# An Augmented Reality-based Software Architecture to Support Military Situational Awareness

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# An Augmented Reality-based software architecture to support Military Situational Awareness

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***Abstract*—Situational Awareness (SA) is the perception of our surrounding, comprehension of its meaning and projection of its status. The lack of SA is a causal factor in many military accidents. In this paper, Augmented Reality (AR) techniques are used to support SA and interaction in time-pressuring crisis situations. Firstly, existing military projects are reviewed. Then, the design of a military AR-based architecture as support to SA, called RAIOM (Augmented Reality for the identification of Military Objectives), is introduced and validated with real users considering traditional military scenarios. A distributed processing in a client-server architecture was implemented using an optical see-through AR glasses by the client side and a mini board by the server side. An AR application using the proposed AR architecture was deployed as an integrated proof of concept. The deployment was evaluated to measure the effectiveness, efficiency and usability of the AR software architecture in terms of three levels of SA such as perception, comprehension and projection. Different techniques were used in the evaluation such as User Testing, Thinking Aloud Protocol and SAGAT / SART. Also the User Experience (UX) was evaluated using UMUX questionnaire. The results were optimistic according to the degree of compliance of the SA got by the participants in the experiment***

***Keywords*—*situational awareness, augmented reality, software architecture, military environment***

## I. Introduction

Azuma, R [1] details that Augmented Reality (AR) allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it.

Endsley, M. R [2,3] said that Situational Awareness (SA) is the perception of the elements in the environment within a volume of time and space, the understanding of their meaning and the projection of their situation in the near future. The SA includes the loss or incomplete perception or change to elements present in the operational environment of the soldier. This factor may be related to an individual's limited perceptions of their operational environment. Some of these difficulties can be overcome by using a technology that can organize and show the information to the user automatically.

During the last years, several AR-based military projects were designed in order to improve SA as support to decision making in unknown environments.

In section 2 a review of military projects and the main elements that are implemented to support the SA are identified. It is also shown how the available AR-based frameworks provide some features that are not enough for SA in military projects. Section 3 describes the proposed AR-based framework, called RAIOM (Augmented Reality for the identification of Military Objectives), as support to SA in military projects. It is shown its design and evaluation of a concrete deployment. Section 4 shows results and discussion. Finally in section 5 some conclusions are summarized and several future works are proposed.

## II. Military AR-based Project and AR tools

### *A. The digital soldier*

Many research activities have explored new features using AR-based techniques. These features include, for example, the capacity of sending navigation and coordination information to the soldier using this technology.

In [4] the Future Soldiers (FS) concept was coined to identify the capabilities of a soldier on the battlefield. It is a concept of how the FS could be equipped. This warrior will be adapted to each technological area with special emphasis on cognitive performance to improve the efficiency of the soldier. There are seven main areas applicable to the soldier: Human Performance and Training; Protection; Lethality; Mobility and Logistics; Networks; Sensors; Power and energy. The FS program have focused their efforts on the research and development of electronic components applying the AR as a technology to visualize information of the environment where the combat occurs and in this way facilitate the decision making in hostile situations. Some examples of these military projects can be found in [5,6].

One of the main technologies to improve the SA of the soldier is sending of information through geographically dispersed sensors and then visualizing that information using AR techniques [7]. The present work takes as a technological base this mode of processing the contextual information to visualize it later using the AR.

### *B. Military AR-based projects*

In the scope of military AR-based frameworks, it is important to consider a set of elements that help to have an adequate SA. These elements are the following [5]:

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1. Terrain recognition: it is important to have a precise reference of the place of operations to increase the perception of the environment.
2. Infrastructure recognition: it is important to identify buildings and infrastructure in a hostile terrain either in order to use it as a location reference or to execute a specific mission.
3. Geographical environment recognition: it is important to obtain additional contextual information such as geographical references, artillery pieces, etc.
4. Threat alert using descriptive symbols: The soldier must understand the symbols of threats to determine the relevance degree of them.
5. Allied location: all the soldiers must know the position of the allied on the battlefield.
6. Path tracking: to check on a digital map the path done by the soldiers.
7. Communication: between the central command and the Chief of Patrol. The communication between the chain of command is part of the command and control tasks.
8. Information filtering: to filter the main information of the contextual environment.

According to the list of elements to have in account in military digital systems to improve the SA on the battlefield, we present a comparative table (Table I) of the SA elements of the main military projects detailed in [5].

