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Augmented and virtual reality based monitoring and safety system: A prototype IoT platform

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ABSTRACT

This paper presents an Augmented and Virtual Reality (AR/VR) based IoT prototype system. Performing maintenance tasks in a complex environment is quite challenging and difficult due to complex, and possibly, underground facilities, uneasy access, human factors, heavy machineries, etc. Current technology is not acceptable because of significant delays in communication and data transmission, missing multi-input interfaces, and simultaneous supervision of multiple workers who are working in the extreme environment. The aim is to technically advance and combine several technologies and integrate them as integral part of a personnel safety system to improve safety, maintain availability, reduce errors and decrease the time needed for scheduled or ad hoc interventions. We emphasize on the aspects that were made "feasible" on the worker's side due to the equipment used (mobile computing equipment). We present that the demanding tasks that previously were simply undertaken on the fixed infrastructure are now possible on the mobile end. The research challenges lie in the development of real-time data-transmission, instantaneous analysis of data coming from different inputs, local intelligence in low power embedded systems, interaction with multiple on-site users, complex user interfaces, portability and wearability. This work is part EDUSAFE, a Marie Curie ITN (Initial Training Network) project focusing on research into the use of Augmented and Virtual Reality (AR/VR) during planned and ad hoc maintenance in extreme work environments.

1. Introduction

In complex environment, various factors are involved and many activities occur simultaneously. Accidents are serious problems that occur repeatedly in complex environments. Numerous studies have shown that accidents cause significant cost overruns and time delays. In (Ho and Dzeng, 2010), Ho at el. reviewed that three worker injuries occurred every hour, causing the loss of human resources and comprehensive costs that were difficult to estimate. A study in (Reese and Eidson, 2006) shows that the accidents are the result of errors, omissions, and misunderstanding. In our study, the ATLAS experiment environment (The ATLAS Experiment at the CERN Large Hadron Collider) is being considered. ATLAS is a particle physics experiment in the Large Hadron Collider (LHC) at CERN, Geneva. ATLAS detector which is about 45 m long, more than 25 m high, and weighs about 7000 t. The detector sensors are degraded due to collisions, thus, experts have to maintain and upgrade them periodically. During the maintenance or upgrade operations, the operators are exposed to radiation. So, the ability to monitor personnel and the state of the surrounding hostile environment is crucial. The risk is that the data transmission system is not performing sufficiently in the ATLAS environment to support high definition real time image. Therefore, we need a system that pushes detection and cognition at the mobile end, adaptable to different environments with varying sensing and transmitting requirements, scalable and robust. The AR integrated system does not meet the required latency specification. Therefore the possibility to have the running locally is assessed and tried. At the same time, advanced state-of-the-art wireless communication systems that can meet the design objectives. More advance algorithms have been sought in this regards. Too bulky or too heavy system and/or is difficult to use by the worker especially for emergency situation. Therefore we investigate of material improvement, electronics miniaturization and possibilities for reduction of power consumption of the electronics, or new head mounted display (HMD) technologies. The mobile system is crucial, because it acquires data, processes the information locally in real time and streams the information to the higher layers of the IoT architecture. Local processing is important in order to avoid latency issues. High computational power is necessary for local processing but

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the size and power consumptions should be less since the system is for portable application. The system alternatively propagates the data from the cameras and sensors to the control system and vice versa from the control system to the HMDs. The rest of the paper organized as follows. In Section 2, we discuss the prior works in this domain. Section 3 describes the overview of our proposed system architecture. We present the operational states of our prototype in Section 4. In Section 5, we describe the details of prototype setup and configurations. Section 6 presents the security and privacy of the proposed architecture and we concluded our conclusions in Section 7.

2. Prior work

In (Poole and Ring, 1989), Poole et al. presented the personnel safety system. This personnel safety system designed for the synchrotron radiation source (SRS) is a unified system covering the beam lines, and the experimental stations. In (van Krevelen and Poelman, 2010), D.W.F. van Krevelen et al. described a survey of augmented reality technologies, applications and limitations. Teemu et al. describes an augmented reality web application with mobile agents in the internet of things in (Leppane et al., 2014). It explains web based AR application within IoT infrastructure. Kumar et al. presented indoor environmental gas monitoring system based on digital signal processing in (Kumar and Singh, 2009). The paper focused on the problem of real time processing of carbon monoxide and carbon dioxide gases measurement using a DSP board (TMS320C6455) and then implementing the proposed gas monitoring system. In (Pantelopoulos and Bourbakis, 2010), Pantelopoulos et al. described a survey on wearable sensor-based systems for health monitoring and prognosis. An emphasis was given to multiparameter physiological sensing system designs, providing reliable vital signs measurements and incorporating real-time decision support for early detection of symptoms or context awareness. Recent advances in Augmented Reality by Ronald Azuma et al. described in (Baillot et al., 2001), shows the potential applications (such as medical visualization, maintenance and repair of complex equipment, annotation, and path planning). Multi sensor data fusion for fire detection has been described by Zervas et al. in (Zervas et al., 2011). The goal of this work was the deployment of wireless sensor network at the urban-rural interface aiming to the detection, monitoring and crisis management of such natural hazards (e.g., fires). In (Mizuno et al., 2004), Mizune et al. presented an outdoor augmented reality system for direct display of hazard information. The paper focused on a tracking system with high accuracy and real-time processing by template matching for augmented reality. Mining risk information in hospital information systems as risk mining, a research was carried out by Tsumoto et al. in (Tsumoto Shimane and Yokoyama, 2007). Shared situation awareness system architecture for network centric environment decision making that has been discussed in (Parvar et al.,). In this system, decision-maker requests the needed information and the system provides the requested information and situation awareness for decision-making. According to this architecture, knowledge organization, activity principles, theoretical approach for design, control and software engineering provide for shared situation awareness system. In (Goldsmith et al.,), AR based environmental monitoring, using wireless sensor network that have been discussed by Daniel Goldsmith et al. In this paper, the authors presented a prototype AR interface specifically designed for monitoring application. However, it is necessary to reduce data risk, keep as much personal data as possible from IoT devices, properly secure data transfers, and so on. A safe and reliable system requires membership entities (devices, mechanisms, etc.), which is designed with a focus on safety. The underlying radio communication medium for wireless networks is a big vulnerability that can be exploited to launch several attacks. Any derogation from this principle provides room for attackers to act in a malicious manner against the network. It is expected that in 2020 there will be more than 50 billion 'things' connected to IoT ("Internet of Things in, 2020", 2008). Technology under development for IoT is enabling our march toward this objective; however the security, threat and attack are concerns in IoT remains a serious impediment to widespread adoption (Basagni et al., 2001). In (Vijayakumar et al., 2016), the authors propose a computationally efficient privacy preserving anonymous authentication scheme based on the use of anonymous certificates and signatures for IoT infrastructure. The certificate revocation list (CRL) is checked rapidly in order to support certificate and signature verification. The use of network resources is also optimized. The system is capable of validating the message source as well as verifying the integrity of messages. The scheme is also capable of tracing the misbehaving devices. Authentication is performed in a batch manner. The authors in (Sun et al., 2016) propose a mechanism for controllable location privacy in mobile online social networks. The architecture called user-defined privacy location-sharing is assessed w.r.t performance and correctness.

