A Fuzzy Logic Based System for Geolocated Augmented Reality Field Service Support

Anasol Peña-Rios, Hani Hagras, Michael Gardner
The Intelligent Environments Research Group,
School of Computer Science and Electronic Engineering,
University of Essex, Wivenhoe Park,
Colchester, UK.

Gilbert Owusu
Business Modelling and Operational Transformation
Practice, British Telecom, Adastral Park, Martlesham
Heath, Ipswich, UK

Abstract— **In recent years, Augmented Reality (AR) started transitioning from an experimental technology to a more mature area, with new types of applications in entertainment, marketing, education, retail, transportation, manufacturing, construction, and other industries. One of the main challenges for AR-based field service tools is to help users to correctly locate company's assets and infrastructure in the field. This paper presents an AR system using private maps to find company's assets to support field workforce tasks. The AR system is based on fuzzy logic mechanisms to provide the user with directions for asset location by comparing his/her current position with assets' location in real-time. Auditory and visual feedback is provided via a head mounted display (HMD), enhancing user's perception to achieve human augmentation.**

Keywords—fuzzy logic system; augmented reality; field service

I. INTRODUCTION

Over the last years, the use of technology to improve and support everyday tasks has increased dramatically. Particularly, technologies that blur the lines between the digital and physical worlds have opened new opportunities for uses in the industrial sector. Augmented Reality (AR) tries to solve the challenge of physical/virtual world's exclusion from one another by adding computer-generated objects and combining them with physical elements in a shared environment to make them appear as if they co-exist in the same dimension [1]. The term was coined by Caudell and Mizell [2] in the early 1990s whilst developing a system to help field force at Boeing Corporation. In contrast, Virtual Reality (VR) refers to a highly-interactive computer-generated environment which creates a synthetic experience for the user, allowing him/her to have a sense of being present in an environment other than the one he/she is by substituting the primary sensory input with data produced by a computer [3]. The term was first used in 1986 by Jaron Lanier, the founder of VPL Corporation [4]. Therefore, VR replaces physical reality whereas AR supplements it with useful information that is not directly detected by user's senses, helping him/her to perform real-world tasks, and facilitating the understanding of complex scenarios [5].

Particularly, AR presents multiple possibilities for its inclusion in the workplace. Researchers and developers have used it in military [6] [7], industrial [8] [9] [10] [11], and medical [12] [13] [14] applications, showing how those areas could benefit from augmentation [15]. The Augmented Reality for Enterprise Alliance (AREA) identifies multiple use cases for industrial AR-based applications in areas such as product design, manufacturing, assembly, training, marketing and sales, field service, warehouse picking, work order and assets repair, remote visualization and inspection among others [16]. Similarly, other initiatives have started exploring different aspects of AR technology. For example, the IEEE Augmented Reality in the Oil/Gas/Electric Industry Group is exploring how AR applications might benefit these three fields using head-mounted and heads-up displays [17].

Specifically, the use of AR-assisted field service tools and applications have the potential to support users in "accomplishing new or ongoing maintenance activities (corrective and preventive) of machinery and equipment by leveraging and augmenting key workflows, procedures and conceptual information selected from existing technical publication repositories, together with other corporate assets such as product information" [16]. Some of the challenges for using AR for industry-related applications include the lack of technical standards, due to inexistent collaboration among companies developing those technologies; and the difficulty to generate meaningful content [18].

AR-based field service applications face two main difficulties: a) provide information to move the user to the correct location; and b) provide information to allow the user to perform the task correctly. In this paper, we focus on positioning the user in the correct location to do his/her allocated work.

Currently, there are numerous examples of geo-located AR applications for cultural heritage [19] [20], and entertainment [21] [22]; which rely on data from public maps (e.g. Google Maps, OpenStreetMap, Leaflet, etc.) and public locations. However, for industry-oriented solutions, it is necessary to consider private maps which hold company's infrastructure data and assets' locations. This paper presents a fuzzy logic-based approach to provide an engineer with directions to locate company's assets in real-time based on a private maps data.