TABLE I. CHARACTERISTICS OF MILITARY PROJECTS

| SA's element | Eyekon [9] | BARS [10] | iARM [11] | ULTRA-Vis [12] | RAIOM |
|---|---|---|---|---|---|
| Terrain operations recognition | X | X | X | X | X |
| Infrastructure recognition | | | X | X | X |
| Geographical environment. recognition | X | | X | X | X |
| Alert using descriptive symbols | X | | X | X | X |
| Allied location | | | X | X | X |
| Path tracking | | | | | X |
| Communication | | X | X | X | X |
| Information filtering | X | X | X | X | X |

Additionally, we can detail a list of technologies that must have the military projects to support the elements of the SA (Table II).

TABLE II. TECHNOLOGIES SUPPORTED IN MILITARY PROJECTS

| Technologies | Eyekon | BARS | iARM | ULTRA-Vis | RAIOM |
|---|---|---|---|---|---|
| AR visualization | X | | X | X | X |
| Lightweight devices | | | | | X |
| Distributed processing | | | | | X |
| Sensors (GPS, IMU, etc) | X | | X | X | X |
| Voice recognition | | X | X | X | X |
| Gesture recognition | | X | X | | X |
| Target recognition | | | X | X | X |
| Terrain recognition | | | | X | X |
| Collaborative communication | | X | X | X | X |
| Open Source software | | | | | X |
| Security | X | | | X | X |
| COTS | | X | X | | X |

One of the most advanced military projects is ULTRA-Vis [12]. Therefore, the Table II takes the main technological features and non-technological (i.e. Open Source software and COTS components) of this project and other additional features. We have added the RAIOM project in the last column of the both tables (Table I and Table II). RAIOM framework must provide all the elements and technological features to support the SA. In the following sections, we show the framework architecture and the software implementation that meets the main requirements to have an adequate SA.

### *C. AR tools*

It is important to mention that there is a great quantity of AR-based framework but they are not enough to cover the military functional requirements to improve the SA. However, we are going to detail some functional and non-functional features of the non-commercial frameworks in order to consider them when we design our own AR-based military framework. A set of technological functional criteria are identified as needed [8]:

1. 3D object
2. Image recognition
3. Geolocation
4. Markerless
5. Online recognition

For the sake of exposing the functional features in AR-based applications, we have selected and analyzed five tools (see Table III).

Furthermore, non-functional features must be also taken into account. A list of non-functional criteria in AR-based system are the following [13]:

1. Off-line availability
2. Easy to integrate
3. Easy to expand
4. Software license
5. Distributed processing

In the Table IV is shown the non-functional features.

TABLE III. FUNCTIONAL CHARACTERISTICS OF AR TOOLS

| Functional feature | ARToolKit | Vuforia | EasyAR | Layar | DroidAR |
|---|---|---|---|---|---|
| 3D Object | - | X | - | - | X |
| Image recognition | X | X | X | X | X |
| Geolocation | X | X | X | X | X |
| Markerless | - | X | - | - | - |
| Online recognition | - | X | - | X | - |

TABLE IV. NON FUNCTIONAL CHARACTERISTICS OF AR TOOLS

| Non-functional feature | ARToolKit | Vuforia | EasyAR | Layar | DroidAR |
|---|---|---|---|---|---|
| Offline availability | X | - | - | - | X |
| Easy to integrate | - | - | - | - | - |
| Easy to expand | X | - | - | - | X |
| Software license | Open Source | Commercial | Freeware | Freeware | Open Source |
| Distributed processing | - | - | - | - | - |

## III. RAIOM MILITARY AR SYSTEM

### *A. RAIOM design process*

The design of a military AR-based architecture as support to SA, called RAIOM (Augmented Reality for the identification of Military Objectives), is introduced and validated with real users considering traditional military scenarios. We use the 3D-SA Model [14] for identification, selection and classification of SA requirements together with the design of AR-based solutions. This 3D-SA Model facilitates the analysis, first, and the design later, of systems where the concept of SA is essential. The presented 3D-SA Model tries to facilitate the use and application of AR-based solutions for SA for different kinds of stakeholders as well as to cover a deficiency in the gap between SA requirements and SA design solutions. With the 3D-SA Model, we document, identify and classify the requirements of SA and we provide prototypes related to the stories of military personnel users who. They contribute to its realization at the level of analysis and its subsequent design. 3D-SA Model considers three main elements: SA phase, SA characteristics and interaction modality (Fig. 1). The first dimension, SA phase, includes the three SA levels by Endsley that are very useful in order to identify requirements in a troubled or confusing environment where the SA defined by Endsley [15]: perception of the elements in the environment, comprehension of the situation, and projection of future status. The second dimension, characteristic, includes ten questions grouped by "who", "what" and "where" proposed by Gutwin and Greenberg [16] to be answered to determine whether a component or tool gives adequate support to SA. Finally the third dimension, interaction modality, is related to the AR solution design including visual, auditory, haptic, somatosensory and olfactory interaction.