However, none of these systems can be used as an integrated platform or meet the current needs for smart environmental monitoring application. The prototype system that we describe here is based on modular architecture. It can be used as whole or as a part for instantaneous data coming from multiple on-site users. We capitalize the local computing equipment that can support the AR system. Too bulky or too heavy system is difficult to use by the worker especially for emergency situation. We investigate of material improvement, electronics miniaturization and possibilities for reduction of power consumption. At the same time more advance algorithms have been used.

3. Overview of prototype system architecture

We propose integrated system architecture in (Figs. 1 and 2). This architecture is structured into two major parts; namely the mobile part (carried by the person/worker), server/database part (control station for supervision and management/control). The mobile part is divided mainly on head mounted data acquisition, personnel trans-receiving unit (PTU) and head mounted display (HMD). The server/database part includes a safety lesson page, search engine, etc. allowing workers/operators on safety knowledge through mobile devices. The database includes with VR and AR scenarios with safety regulations. The management/control station manages the safety assessment management which manages how worker interact with the VR, AR scenarios. In the following section we elaborate an overview of this proposed system.

3.1. Mobile part

3.1.1. Head mounted data acquisition system

This includes hardware integrated on the helmet, cameras, IMU (Inertial Measurement Unit) sensors, laser, LED light, electronic board, WiFi module plus its associated software. From a functional point of view, two cameras are needed: One for supervision purposes and another one for computer vision purposes. The supervision camera is used for video supervisor of the environment while computer vision camera is used for AR/VR application. AR/VR technologies require the use of an image sensor to be used with vision algorithms. This image sensor is the part of a vision camera in order to provide the required data (image data) to the vision algorithms. There are several factors to consider when choosing a camera for computer vision (e.g., support for OpenCV, Linux and image quality). The cameras, as part of a wearable embedded system, meet a number of requirements related to the processing power, interfaces, size, and weight of the embedded system. Compared to desktop systems, embedded systems have limited resources in terms of memory and processing power, and usually run an embedded version of the Linux operating system. Furthermore, a battery powered wearable embedded system must be small and light enough, because it needs to be carried by personnel. The use of LEDs lights are important for supervision and vision cameras. The low

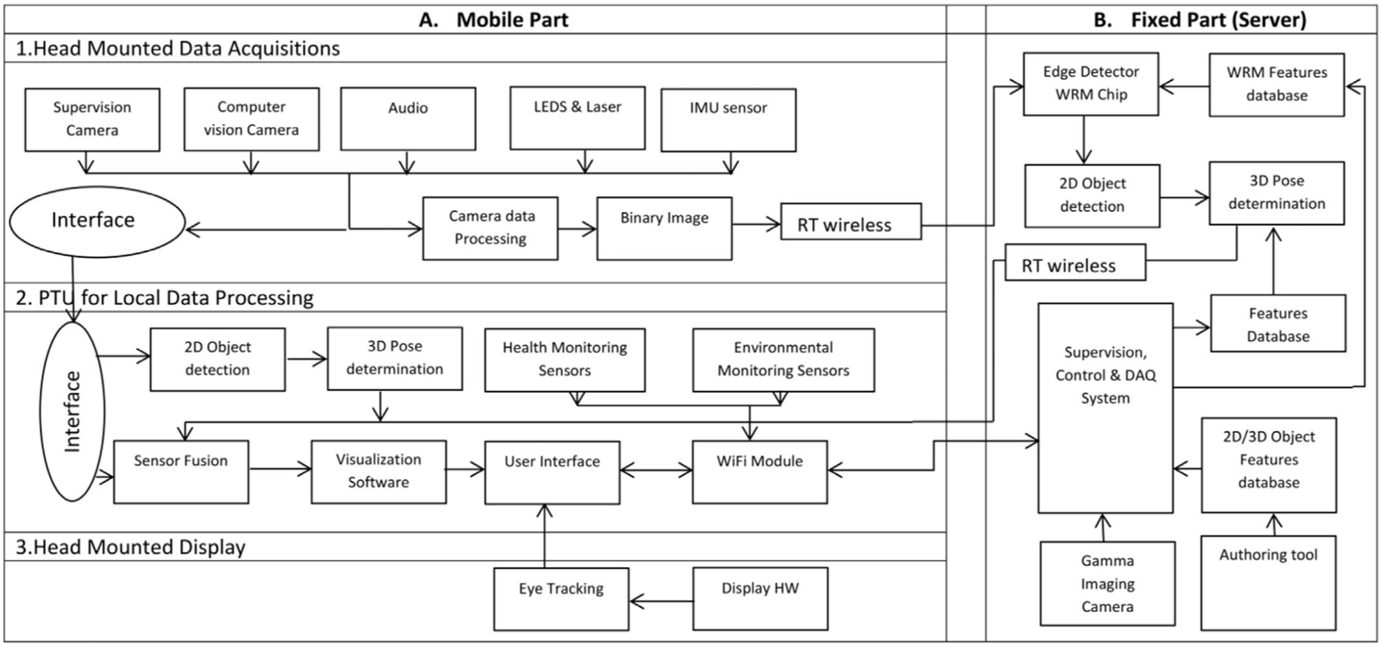

Fig. 1. Overview of the AR/VR system architecture.

lighting conditions give a large percentage of blurry images. At the same time high luminance of light cannot be accepted because most of the elements in the environment are reflective. Therefore, proper adjustment of luminance is important. The LEDs can be used in 3 (three) modes depending on the required light intensity. A button can be pressed once for Mode 1: Low Intensity, twice for Mode 2: Medium intensity and three-times for Mode 3: High Intensity. The cameras are interfaced to the rest of the embedded system that acquire, process, and wirelessly transmit the captured images. The video signal from the camera is transmitted to the PTU. Camera control interfaces are connected to a CPU (Central Processing Unit) inside the PTU that includes a System on Chip (SoC). SoC integrates all components of a computer or other electronic system (Furber, 2000).

3.1.2. Personnel transreceving unit

The mobile PTU is responsible for data processing for various sensors, image, audio data acquisition, visualization and wireless interfaced devices. We propose a stackable hardware design of PTU that can be represented based on the interactions and combinations between the modules. By designing a hardware modularity (Fig. 3(a)), we have design tasks divided among groups that can work independently. Preliminary, it has been divided into four major groups but it can be divided into many groups as per requirements. Each group has the same dimension in X-Y level with required input/output interface (Fig. 3(b)). The name of the groups: power supply, processing, environmental monitoring, health monitoring. Groups are internally connected by suitable board to board modular (Male/Female) connector. Power supply group is the host for supplying power to the head mounted data acquisitions system as well as to all the subgroups (processing group, environmental and health monitoring sensor group) inside PTU. The main task of the processing group are 2D object detection/3D pose determination, Pose filtering/interpolation (Sensor Fusion), visualization of the information from different sources, environmental and health monitoring data processing and wireless communication with control and data acquisition (DAQ) system. The aim is to adapt the different existing techniques to achieve a better modularity and scalability of the overall system. We focus a new and generalized architecture taking into account the role of each components interfaces to ensure efficient exchange of the information and optimization of the overall resources of a Wireless Sensor Network (consumption, bandwidth and memory). Our target is to optimize the use of those resources by selectively use the push or pull model to ensure reusability of the system. By doing this, we are providing scalability,