The rest of the paper is structured as follows: section II presents related work and describes outdoor tracking mechanisms. Section III describes our proposed model using fuzzy logic and AR for field service support. Additionally, this section explains the architecture and implementation of the

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system. Section IV describes the experiments and results while the conclusions and future work are presented in Section V.

II. RELATED WORK

Augmented Reality (AR) blends computer-generated objects by superimposing them on what the person sees in the real world. For industrial applications, AR has been used to help maintenance personnel and field service technicians with complex machinery or structures which require a specific set of skills and knowledge. For example, it can assist technicians with assets' history and repair information [23], or guide them in a particular task [24]; providing with "x-ray vision" to show machinery elements [23], or to point out users' attention to problem sites [25]. Additionally, it can support remote expert interaction and feedback with integrated video conferencing and collaboration tools. Some of the benefits for AR industrial applications include [16]:

a) Rapid and consistent access by all field service professionals to current records, instructions or policies.

b) Reduced risk of delays in field service due to lack of familiarity with new or old products.

c) Reduced risk of errors in field service

Azuma [5] identified the three main technologies involved which are: a) interaction technologies, which allow the user to manipulate virtual elements in real-time; b) display technologies, which combines real world elements with computer-generated objects and information, superimposing them on user's field of view (FOV); and c) tracking technologies, which allow positioning and tracking of users and virtual objects.

Tracking is one of the most important functionalities in AR as its accuracy makes possible the illusion of a true blend between virtual elements and the real world. For example, in a see-through AR display it is very easy for the human eye to perceive any mismatch between real objects and virtual graphics, breaking the illusion of co-existence [26]. AR tracking has moved from simple marker based systems, to natural feature tracking, and hybrid sensor based methods [26].

For outdoor AR tracking, Global Positioning System (GPS) hardware can be used to provide accurate location over a wide area. The GPS is a global navigation system based on satellite information, owned and maintained by the United States government; and accessible to anyone with a GPS receiver. It consists of three segments: the space segment formed by 24 satellites transmitting one-way signals that give the GPS receiver satellite position and time; the control segment, which monitors and control and maintain the satellites; and the user segment, which consists of GPS receivers which uses the transmitted information to calculate the user's three-dimensional position and time [27].

GPS hardware can be used for position sensing, but consumer grade GPS in mobile devices typically provides an average accuracy of 5 to 10 meters depending on satellite signal strength [26]. According to the U.S government GPS accuracy depends on multiple factors, including atmospheric effects, sky blockage, and receiver quality [27]. However, higher accuracy is attainable by using GPS in combination with augmentation systems [21].

III. THE PROPOSED FUZZY LOGIC BASED SYSTEM FOR AUGMENTED REALITY FIELD SERVICE SUPPORT

To deal with uncertainty generated by sensors and human error, we propose an intelligent agent based on a Fuzzy Logic System (FLS) to provide field service engineers with directions to reach specific assets based on private maps. Fuzzy logic systems attempt to mimic human thinking; performing well despite the uncertainty, noise, and imprecision attributed to real-world settings; and playing an important role in modelling and representing imprecise and uncertain linguistic human concepts [28]. Approaches using intelligent agents to model user's behaviours based on the output of FLCs have been used in different scenarios to learn and track human behaviour [29], [30], [31].

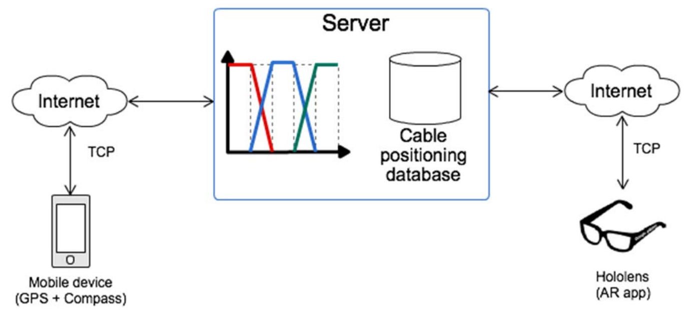


Fig. 1. Augmented Reality Assistance System – Conceptual Model.

