment simulates multiple users accessing web pages simultaneously and measuring various factors, such as server response time, concurrent user capacity, and page load time. The goal is to ensure that web pages can handle high traffic and load without any failures, because web pages that are slow to load or fail under heavy traffic can lead to a poor user experience and the loss of users or customers.

2) API Load Testing: This strategy involves sending a high volume of requests to the API endpoint concurrently to evaluate the scalability and reliability of APIs used in a web application. In contrast, instead of simulating user interactions with a website, API load testing works by sending requests directly to an API and measuring how it performs. API load testing is important for applications that rely heavily on APIs, such as microservice architectures, mobile applications, and modern web applications. The main objective is to examine its ability to handle concurrent users, analyzing response times and latency under different network conditions that could impact the functionalities and user experience.

Overall, the mentioned strategies are used to assess the performance of the proposed architecture under various conditions, such as different user loads, and network speeds. This can assist in identifying any performance issues for the purpose of overall improvement.

B. *Experimental Settings*

To show that the proposed architecture is proofed and achieved, all experiments were conducted on a Personal Computer (PC) with an Intel (R) Core (TM) i5-4570 CPU at 3.20 GHz and 8 GB of RAM as a sandbox server placed in an independent environment. The Xiaomi Redmi Note 11 Pro, based on the Android 11 operating system, was used as a mobile device in all of the experimental testing. Apache JMeter version 5.6.1 was used to simulate various realistic scenarios and implement load testing solutions. Nginx version 1.23.3 was set up as a web server to serve dynamic web pages and web applications written in Python and Java. The backend data was stored in MySQL Server version 8.0.31, which was running on an Ubuntu 22.04 LTS Linux server.

The proposed architecture was evaluated based on the two strategies mentioned above. In web page load testing, a test scenario was set up for evaluating the performance of web pages under the peak load of 500 virtual users. It simulated virtual users performing a complete action on two individual web pages that reflect different types of user interactions, including a landing page labeled as *WebPage1* and a contact page labeled as *WebPage2*, within 60 seconds. The ramp-up period was set to 10 seconds, meaning that the test would start with a few virtual users and increase gradually over 10 seconds until it reached 500 virtual users. In API load testing, a test scenario was created to identify the maximum load of APIs hosted on a sandbox server and potential bottleneck issues. It simulated 1,000 virtual users to execute different scenarios of APIs, including a topic recommendation API labeled as *API1* and a registration API labeled as *API2*, within 100 seconds. The ramp-up period was set to 5 seconds. In addition, the expected response time was less than 200 milliseconds for 95% of requests.

V. Experimental Results and Discussion

To test how well the proposed architecture works, the experiments were run on two main strategies. The results show

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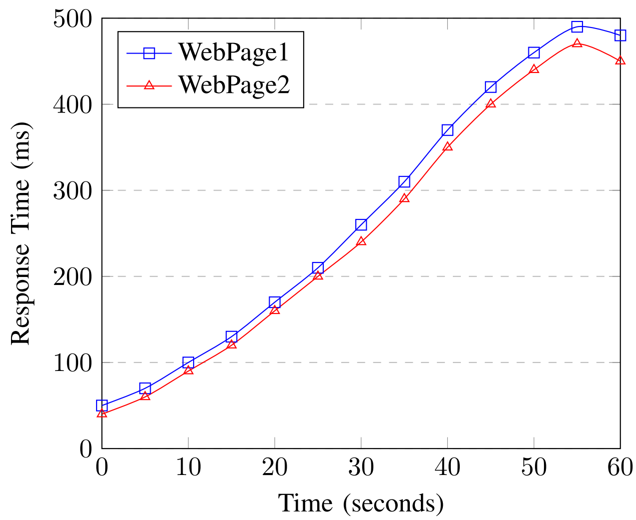

Figure 4. Web page load testing results

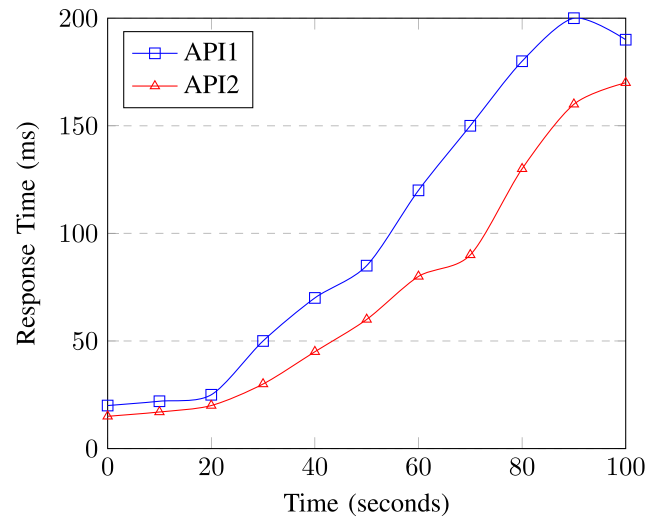

Figure 5. API load testing results

how effectively it works in different situations, indicating that it is good at optimizing performance.

A. The Results of Web Page Load Testing

The experimental results of the proposed architecture in terms of web page load testing were reported to address RQ1 and RQ2. The response time measurement was an important metric to assess the performance of both web pages.