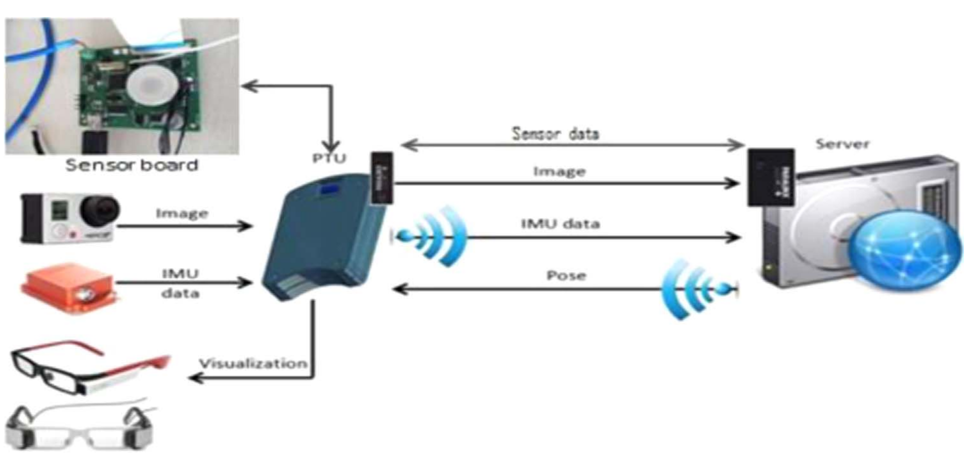

Fig. 2. System components.

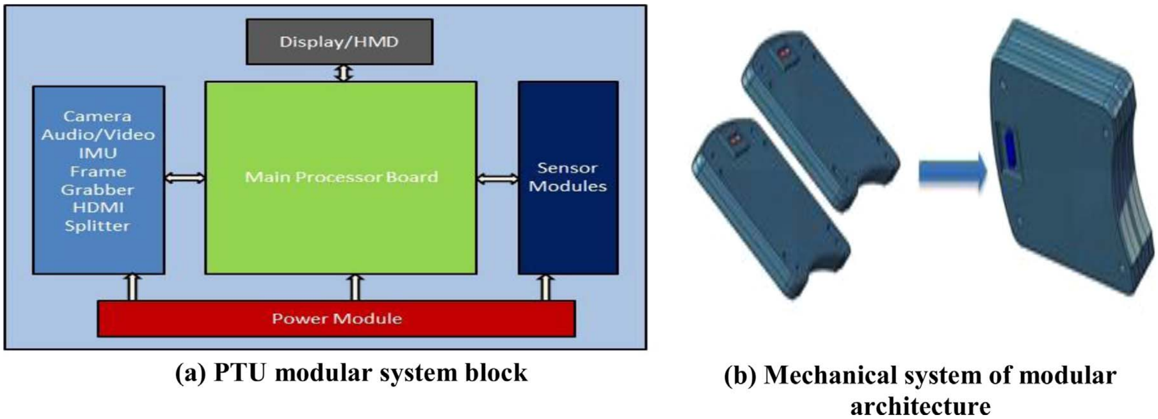

Fig. 3. (a) PTU modular system block. (b) Mechanical system of modular architecture.

adaptability and modularity. Additionally, we focus on a very challenging optimization in order to produce the system sufficiently powerful, highly reliable, low power consumptions, with small size and weight, suitable to the workers in the most demanding environments.

In order to satisfy the proposed system as an IoT platform, we divide the processing task inside the general purpose processor and Digital Signal Processor (DSP). This is currently defined as 1.4 GHz dual-core CortexA9 ARM CPU and OpenGL 2.0 GPU and intel i5 based multicore embedded system. Sensing group is accomplished by Oxygen, Carbon dioxide, Environmental Temperature, Humidity, Body temperature, Pressure, Gamma dose radiation sensors. A list of health sensors are operating in this group. Some of these are body temperature, ECG, blood pressure, Oxygen saturation, Accelerometer, Air flow monitoring. All of these sensors.

are connected to the same microcontroller implemented on sensor hardware. The calibrated measurements are stored in the database. The details of the senor data integration and acquisition process are described in the sections 5.4 and 5.5. The measurements are stored in the corresponding registers of the controller. The HMD is used in order to visualize the acquired information. These are HW ad SW that renders the required information (video, 3D, 2D, and sensors data) on the Head Mounted Display (HMD; for example google glass) hardware. This component includes HW and SW to communicate the augmented reality content to the user (HCI – Human/Computer interaction) and to display visual information on a worker's field of view. The aim is to technically advance and integrate them as part of a PSS to improve safety, reduce errors and decrease the time needed for scheduled or sudden interventions in extreme environments.

3.1.3. Operational states of PTU system

The basic states of the PTU system are:

- Hibernate (Off): The device will never be actually powered off but it will be in hibernate mode with very small power consumption.
- Normal: In this state the device is fully operational and connected to server. In case that the connection to the server is not possible the device will go to a sub-state.
- Hang Up: Only the supervisor will have the authority to turn off or on the audio connection. In this state the audio connection is off. The camera will be always on.
- Alarm: When an event occurs, like system error or warning or a measurement is outside the defined limits, the PTU will produce a sound signal.
- Panic: In this status camera and the audio are turned on automatically.

We sketch these states diagram in Fig. 4. By pressing the Power Button the device will be turned on. The supervisor can turn on or off the Audio connection. By default in Normal state the audio is on. Any time that an event occurs the device will go on Alarm state and a sound from the buzzer will be produced. From any state by pressing the panic button the device will go on this state. The supervisor can send a signal to the device to insert in Panic state. When the device is in HangUp state, the user can request from the supervisor to establish an audio connection.

3.2. Server/Database part

Several functions and processes are concentrated in the server side. The data acquisition, control and supervision systems manage the data flow among the mobile and fixed systems and coordinates the worker activities. The link to the mobile system is constituted by a standard WiFi for the monitoring activities. The control and data acquisition handles centrally the various inputs from: Mobile radiation sensors, visual tracking, AR contents, supervision video/audio stream, gamma imaging, and supervision post. The module serves as a supervision post, providing sensor data, video and audio stream to the supervisor. It stores data and provide the means for the supervisor to easily communicate and instruct the worker. As an alternative of local image processing in the PTU, this module also processes full color images and produces an estimation of the camera pose in the server side. This is the database where the AR content created by the authoring tool (authoring tool is the software and a part of server used to author AR content appropriate for procedure description and industrial environment dangers/info display) is stored, and from which the control system and ultimately the PTU display system retrieve the information. The use of gamma camera is to capture emitted radiation from radioisotopes to create two/three dimensional images to the display device. This component is responsible for the data flow between mobile and fixed systems. The WiFi communication channel ensures different QoS (Quality of Service) levels depending on the type of information, since supervision video/audio streams, as well as sensors, synchronization and AR content will pass through the same wireless medium. Proper QoS, bandwidth guaranties error free communications taking into account the lossy wireless medium and the specific requirements of each payload type.