Fig. 1 illustrates the conceptual model of the proposed system. In the proposed system, a mobile device captures location and orientation of the engineer, based on GPS and compass sensor information from a mobile phone. User's latitude and longitude is captured in decimal degrees (DD), which express latitude and longitude geographic coordinates as decimal fractions. This information is sent to the server, in which a software agent obtains the DD coordinates of the selected asset from the main database, and calculates the difference between engineer's position and asset's position. The difference is then used as input of the fuzzy logic system which provides two outputs: direction and movement. After that, the agent process the outputs to provide the user with human-understandable instructions to locate the asset. Finally, the instructions are sent to the head-mounted display (HDM) where the engineer can hear them using text to voice functionality, and visualise the asset location once it has arrived at the goal location.

For AR-assisted field service applications, display options such as HMD that free up operators to use their hands, provide an extra advantage to increase efficiency. Smart glasses are a combination of wearable devices and AR technologies [32]. Currently, the use of smart glasses is limited to some technical factors, such as battery duration, limited field of vision, and lack of ubiquitous high high-speed internet connection. However, the IEEE Smart Glasses Roadmap Group [33] is working to promote and facilitate the adoption of smart glasses in several markets and applications, and it is likely that further developments in technology will address these barriers.

It is worth noting that virtual reality glasses, such as Oculus Rift[1] or HTC Vive[2], are different from AR smart glasses such as Microsoft HoloLens[3] or Meta 2 glasses[4]. Whereas VR devices are completely closed off from the real world, presenting a synthetic 3D virtual world; AR glasses overlays digital content onto the real world. The advantages of AR smart glasses are [32]: a) only relevant information is displayed; b) information is automatically available when needed, and can be enriched with additional online information, if desired; and c) in contrast to other mobile AR devices, smart glasses can be used hands-free, offering workers greater flexibility.

A. The system Implementation

The system was implemented using Microsoft's HoloLens (depicted in Fig. 2), an AR headset which uses see-through holographic lenses in a 2 HD 16:9 light engines with a resolution of 2.3M total light points; and holographic density of >2.5k radians (light points per radian) [20]. Moreover, the HoloLens are a full untethered wearable computer running Windows 10 with 64GB Flash, 2GB RAM, an Intel 32 bit architecture with TPM 2.0 support processor plus a custom-built Microsoft Holographic Processing Unit (HPU 1.0) [34]. Additionally, the HoloLens have 1 Inertial Measurement Unit (IMU) sensor, 4 environment understanding cameras, 1 depth camera, 1 2MP photo / HD video camera, 4 microphones and 1 ambient light sensor [34].

Fig. 2. Microsoft HoloLens.

Although the HoloLens include indoor positioning sensors, they lack of outdoor positioning devices such as GPS. Thus, for our experiment, we used values from navigation sensors in a mobile phone. To do so, we created a mobile app using Microsoft Visual Studio 2015 and Unity 3D[5], a cross-platform game engine for creating interactive 3D content. This mobile app sends real-time values to the server, which calculates the difference between user's current location and goal (asset) location, providing them as input for the fuzzy logic-based location system.

The mobile app was deployed in a Microsoft Lumia 640 XL LTE mobile phone, with a quad core 1200 MHz Qualcomm Snapdragon 400 processor, 8 GB of internal memory, 1 GB RAM, magnetometer and GPS, running on Windows 10 operating system [35].

A second application was developed for the HoloLens to show the result of the fuzzy logic system using AR feedback (auditory and visual). Synchronisation between devices was achieved using SmartFox Server[6], a middleware application to create large scale multiplayer games, massively multiplayer online games (MMO) and virtual communities.

A well-known issue of HMDs for outdoor applications relates to visual clarity and the difficulty to see displayed graphics in daylight. HMDs outdoor evaluation studies, have shown that text and colours could appear altered or washed out on the displays, thus, augmented elements should be 10-15% brighter than the background to be visible on a stereoscopic display [36] [37]. Hence, we incremented brightness of virtual elements in this rate to allow users see augmented content.