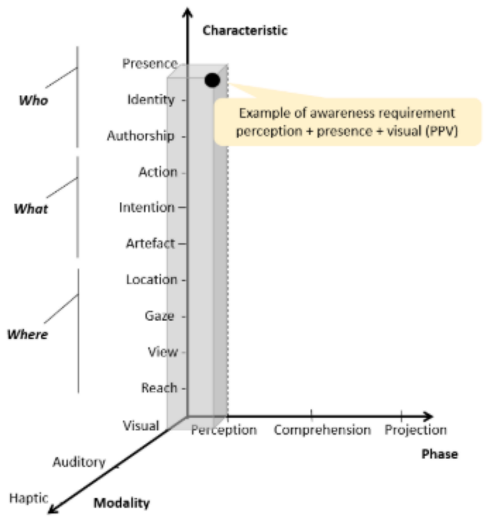



Fig. 1. 3D-SA Model [14], a model for the documentation of requeriments together with the design of AR-based solutions

The software development methodology used combines an agile method and User-Centered Design (UCD) techniques [17]. The interest in the integration of UCD and the agile approaches is growing [17]. SCRUM was chosen as an agile method in conjunction with the design principles provided by the UCD resulting in a combined methodology SCRUM-UCD [18-19]. UCD includes interviews with main users (military), identification of relevant tasks for users (considering the questions Who, What and Where), carrying out prototyping, evaluation and iteration activities. SCRUM includes iterative design, user participation, continuous testing and creation of prototypes.

## B. *RAIOM layer-based architecture*

The layer-based architecture is composed by Applications, Middleware and Operating System (Fig. 2). The Middleware -the software that is between the operating system and the applications that run on it- facilitates the technological integration [20, 21] and it is composed by the Modules layer and the Libraries layer.

The Modules layer is composed by components where each component communicates with each other offering services. The components that belong to Modules layer are as follow:

- Input: it allows data entering to the system by voice or gestural recognition.
- Location: it allows obtaining geo-referencing information from the device. Besides, it allows tracking the user using the device's sensors.
- Mapping: it allows loading maps to the system. It implements a SIG interface.
- Communication: it allows communication between devices by structured messaging.
- Visualization: it shows graphical representation of the military symbols in the Client side and it filters of priority information of withe contextual environment.
- Vision: it implements image processing, object recognition and tracking algorithms. Beside, part of the gestual recognition is computed in this module

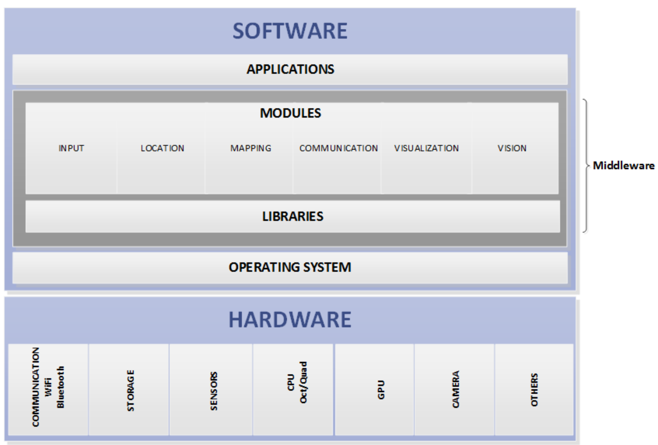



Fig. 2. RAIOM layer-based architecture

## C. *RAIOM client-server architecture*

First of all we compare the performance time of executing object recognition algorithm ORB with different devices. The ODROID-XU3 demonstrates a big advantage over the performance of smartphones, particularly Huawei G8 (Fig. 3)

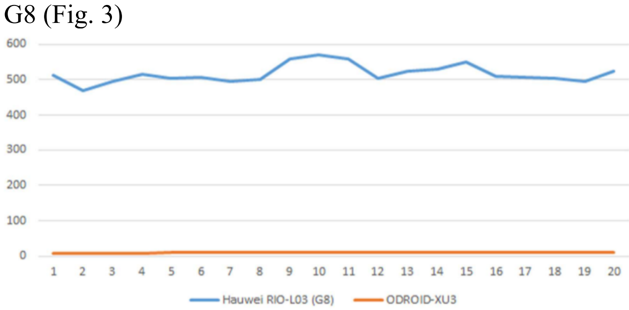



Fig. 3. Performance of Huawei G8 and ODROID-XU3 for Object Recognition ORB algorithm (in miliseconds)