4. Prototype setup

The setup of our prototype system is shown in Fig. 5. It consists with the following independent systems: the mobile PTU and HMD based data acquisition system are placed on the helmet. The AR display device used by worker hands or by wearable glass. The dosimeter sensor is fastened with body and EDUPix gamma camera, a standalone device which connects wirelessly to the AR prototype.

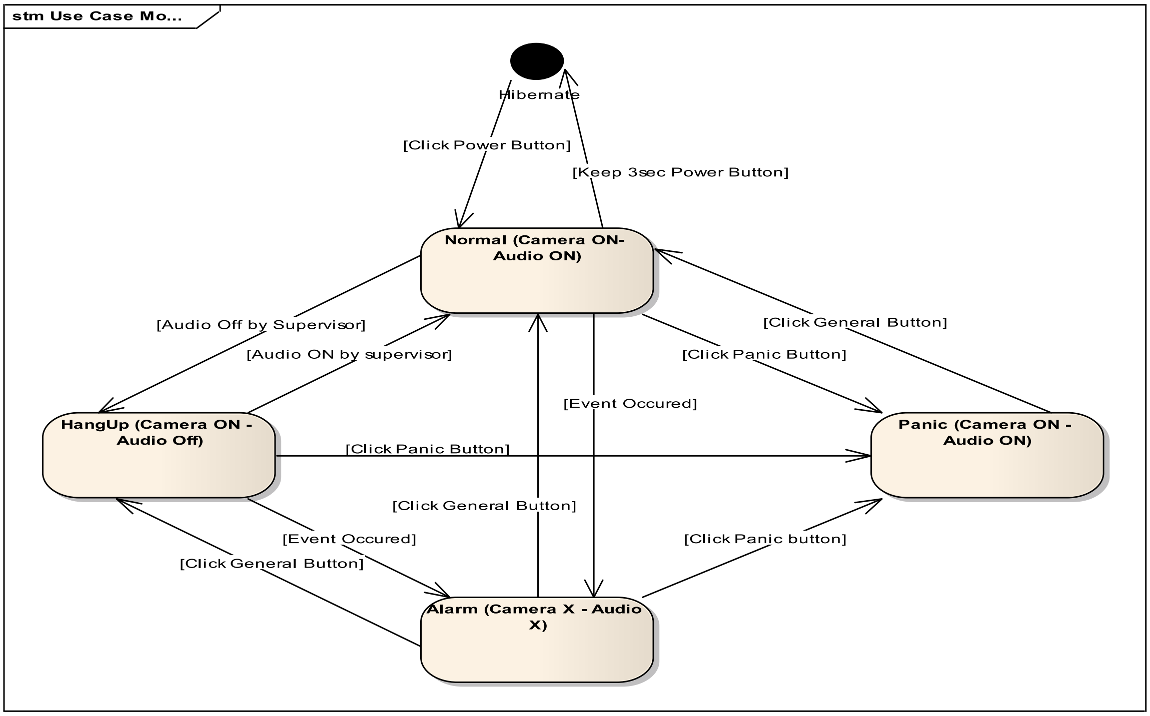

Fig. 4. Operational sequence of PTU system.

4.1. Markerless pose estimation

The markerless pose estimation SW is responsible for computing the camera pose with respect to the object of interest (e.g. the electric box) starting from the incoming frames. The RGB frames sent by the camera mounted on the user's helmet are grabbed and procced locally on the mobile device (carried by the worker). Then, a pose is computed starting from the image data, making use of the robust segment detection. The final outcome consists of the 6 degrees of freedom of the pose of the camera (6 dofs for rotation; 6 dofs for translation) with.

respect to the object. This pose is then sent to the fusion engine, where it is merged with the information coming from the accelerometers placed on the user's helmet, and finally employed for rendering the augmented content.

on the visualization HW. A WRM (Weighted Resistor Matrix) chip is used for possible optimization to increase performance. A software process can send image data through libWRM to the FPGA and get back segments detected in the image at the speed of ~20 ms/frame. The main building blocks of markerless pose estimation SW are shown in Fig. 6. The pipeline has been conceived in order to guarantee high degree of confidence in presence of occlusions, clutter, light changes and drastic changes of the object appearance (such as the inner part of the electric box during a technical intervention). Instead of relying on the appearance of the whole object, as in traditional model-based visual tracking (Lepetit and Fua, 2005), or on the detection and matching of interest points across frames, such as in common visual tracking approaches, we rely on small, stable parts of the object, which are likely to stay visible and not change their appearance during the whole sequence. The object parts are manually selected in advance: for this application, they consist of the box corners.

The main steps of our pipeline are:

1. Detect the stable parts on the image. This step is achieved by an image detector made by a Convolutional Neural Network. The outcome of this step consists of a certain number of candidates for the location of the parts of interest on the image.
2. Select the most likely detection candidates according to a given pose prior hypothesis. The pose prior hypothesis can be the pose computed at the previous frame, or a generic hypothesis (e.g. the user standing in front of the box). This step is useful for rejecting spurious detection candidates that may occur because of clutter and ambiguous patterns present in the image, and its outcome consists

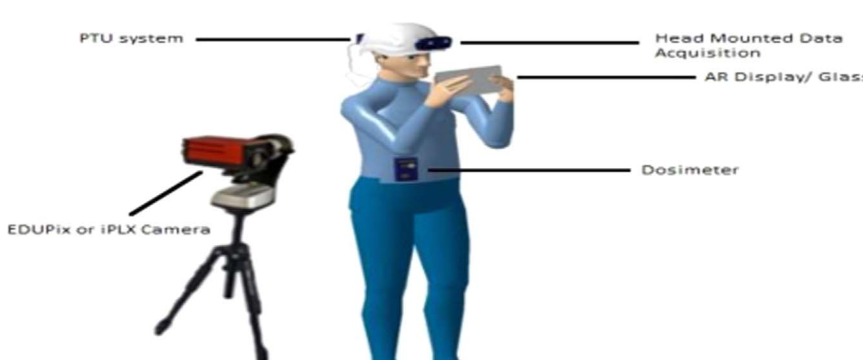

Fig. 5. Prototype components.