B. The Fuzzy Logic System Design

The prototype implementation provides instructions to locate an asset using a Fuzzy Logic System (FLS). Here, the fuzzifier receives the difference between user location (taken from the GPS) and asset location (taken from the database) as crisp numerical values; and maps those values into fuzzy sets to activate rules defined in linguistic terms. Hence the inputs to the FLS are the Δ *Longitude* and Δ *Latitude* which are defined as follows:

$$\Delta\, longitude = long_{asset} - long_{user} \tag{1}$$

$$\Delta\, latitude = lat_{asset} - lat_{user} \tag{2}$$

$long_{asset}$ and lat_{asset} represent the asset longitude and latitude respectively where the $long_{user}$ and lat_{user} represent the user longitude and latitude respectively. The rule-base (shown in Table 1) consists of 9 rules. Rules have two consequents: direction, which refers to user's heading; and movement, which indicates if the user should move or not. The fuzzy sets membership functions (MF) were designed using expert knowledge. In particular, MF for direction, which had a specific universe of discourse (U) of 360°, was designed dividing the Compass Rose (shown in Fig. 3) in 90° for each cardinal direction (N, E, S, W) using 45° to the right and 45° to the left to its exact location.

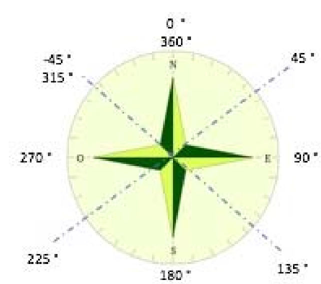


Fig. 3. The Compass Rose.

1 Oculus Rift - https://www3.oculus.com/en-us/rift/

2 HTC Vive - https://www.vive.com/uk/

3 Microsoft Hololens - https://www.microsoft.com/microsoft-hololens/en-gb

4 Meta - https://www.metavision.com

5 Unity 3D – www.unity3d.com

6 SmartFox Server – www.smartfoxserver.com

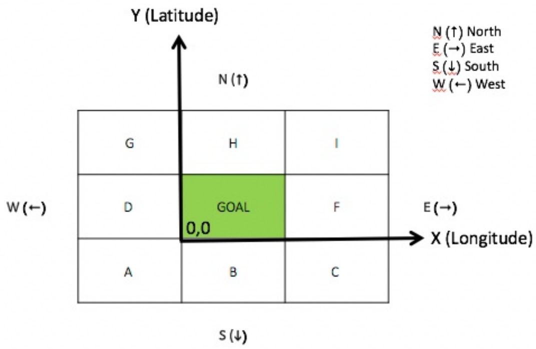


Fig. 4. Positioning diagram.

To create the rule-base in table 1, we used the positioning diagram in Fig. 4 where, we assumed the asset is in coordinates (0,0). Based on this, we evaluated the surrounding positions. For example, if the engineer is in position B (which corresponds to X equal to zero and Y within the negative domain), then to reach the goal, the user should head to the '*North'* and '*Move further'*. North direction is considered as the default value, thus, if the user has reached GOAL position (X = Zero and Y = Zero) output for movement variable will be '*Stay*' and direction variable will equal to '*North*'.

TABLE I. POSITIONING RULE BASE

Code in Positioning Diagram	***Antecedents***		***Consequents***	
	Δ Longitude (X)	***Δ Latitude (Y)***	***Direction***	***Movement***
A	Negative	Negative	North	Go Further
D	Negative	Zero	East	Go Further
G	Negative	Positive	East	Go Further
B	Zero	Negative	North	Go Further
GOAL	Zero	Zero	North	Stay
H	Zero	Positive	South	Go Further
C	Positive	Negative	West	Go Further
F	Positive	Zero	West	Go Further
I	Positive	Positive	South	Go Further

The antecedents and consequents fuzzy membership functions are shown in Fig.5. Using the product t-norm to represent the AND logical connective, the system calculates the firing strengths of each rule to decide whether a rule will be fired in response to a specific input. When the inference engine returns a result, this result is converted by the defuzzifier into a crisp number; using height defuzzification. This result is the expected next movement and direction to be done by the user, however, since this would be difficult to interpret by a human, an additional post-processing step is used to give human-understandable directions using linguistic terms.