Figure 4 demonstrated the graph representing the result of web page load testing over time. The response time values corresponded to different times ranging from 0 to 60 seconds. The blue line represented *WebPage1*, which started with a lower response time of 50 milliseconds at the beginning, but its response time dramatically increased, reaching a peak of around 490 milliseconds at 55 seconds. After this point, the response time slightly decreased to nearly 480 milliseconds at 60 seconds. On the other hand, the red line represented *WebPage2*, which had a response time of roughly 40 milliseconds at the start of the test. It reached a peak of approximately 470 milliseconds at 55 seconds. The response time then reduced slightly to about 450 milliseconds by the end of the test.

In comparison with the two web pages, *WebPage1* always had a slightly longer response time than *WebPage2* because it is the landing page, has a larger data size, and embeds more complex functionalities, images, videos, and audio content, causing it to respond slower under the same load conditions.

This graph indicated that the response times of both web pages increased as the number of concurrent users grew. Another point was that both web pages would be in trouble after about 30 seconds because their response times exceeded the acceptable threshold.

B. The Results of API Load Testing

The experimental results of the proposed architecture in terms of API load testing were reported to address RQ3 and RQ4. The response time measurement was a crucial metric for comparing the performance of the two APIs.

The graph in Figure 5 illustrates the result of API load testing, which was tested over a period of 100 seconds. The response time was in milliseconds, ranging from 0 to 200 milliseconds. Each point on a line represented the response times of APIs at a particular second of the test. The blue line represented the performance of *API1*, whose response time started at 20 milliseconds and gradually increased. There was a significant shift in the response time from 60 seconds to 90 seconds, with a peak at around 200 milliseconds before slightly dropping to 190 milliseconds at the end of the test. The red line represented the performance of *API2*, which started with a low response time of 15 milliseconds. The peak response time was around 170 milliseconds at 100 seconds.

According to these results, *API2* outperformed *API1* under load because *API1* was a recommendation engine, which ran more complicated algorithms and processes than the algorithm of *API2*.

From the graph, it could be observed that the response time gradually increased as the number of concurrent users grew. Moreover, both APIs achieved a good response time because it was under 200 milliseconds.

In summary, the proposed architecture achieved remarkable performance for web pages and APIs. It could be deployed in a production environment because it can satisfactorily maintain several factors at acceptable levels, including reliability, scalability, robustness, and efficiency. Additionally, the response time of both web pages and APIs remained consistently below the desirable threshold of 200 milliseconds, ensuring a positive user experience. This could involve optimizing the backend, such as improving database queries, increasing server resources, using connection pooling to leverage load balancing techniques, or deploying on cloud platforms, and the frontend, such as minimizing JavaScript or optimizing images.

VI. A USE CASE

In this section, an example of a local conference scenario located in a specific area is considered to describe the storytelling and planning processes of the proposed architecture. For instance, imagine that hundreds of participants enter a conference room and also open a mobile application connected to a local Wi-Fi network. They will receive necessary services, information, and recommendations in real time, such as a list of participants with profiles, scheduled programs, presentations, documents, videos, and any other relevant material, which will be reflected immediately in the mobile application for participants who are granted access to the network. These services and information generated by a local sandbox server are sent proactively and reactively as instant notifications when participants enter the conference room in proximity. Moreover, the mobile application can be customized to allow participants to collaborate with each other who are in the same geographical location, meet new friends, make comments, and share information while displaying relevant information, providing a personalized experience for each participant.

Finally, when participants enter the conference environment, they can explore all of the services and information they need. In addition, the full integration between a local sandbox server and a mobile application should be designed to create a comprehensive and engaging experience, making it easy for participants to seamlessly navigate through the conference digitally and identify what topics or items interest them the most.

VII. OPPORTUNITIES AND CHALLENGES

The proposed architecture has great potential for use in various smart environments within geographical areas, such as smart homes, innovative universities, smart cities, and smart industries. In the context of smart cities, it utilizes real-time data and location-based intelligence to create digital landscapes of urban infrastructure, in some cases resulting in a digital twin of a particular city. The proposed architecture is designed as a generic concept that could provide opportunities for full integration into smart cities, towns, or villages via a mobile application to enhance the quality of life for citizens and make their lives more efficient and convenient.

VIII. CONCLUSION

This paper proposes an intelligent, location-aware architecture for mobile computing environments. The main idea is to attempt to interact with individual mobile users by automatically offering suitable local services, information, and recommendations that meet their needs and expectations based on their current location and profile when mobile users appear in the vicinity of a sandbox server and keep track of their position, presence, and movement. It also deals with crucial aspects, including user privacy, data security, and scalability. According to the experimental results, the proposed architecture is smart, scalable, and reliable enough for practical deployment in various real-world environments.

Based on this research, future work will involve simulating the proposed architecture in real-world scenarios to examine its performance. This can help identify issues that might not appear in laboratory testing. Real mobile users will also assess the proposed architecture to gather feedback on usability, responsiveness, and the overall user experience. Future research could also investigate integrating emerging technologies, such as 5G networks and edge computing, to enhance the capabilities of intelligent location-aware platforms.

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