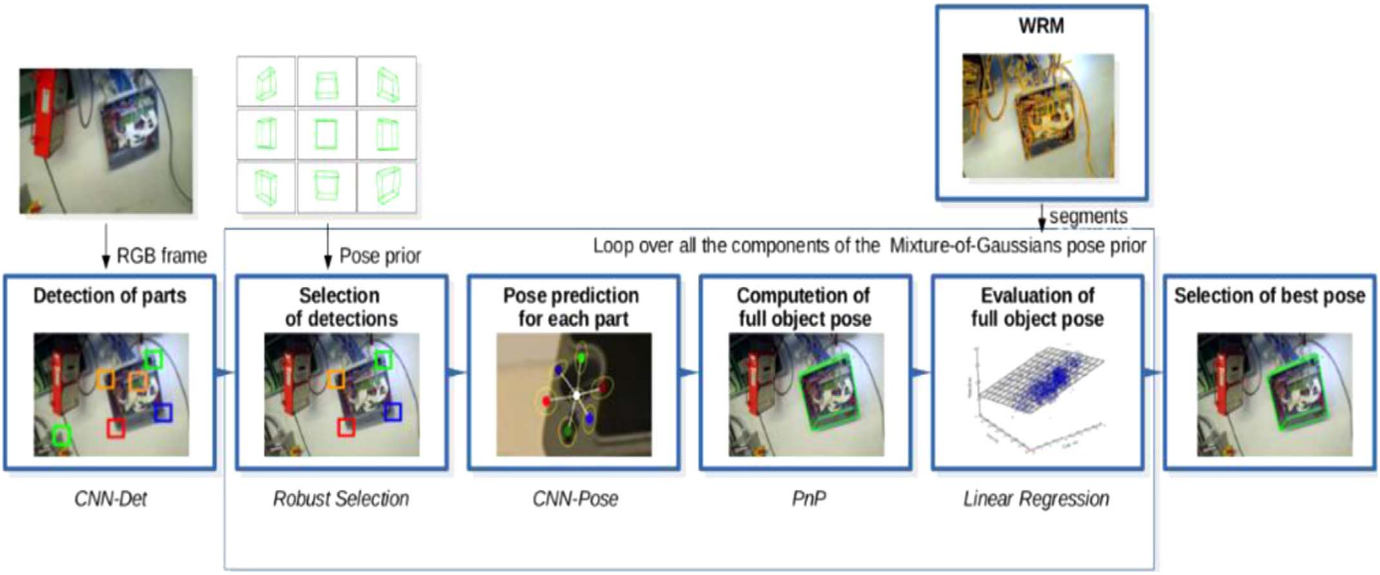

Fig. 6. Building blocks of the markerless pose estimation SW.

of (at most) one candidate for each part.

3. For each selected part candidate, a rough 3D pose starting from its appearance is predicted.
4. If only one part is detected, the pose computed is retained as pose for the full object. If more than one parts are detected, the poses predicted for each part are combined together for giving a more robust pose estimation of the whole object.
5. Steps 2–4 are repeated for different pose priors, and a different posterior hypothesis is generated starting from each of them. In order to select the final pose of the object, we rely on the local features detected and compute the cross-correlation between the detected features and the predicted occluding contours of the box. The pose candidate with the highest correlation is retained as final pose.
6. The final pose is sent to the pose fusion engine via TCP/UDP protocol.

The interested reader is referred to (Crivellaro et al., 2015) for further details about the employed method. Some examples of the visual tracking outcomes are shown in Fig. 7. The pose estimation is stable regardless of all the appearance changes of the box and its environment.

4.2. AR system prototype with HMD

This section is a summary of the Augmented Reality (AR) System with a Head-Mounted Display (HMD). Fig. 8 shows our final display system. We employed an optical see-through HMD from Vuzix, STAR 1200XL-D, which has a 1280×720 image resolution. The display has a controller box which can take video signals via HDMI connection. For a desired AR visualization where display contents have to be visually fused in the real world from a user's viewpoint correctly (Fig. 9), HMDs need to be mounted stably on the user's head. An adjustable display mount on the headband allows users to configure the display position easily so that they can clearly see the image. The display system has some cables coming from the head part and going to the control box (Fig. 10).

4.3. Authoring and visualizer software

The visualization software is then using this pose data to render the AR on a head mounted display (HMD). Throughout this process the pose data has to be real time with any delay introduced by the transmission system or the drift by inertial measurement unit (IMU). For the debug reason on the server side, the AR virtual red screws are

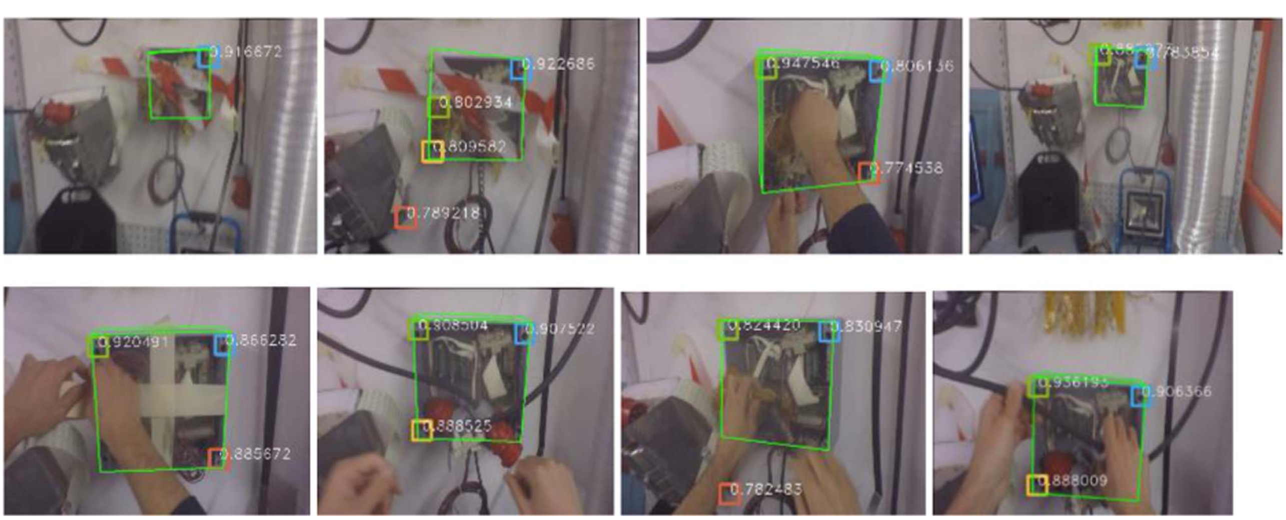

Fig. 7. Examples of the visual tracking outcomes.

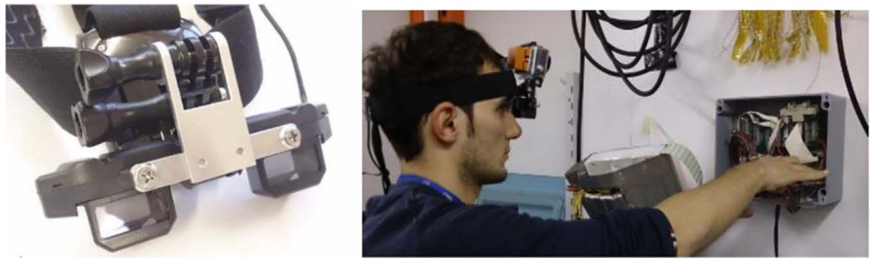

Fig. 8. The HMD system. The display part without the tracking component (left), the system warn by a user with a tracking camera & an inertial measurement unit integrated (right).

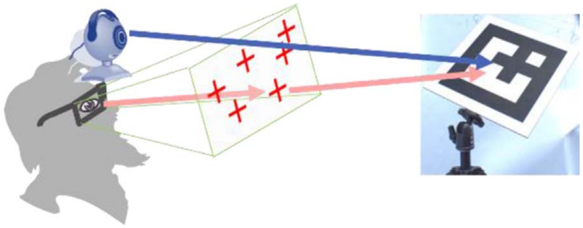

Fig. 9. Schematic diagram of AR registration with an HMD. The display position with respect to the user's eyes has to be kept stable.

Fig. 10. A user with the display system (left), front view (right) back.

rendered on the images (Fig. 11). Similar sort of visualization is used to render the maintenance procedure on an optical see through head mounted display. The authoring tool provides AR virtual model features with the addition of the audio or text instruction.