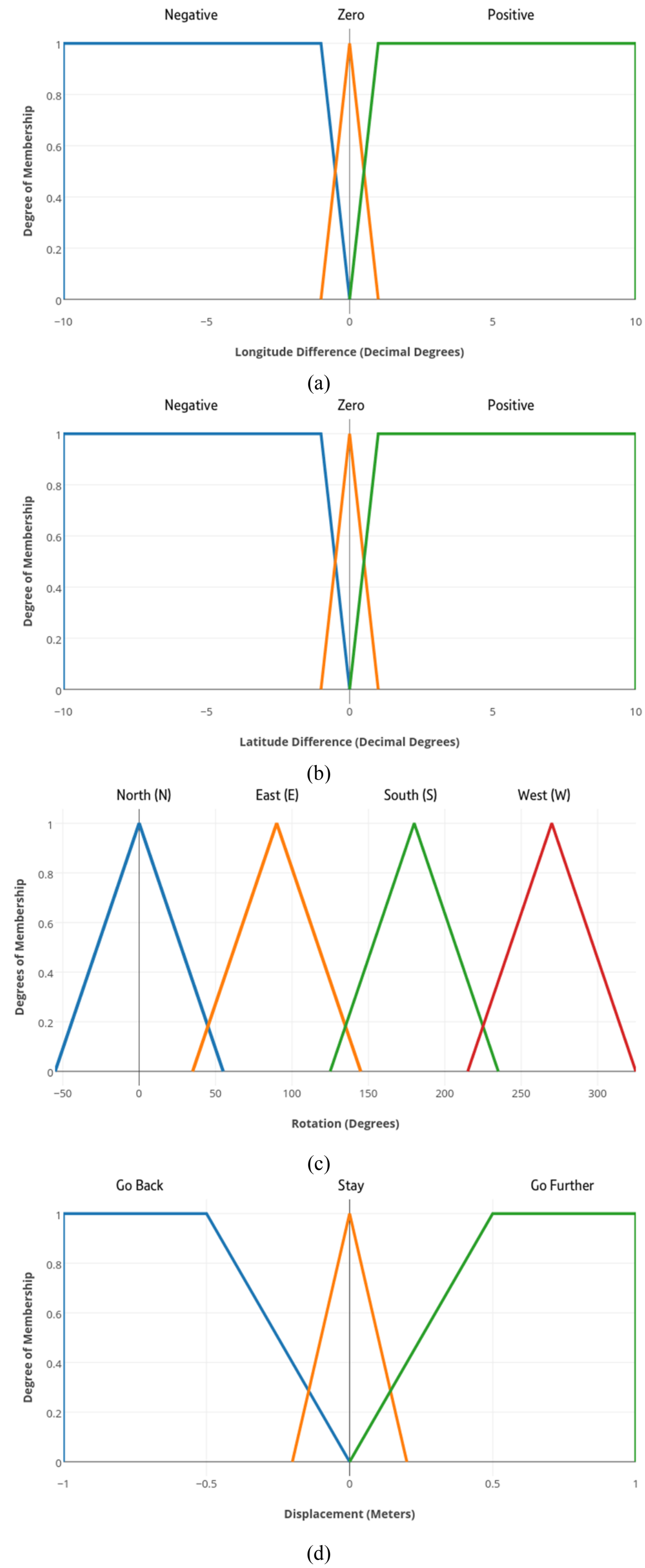


Fig. 5. Membership functions for assets' geo-location system. Antecedents: a) ΔLongitude. b) ΔLatitude. Consequents: c) Direction consquent d) Movement consquent

For direction, we compare the previous value with the new one obtained from the FLS, to generate user instructions per rules on Table II. For example, if the previous direction value was 'North' and the new value is 'South', instead of asking the user to walk backwards (which is unsafe and unnatural), the system suggests to 'Go Further' by 'Making a U-Turn'; assuming the natural way of human walking, in which the user always faces the direction where he/she is going.