We choose a client-server architecture. The four different levels of outsourcing processing tasks to a server [22] were analyzed. RAIOM takes an intermediate level where the processes that are less computational intensive are executed on the client side, such as video feed, sensors, mapping and image rendering. Meanwhile the more intensive processes are performed on the server side, such as images processing, object recognition and tracking implemented in the Vision module (Fig. 4).

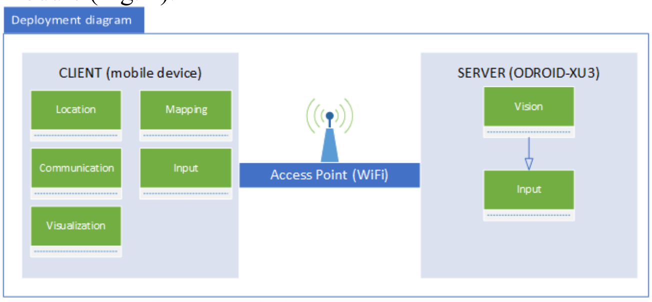
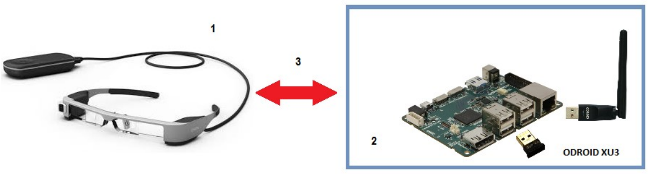


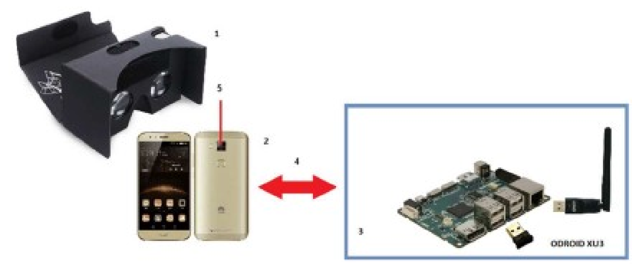

Fig. 4. RAIOM client-server deployment

A mini board ODROID-XU3 was used as server (Figure 4). The software installed in the server are: Ubuntu Server version 16.04, Python version 3.0, OpenCV 3.1 and Node.js. The software components installed on the client side are: Android 6.0, OpenCV 3.1, Socket.io and libraries; the communication between both sides was implemented by Socket.io. The communication between the client and the server is executed by sending a frame (image) from the Client to the Server by encoding the data in JSON format.

In the client side we compare between optical see-through AR glasses Epson Moverio BT-300 (Fig. 5.a) and video see-through glasses emulation by a smartphone within a cardboard (Fig. 5.b). From the video acquisition time performance tests (Fig. 6) we conclude that Huawei G8 performes the best. The Epson Moverio BT 300 glasses has the second best performance time.




(a)




(b)

Fig. 5. RAIOM hardware: (a) AR optical see-through glasses Epson Moverio BT-300 as the client and mini board ODROID-XU3 as the server. (b) Video see-through glasses emulated with a smartphone within a cardboard as the client and mini board ODROID-XU3 as the server.

Although the fastest device for video capture was the Huawei, we also compare the Epson Moverio BT 300 performance in the complete AR pipeline executing ORB recognition algorithm in server side. Fig. 7 shows that Epson Moverio BT 300 performed the best and it was the option with better ergonomics too.