4.4. Sensor board integration and sensor data acquisition

The worker carried equipment features a number of sensors. Their measurements are currently posted to the display system and also to the control station and interpreted there by the supervisor. However, this architecture can be easily extended to include mobile intelligence. Such intelligence can be based on previous work by the authors in the following directions:

a) The sensor feed can be collectively assessed in the local level using an information infrastructure similar to the one discussed in (Nomikos et al.,). Contextors like thresholding and fusion can be combined together to filter the (multidimensional) sensor feed and detect situations that call for further attention. Whenever such an incident occurs the mobile equipment decides to forward all the measurements to the control station for further inspection.
b) Sensor Feed forwarding is an expensive operation as it consumer wireless resources that may be scarce especially in an electromagnetically polluted industrial environment. Therefore, and subject to the severity of the detected incident, the mobile equipment decides to forward the entire stream, unmodified, for a predefined period of time or compress the stream and relay the reduced information to the control station. In this latter case, the principal components analysis (PCA) framework (Anagnostopoulos et al., 2012) can be adopted in order to reduce the dimensionality of the original stream and thus save wireless resources throughout its transmission period. This compression (dimensionality reduction) comes at the expense of accuracy as the reduced stream can be restored to its original form with a certain (controllable) noise. For both schemes, i.e., the application of a context sequence and the stream compression, the mobile equipment features sufficient processing capability. The sensors interface is implemented with the MSP430F1611 microcontroller by Texas Instruments, running the Intelligent Sensors Operating System (ISOS). The various sensors are connected to the microcontroller to either its analogue or digital inputs as it is illustrated in Fig. 12. The dimension of this sensor board is 50×60 mm with 6 layers custom PCB design. Most of the sensors are mounted on the PCB (for example accelerometer, O2, CO2, Humidity/pressure, environmental temperature) and some of them are connected externally (for example body temperature and heart beat sensor). The board is integrated with Zigbee module in order to

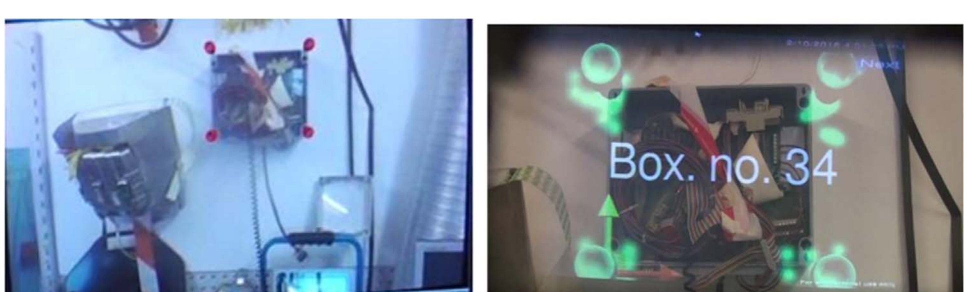

Fig. 11. AR virtual content. Left screws rendered together with images on the server side and Right screws rendered on the optical see through HMD.

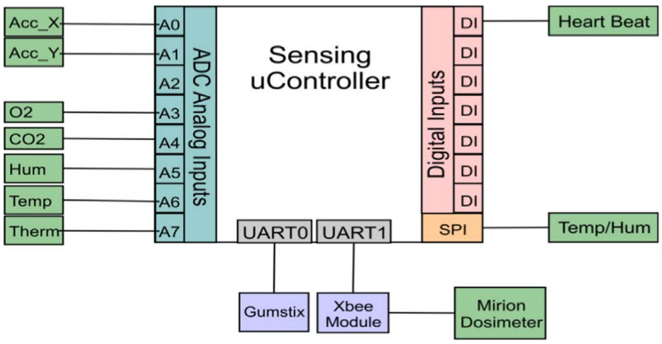

Fig. 12. Sensors interface.

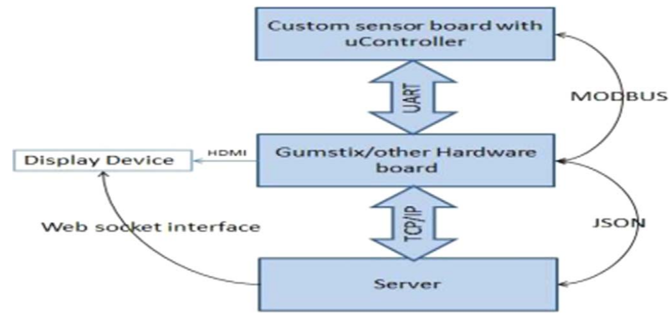

Fig. 13. UART-to-TCP forwarding utility.

interface to the dosimeter sensor. The main responsibility of the Sensing uController software is reading and sampling the measurements from the sensors and forwarding them to processing embedded board. The mechanical design of PTU system is based on modular that facilities to accommodate different embedded hardware board.

4.4.1. Accelerometer sensor

The acceleration_application is implemented in intelligence sensor operating system running on the microcontroller and continuously reading measurements from the accelerometer and implements an algorithm for detecting falls. The accelerometer (sensor model ADXL320 (2-axes)) provides data about its position in terms of X and Y axes. The analogue signals are two input signals at the microcontroller MSP430; these two input signals alter their voltage amplitude according to their position. The two analogue input signals are converted to digital signals through an ADC (analogue-to-digital converter). The relative outputs of the ADC are processed in a way that detects falls. The first step of the signals processing is the conversion to digital form. This has as a result the alteration of the X and Y amplitude voltages to be in the values range of 0–4096. The common reference point of the fall effects were the sudden increase of the Signal Ratios of the X and Y axes signals. Specifically the sudden change of the X and Y values, that is a common element during a human fall effect, has as a result the increase of the Signal Ratios over a specific limit. This observation was used for the implementation of the fall detection algorithm.

4.5. Sensor data acquisition

The communication between the Sensing uController and the mobile hardware is established through USART0 using the modbus protocol. The processing embedded hardware reads and writes the PTU registers by sending the appropriate modbus commands to USART0. The main program in the processing embedded hardware performs the actual communication forwarding between the server-side program/user interface program and the Sensing uController. Specifically, it requests sensor measurement values from the Sensing uController via UART in every 20 ms. This sampling happens whenever the respective sensor timer, held by the main program, expires. The main program polls the serial port and when a response with a measurement or event is received, it is forwarded to the display device by HDMI over user interface and also to the server. The raw information that feeds directly to the display device is the real-time information from the environment. The user can monitor and decide what to do based on displayed information. This increases safety of the personnel as decision making is facilitated. On the other hand, it minimizes the bandwidth and manpower involving with task as the information process locally. Additionally, same information also sends to the server for more analysis for example graphical representation, peak or trends over certain period of time.

The UART-to-TCP forwarding utility is configured to run as a daemon process and implements the communication with the Sensing uController (MODBUS over UART) and the server-side program (JSON over TCP/IP) (Fig. 13) over an established TCP connection, to which the main program connects as client. All the communication between the main program and the server-side program running on the platform is done using JSON formatted messages. The main program writes the events that occur to the named pipe and reads another named pipe for incoming messages eg. panic button pressed. In Table 1 we show the regular JavaScript Object Notation (JSON) message with a measurement contains information about the sender, the sensor and the received measurement.