TABLE II. POST-PROCESSING OUTPUT

Condition	***Human-understandable direction***
If previous heading is the same as new heading	Keep Heading
If previous heading is directly opposite as new heading	Make a U-Turn
If previous heading is next on the left side of the new heading	Turn Right
If previous heading is next on the right side of the new heading	Turn Left

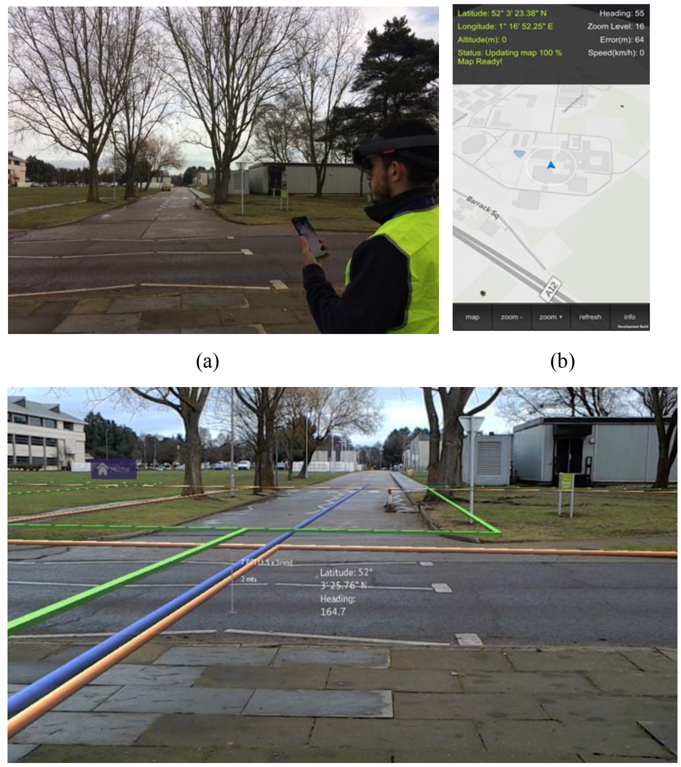
IV. EXPERIMENTS AND RESULTS

We carried out 110 path explorations in an area of ≈ 5000 m^2; locating the asset (underground cables in our case) in coordinates (1.283149, 52.057338) with a default compass heading of 0.0° (as shown in Fig. 6).

The mobile's phone 4G connection was tethered with the HoloLens to achieve connectivity with the server. The fuzzy system obtained the difference between engineer's and asset's position in real-time and provided feedback to the HoloLens in the form of auditory instructions for the engineer. We started the experiments locating the engineer in an initial coordinate, where after getting feedback from the system, he moved following the given instructions. The system was continually updated as soon as it detected that the current engineer's location was different from the previous one registered by the system. Fig. 7a shows the system inaction, while Fig.7b shows the engineer position which was taken from the mobile app. Fig. 7c shows engineer's view from the HoloLens for the located assets (underground cables).

Fig. 6. Experimental scenario. An Asset position.

The system worked efficiently achieving a RMSE of 3.26635E-05 DD for Asset longitude vs Engineer's final longitude as well as RMSE of 3.14543E-05 DD for Asset latitude vs Engineer's final latitude.



(a) (b)

(c)

Fig. 7. Experimental scenario. a) Field engineer. b) Mobile app. c) View from HoloLens.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed an innovative augmented reality system combined with fuzzy logic mechanisms to create a system able to direct engineers and technicians to an asset's location, targeting one of the current issues for AR field force applications. The proposed system showed a RMSE of ≈ 3E-05 with respect to a specific asset location longitude and latitude.

Our system introduces an option to assist technicians and engineers working on installation and repair of specialised equipment, particularly with underground or difficult to access equipment and installations; fostering faster responses with the aim of improving customer service. Similarly, the system could be used as part of engineers' training, to locate and understand topology of network installations.

Additionally, we tested our system with Microsoft's HoloLens to enhance users' feeling of immersion, and providing interaction with the overall platform via a hands-free interface. Although, the field of vision that head units can provide is significantly less than that of a human's field of vision (170 degrees) [38], user's feedback on the use of these devices has been positive.

For our future work, we will work towards the implementation of diverse automated assistance tasks, where the user could be guided by the AR application to achieve simple tasks. Similarly, we will continue developing visual tools for the expert to point specific areas or elements in the private maps where the user needs to focus to solve an issue.

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