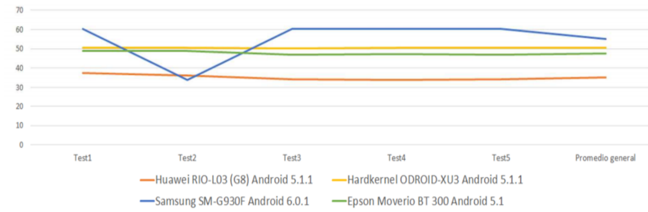



Fig. 6. Video acquisition time of different devices measured in milliseconds

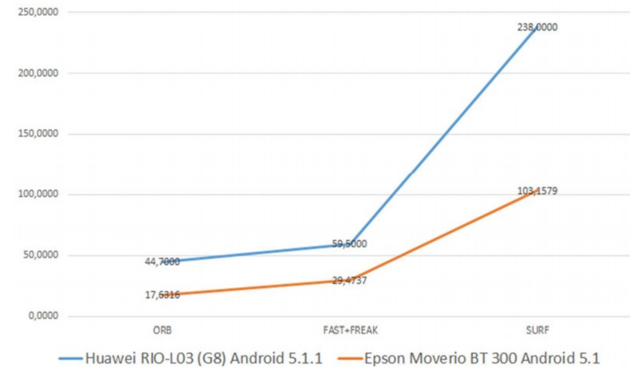



Fig. 7. AR pipeline time of different devices measured in milliseconds

*D. RAIOM functionalities*

All the functionalities were integrated into an application that used the RAIOM software architecture, implementing the following characteristics:

1. 360-degree radar: tactical and threat targets are visualized on the radar by using military symbols (Fig. 8.a).
2. Operator pose: the magnetic north serves to guide the operator. The relative position of the operator is calculated according its movements.
3. Adaptable military symbols: the symbols used are adaptable in order to identify the threats and tactical targets.
4. Landmark recognition: the application is capable of recognizing buildings and other types of infrastructure (Fig. 8.b).
5. Menu by Gesture recognition: data on demand can be got using gesture recognition (Fig. 8.c).
6. Interactive maps: the operator can visualize the terrain maps superimposed over his hand by means of gesture recognition (Fig. 8.d.)

## IV. Evaluation and Results

*A. Evaluation methodology*

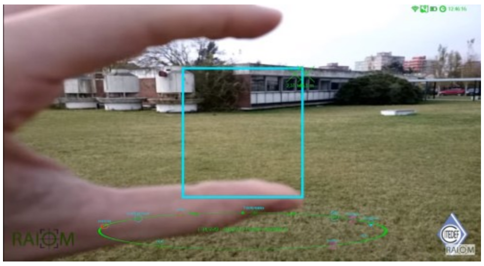
The presented RAIOM deployment was evaluated in order to measure the effectiveness, efficiency and user experience to comply 3D-SAM.

Different techniques were used to carry out the evaluation activities such as:

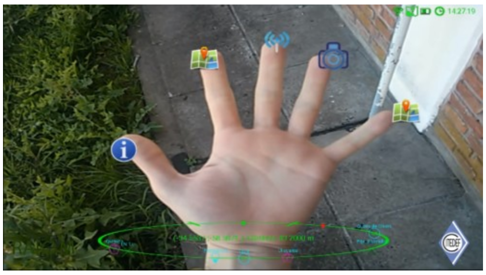
- User Testing: refers to a technique used in the design process to evaluate a product, feature or prototype with real user
- Thinking Aloud: is a protocol used to gather data in usability testing in product design and development

- SAGAT / SART: SAGAT was developed in order to assist in interface designs by providing an objective measure of user's situation awareness. SART allows to operators to rate a system design [23, 24].

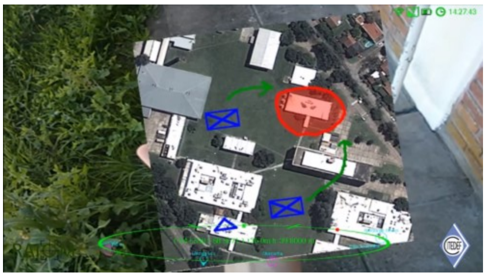

(a)




(b)



(c)



(d)

Fig. 8. RAIOM functionalities: 360-dregree radar (a), landmark recognition (b), menu by gesture recognition (c), and interactive map (d)

The tests to evaluate the SA of the participants were based on tasks they have to execute. Table V shows examples of proposed activities in the evaluation experiment in traditional military situations.

The taxonomy proposed by Bloom [25] was used to identify actions and to elaborate the questions that were made to each one of the participants. Table VI shows the cognitive levels, example of actions and questions performed to the participants. Evaluators asked questions to each participant about the recreated situations by following a Think-Aloud protocol between evaluator and participant. The questionnaires were answered based on a 5-point Likert scale (SART). Finally, effectiveness and efficiency metrics were tabulated by documenting associated failure/success rates and times.

Moreover, the UX was evaluated using UMUX questionnaire [26]. The questionnaire was integrated with the following questions about RAIOM: covers my needs, it is pleasant in use, it is easy to use, it doesn't need settings. Also the questionnaires were answered based on a 5-point Likert scale.