When a measurement exceeds the upper or lower thresholds, the processing board also sends an event type message together with the measurement message. Moreover, in case a sensor value changes significantly (more than the configured value change threshold), a value change event is sent together with the measurement message. Also, an event message is sent to the server when a fall is detected by the accelerometer, a non-zero dose rate value is received or the panic button is pressed. The communication between the PTU systems and the other users, such as supervisors and administrators, is implemented over TCP (Fig. 14). All the PTU systems are connected to the server through WiFi. The PTU systems transmit the sensor measurements and other information about their status to the server through TCP socket over WiFi. The DAQ services that are installed on the server are responsible for handling the communication with all the clients and also for storing the received data in a database.

Other portals, mobile or web based applications for the presentation and analysis of these data are not directly connected to the PTUs but only through the DAQ (Data Acquisition) server. The DAQ Windows Services forward all the received JSON packages from the PTUs to another TCP socket, where these applications can be connected. Moreover, all the JSON messages that are sent to this socket by the applications eg. order for changing a PTU parameter, are directly transmitted to the PTUs. A TCP socket (Fig. 15) is created for the communication with the PTU systems and another one is created for the communication with other client applications. The communication between the server and all the clients (PTUs & other applications) is carried out using JSON formatted messages. Moreover, a connection with the Oracle database is established in order that the received sensor measurements, events and other information are stored into the database.

Following, an Oracle connection to the database is established and the TCP sockets for handling the communication with the client devices are created. The server continuously listens for TCP clients. When a TCP client gets connected, the server handles the communication by parsing the received package and storing the contained information to the database.

Moreover, the DAQ Windows Services establish a TCP connection with the video server. When an inspection starts or ends, the services

Table 1
JSON message for measurement.

Sender	The name of the sender	
Receiver	The name of the receiver. “Broadcast” for broadcasting the message to all connected receivers	
FrameID	The FrameID of the package	
Acknowledge	“True” if acknowledge is required. “False” if acknowledge is not required	
Messages		
Measurement Message	**Type**	“Measurement”
	Sensor	The sensor type. Can be “Temperature”, “Humidity”, “O2″, “CO2″, “HeartRate”, “DoseAccum”, “DoseRate”, “BarometricPressure”, “BatteryLevel” or “BodyTemperature”
	Time	The time when the measurement was received
	Method	The measurement method. Can be “OneShoot”
	Value	The measurement value
	SamplingRate	The sampling rate in msec
	Unit	The unit of the measured value
	UpThreshold	The configured up threshold of the measurement
	DownThreshold	The configured down threshold of the measurement

Example of a measurement message:


```
{
  "Sender": "PTU1234",
  "Receiver": "Broadcast",
  "FrameID": "90",
  "Acknowledge": "False",
  "Messages": [
  {
  "Type": "Measurement",
  "Sensor": "DoseAccum",
  "Time": "21/07/2016 10:14:09",
  "Method": "OneShoot",
  "Value": "0.052",
  "Unit": "mSv",
  "SamplingRate": "10000",
  "UpThreshold": "1.1",
  "DownThreshold": "0.0"
  }
  ]
}
```


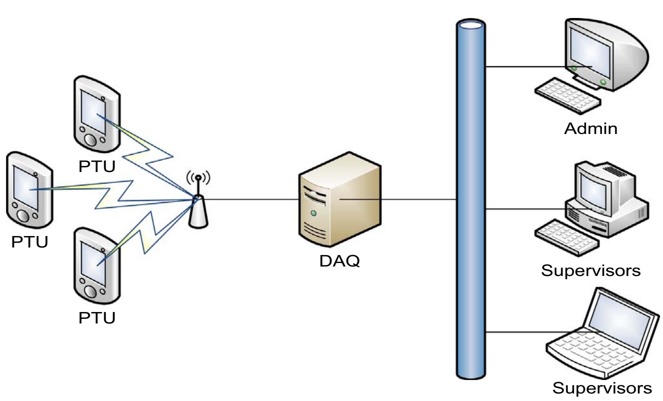

Fig. 14. PTU setup over TCP/IP network.

send a start or stop recording JSON message respectively to the video server and update the corresponding database. In this way, the video server starts recording when a new inspection starts and stops recording when an inspection ends.

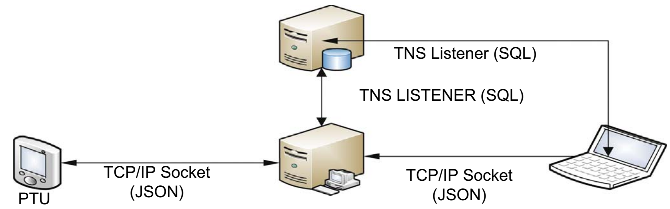

Fig. 15. Network connections between components.

4.6. DAQ and CS integration with the supervision system

The DAQ system and the Control System (CS) are based on the ATLAS Personnel Visualizer System (APVS). The Software Architecture design of the Control System and Data Acquisition System is graphically shown in Fig. 16. This system consists of the following functional blocks:

A. Java server hosts the web application that is needed in order to communicate with the client-side.
B. EDUSAFE User Interface running on the browser client enables the supervision of the worker personnel in the ATLAS environment.
C. DAQ server enables the acquisition of the various sensor data from the supervision system.
D. Oracle Database is used to store data for various purposes such as offline analysis.

4.7. Gamma camera

Localization of radioactive sources is a major issue for radiological safety of operators in radiation facilities. For this purpose, a new gamma imaging system - the “EduPIX” - has been emerged. The system allows operators to visualize the locations of the main surrounding radioactive sources (Fig. 17) that contribute to their current dose rate directly on the EDUSAFE prototype display, so that they may perform their work accordingly, respecting ALARA (As Low As Reasonably Achievable) principles for minimizing occupational exposure.

The EduPIX gamma camera is able to produce single gamma shots and panoramic images. By panoramic images, it is intended the capability of the system to locate sources of gamma radiation and provide the respective 360-degree picture of the surrounding scene. The system use a Timepix Chip (TimePix, device; Gottesman and Fenimore, 1989), a pixellated chip developed by CERN in the frame of the international collaboration Medipix (Llopart et al., 2014), hybridized with a 1 mm thick CdTe substrate. In order to localize radioactive source from a distance, the camera uses an optimized version of the coded mask described in (Medipix, collaboration): this multi-pinhole collimator enables to improve drastically the sensitivity of the camera, requiring though a decoding step in order to convert the raw image into a decoded gamma image.

5. Security and privacy

In our architecture security is treated on the network level through simple encryption processes (Anjum and Mouchtaris, 2007). This is further supported by the hardware that the mobile end is using (encryptions tasks are performed on the security accelerator of the mobile device). Symmetrical encryption is used to improve the throughput in the communication between the worker end and the supervisor end (keys are pre-shared). The authentication process is simplified as it does not pose serious scalability requirements. However, more advanced solutions can be applied especially given the computational adequacy in the mobile end. In addition to that, solutions that guarantee worker privacy can be applied to further strengthen the security framework in this application. This is not always required, especially in the case of a highly specialized industrial

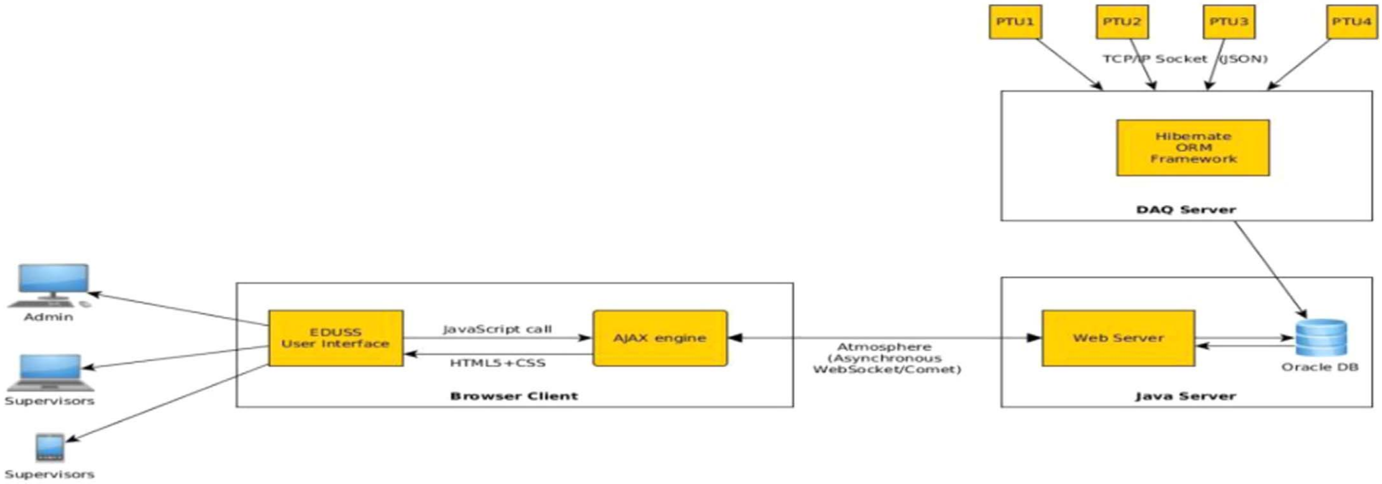

Fig. 16. Software architecture design of the control system and data acquisition system.

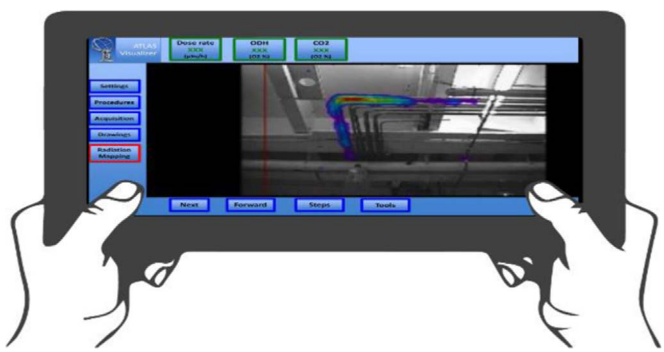

Fig. 17. The gamma camera provides the possibility to acquire and display gamma images superimposed on visible images directly on the tablet.

environment like that of CERN. More scalable solutions in either aspect of the system are discussed below. Changa et al. (2016); Chang et al., proposed a cloud computing adoption framework (CCAF) security suitable for business clouds. CCAF multilayered security is based on the development and integration of three major security technologies: firewall, identity management, and encryption based on the development of enterprise file sync and share technologies. A research on Data Security – Challenges and Opportunities (Bertino, 2014), that elaborate open issues, such as data protection from insider threat and how to reconcile security and privacy. Cloud computing: state-of-the-art and research challenges by Zhang et al. Zhang Lu and Raouf Boutaba (2010), in this paper authors presented a survey of cloud computing, highlighting its key concepts, and architectural principles. Security in wireless sensor network (Perrig et al., 2004), where authors outlined security issues in the sensor network; they covered several important security challenges, including key establishment, secrecy, authentication, privacy, robustness to denial-of-service attacks, secure routing, and node capture. The complexity of securing today's networks demands a Unified Threat Management (UTM) approach. A single-processor and ASIC solutions cannot keep up with evolving complex attacks in real time from both inside and outside the network perimeter due to the increased inspection demands required. A multi-core architecture is the best platform for delivering UTM with real-time DPI. Compared with general purpose and ASIC processors, multi-core technology offers higher performance, scalability, and energy efficiency than other network security platforms available today. Our prototype platform is based on multicore embedded system which has iManager embedded system; this intelligent, self-management, cross platform firmware monitors system status for problems and takes action if anything is abnormal. Additionally, it includes remote management software WISE-PaaS/RMM which builds intelligent management functions into embedded computing applications, ensuring continuous system uptime and reduced maintenance costs.

6. Discussion of the results

We discuss a generalized architecture taking into account the role of each components interfaces to ensure efficient exchange of the information and optimization of the overall resources. We emphasize on the aspects that are made “feasible” on the worker's side due to the equipment used. By designing in modularity, we have designed tasks divided among groups that can work independently. We argue that the demanding tasks that previously were simply undertaken on the fixed infrastructure are now possible on the mobile end. With current technology, the AR integrated system does not meet the required latency specification. In order to mitigate that we have the full AR system running locally that can be accessed as an IoT device. The visualization software is then using this pose data to render the AR on a head mounted display (HMD). Throughout this process the pose data has to be real time with any delay introduced by the transmission system. The mobile system is responsible for data processing for various sensors, image, audio data acquisition, visualization and wireless interfaced devices. The raw information that feeds directly to the display device is the real-time information from the environment. The user can monitor and decide what to do based on displayed information. This facilitates the proper safety of the personnel as they can make quick decision. In order to have a lightweight system, we improved materials, design, and electronics miniaturization by reducing power consumption of the electronics, or new HMD display technologies.

7. Conclusion

The study was initiated with a thorough literature review investigating the safety education problems and the state-of-the-art of mobile computing, VR and AR for learning. The HW and SW system were successfully integrated resulting in the development of AR/VR prototype system. The proposed approach is evaluated to identify the advantages of using mobile based AR/VR for the maintenance task in a complex environment. A system prototype was developed and preliminary evaluation results suggest that the proposed system would be effective in improving access to safety information and transferring safety knowledge. The head mounted data acquisition system includes hardware integrated on the helmet, cameras, IMU (Inertial Measurement Unit) sensors, laser, LED light, electronic board, WiFi module plus its associated software. The mobile PTU is a modular structure and is responsible for local data processing for various sensors, image, audio data acquisition, visualization and wireless interfaced devices. The sensor board, processor board, power board were successfully integrated into the PTU. The markerless pose estimation SW, responsible for computing the camera pose is integrated with the IMU data. The pose from the visual tracking algorithm was fused together with the IMU data in the server and the final pose is sent to the PTU. The data acquisition, control and supervision systems manage the data flow among the mobile and fixed systems and coordinates the worker activities. The DAQ and CS were integrated with the mobile modular system, as well as the gamma camera graphical interface in order to achieve optimum supervision through the EDUSS GUI. The EduPIX platform has been developed as a module of the EDUSAFE prototype system, integrating gamma radiation imaging features into the prototype. We analyzed the architecture, the electronic designed and the software pointed out the advantages, the problems or issues. The results of this analysis will help us for further development in this domain.

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