TABLE V. EXAMPLE OF PROPOSED ACTIVITIES IN THE EVALUATION EXPERIMENT

| *Perception* | *Comprehension* | *Projection* |
|---|---|---|
| Terrain type / capabilities of threats | Ability to support plan | Projected ability of plan to meet mission objectives |
| Resources available | Risk of mission failure/success | Projected risk of troops |
| Civilian disposition | Risk of casualties / loss of equipment | Projected ability to obtain information |
| Weather | Ability to counteract enemy actions | Projected ability to communicate |
| Enemy disposition | Ability to mitigate risk | Projected actions of enemy |

TABLE VI. QUESTIONS TO EVALUATE THE DEGREE OF PERCEPTION, COMPREHENSION AND PROJECTION

| *Cognitive level* | *Example of Actions* | *Questions* |
|---|---|---|
| Perception | Describe<br>Find<br>Locate<br>Identify<br>Recognize | Q1. What is your geographical location?<br>Q2. Can you recognize that building?<br>Q3. Can you find the purpose of the mission?<br>Q4. Can you identify the threats? |
| Comprehension | Classify<br>Interpret<br>Infer<br>Explain | Q5. Could you explain what is happening around you?<br>Q6. Could you classify the type of threat?<br>Q7. What can you say about the distance to the target? Do you have that information?<br>Q8. Could you say that the available information is enough to determine the dangerousness of the environment? |
| Projection | Calculate<br>Use<br>Perform<br>To plan | Q9. How would you use the information provided by the system to preserve human and material resources?<br>Q10. Could you plan an escape route? (taking into account the surrounding threats)<br>Q11. How would you organize your human and material means in case of attack? |

## *B. Participants*

The experiment is carried out by ten participants selected from the *Instituto de Investigaciones Científicas y Técnicas para la Defensa (CITEDEF) and DIC 601* in November 2019. All the participants have the following features: military training in commands, knowledge of military symbols, knowledge about of situational awareness in military processes and experience over three years in command functions. The participants conform two different groups: four expert users with decision-making power in military operations (group A) and six participants with operational profile (group B). Both groups perform the evaluation tasks related with SA perception and comprehension levels, while tasks related with projection level are only performed by participants of group A who has the power to decide in the military chain.

## *C. Results*

Table VII shows the average values of the perception, comprehension and projection. From the obtained scores ranging from 4,08 to 4,67 we conclude that the level of SA is high and the system facilitates the SA of the participants in the experiment. Group A scores were higher than those of Group B. The degree of compliance of the SA was 89% for group A and 86% for group B.

Results of User experience is shown in Table VIII. From the obtained scores ranging from 3,67 to 5,00 we can say that the users are satisfied with the application developed using the RAIOM software architecture. The designed interface meets 88% of compliance (group A) and 87 % (group B), respectively.

TABLE VII. QUESTIONS TO EVALUATE THE DEGREE OF PERCEPTION, COMPREHENSION AND PROJECTION

| Level | Participant Score | | |
|---|---|---|---|
| | Group A | Group B | Total |
| Perception | 4,67 | 4,50 | **4,58** |
| Comprehension | 4,33 | 4,08 | **4,21** |
| Projection | 4,33 | - | **4,33** |

TABLE VIII. QUESTIONS TO EVALUATE THE DEGREE OF PERCEPTION, COMPREHENSION AND PROJECTION

| | Group A | Group B | Total |
|---|---|---|---|
| RAIOM covers my needs | 4,00 | 4,00 | 4,00 |
| RAIOM is pleasant in use | 5,00 | 4,67 | 4,84 |
| RAIOM is easy to use | 5,00 | 5,00 | 5,00 |
| RAIOM does not need settings | 3,67 | 3,67 | 3,67 |
| TOTAL | 4,42 | 4,33 | 4,38 |

## V. CONCLUSION

The main goal of this paper is to justify, introduce and evaluate an AR-based software architecture to support the SA on a military environment. A distributed processing was implemented in an AR-based framework client-server architecture. It was implemented using an optical see-through device and a miniboard ODROID XU3. The results of the testing shown that the proposed activities and tasks were highly effective and efficient, significantly improving the SA of the users by using RAIOM. Moreover, UX of the RAIOM system was high. Regarding future work, there are three important features to be added. First, it is desirable that image recognition algorithms work in low light conditions. Second, the main aim is to replace the current classification algorithms by Deep Learning techniques such as Convolutional Neural Network. Finally, it is necessary to develop a security module in order to protect the client and server communication link.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