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The ENDORSE concept, an integrated & mobile robotic solution, targeted at Medical Diagnostic support

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Abstract - Hospitals are considered a logistics field of commercial potential. This is attributed to the fact that each hospital involves annually several hundred-person months dedicated to mere delivery of goods, equipment and bio-samples. Today, a handful of mobile robotic solutions for hospital logistics exist but they have failed to trigger widespread acceptance due to technical challenges and functional limitations. ENDORSE functionality will be demonstrated via the integration of a non-invasive e-diagnostic support module on a fleet of mobile robots, facilitating connectivity to cloud-based Electronic Health Records (EHR), and validated in an operational hospital environment for realistic assessment.

Keywords: Robotics, Hospitals, Logistics, Cloud-Based, EHR, eHealth, mobile.

I. INTRODUCTION

As autonomous mobile robots offer several administrative and financial advantages, currently they are widely incorporated in big industrial infrastructures and logistic warehouses for materials and relative product transportation. Nonetheless, current constraints of indoor commercial spaces and their default design specifications, are a limiting factor in their full implementation in the service industry and in healthcare services. The main and fundamental difference between indoor commercial spaces and industrial spaces, is that the latter's environment is well defined, structured and predictable. In such environments, robots move in predefined paths and robot-human interaction is minimized, whereas it is more frequent in indoor commercial dynamic spaces, with constrained interior architecture and different load specifications.

The introduction of automation would positively impact financially these enterprises, as there is a large number of transfers that take place every day. More specifically, in the healthcare sector as much as more than 850 man-hours per week in a 500-bed hospital [1] are spent on the transfer of medical devices, equipment, biological samples, mail,

pharmaceutical products, medical waste, administrative documentation, linen and several other goods. These man-hours are mostly manual labor, with the use of medical carts over potentially long distances. The healthcare professionals involved are usually nurses and / or caregivers, who are consequently deprived of valuable time for their actual and formal healthcare services, as these tasks are of no added value.

As automation of the supply chain would improve the traceability of products and goods, from the moment they are first ordered, to their introduction in the system, to, finally their delivery to the end user and recipient, the above-mentioned arguments would apply in all commercial spaces and healthcare services. Improved and even optimal traceability methods would minimize response times, ensure correct delivery of products (something especially important in healthcare) and would overall improve the services offered. Therefore, there is a high commercialization potential as the involved stakeholders have tangible problems which can be solved and the indoor supply chain is a fruitful field for automation and there also lies a high commercialization potential as the involved stakeholders have tangible problems which can be solved.

II. BACKGROUND

The way commercial spaces and specifically hospitals and healthcare spaces in general are designed in the interior, is a suitable environment for the implementation of mobile robots, as their deployment would be facilitated by the space. They are obliged by law [2] to conform to strict building codes and technical specifications. Therefore the robotic navigation, could be considered structured adequately and pose moderate technical challenge (when in contrast compared with home environments). As it is a requirement for basic business operations [3], healthcare buildings have already an established, reliable and tested system, with WIFI, cellular connectivity and possibly data centers, so in terms of communications infrastructure, next to logistics and industry,

the healthcare services industry can be considered the next field of mobile robot's development.

Despite all the above-mentioned advantages regarding structure and existing infrastructure, the use of mobile robots and robotic solutions and products, is neither so widespread in the healthcare sector, nor broadly accepted by the market yet. One of the main reasons is the time and cost relationship of main infrastructure installation, as there is a significant cost for peripheral sensor installations, mapping, etc. Additionally, a mobile robotic solution would need to be integrated to the existing corporate IT systems. This means that there would be a need to address data protection and cybersecurity threats in a lawful yet extensive manner.

Currently in the market there are solutions for small and medium commercial spaces, in healthcare, such as the Aethon [4] and SwissLog [5] systems. They are both of high cost (estimated costs rise to more than seventy-five thousand euros plus additional installation expenses) and present with several functional and operational limitations, such as not enough motion flexibility, challenging design. Apart from the high cost, they can implement their routing in confined areas and small spaces only. Their level of customization is low, they are not modular and there is no potential to perform tasks beyond the mere transfer of goods. These existing solutions that are mentioned have irreplaceable incorporated carts, while it would be more useful to have the potential of replacing carts with functioning medical units. These could be for example: e-health diagnostic stations or UV light sanitizers. Communication protocols for medical purposes exist and are widely used, but most organizations have ERP's and business intelligence systems, that are already preconfigured according to the healthcare building specifications and the business operational needs. Therefore, integrating a mobile robotic solution would be challenging. Data collection from the robotic systems' sensors and task execution can be recorded but it cannot be registered in the corporate records and data management system. Cybersecurity imposes another threat, as it is difficult to maintain traceability within the existing IT infrastructure, as it is a field with vast human involvement. The ENDORSE concept, is a solution to the afore-mentioned limitations, as its overall goal is to design and develop integrated robotic systems that enable efficient, cost-effective and safe in-door logistic services for hospital facilities. More specifically, the ENDORSE's concept aims towards the following objectives that when met would allow the system to comply with the industry's requirements.

A. Cost - Effectiveness

The development of a cost-effective logistics robotic system for indoor healthcare facilities, with minimal installation time and reduced costs.

B. Human – Robot Interaction

The advance in the frontier of Human – Robot interaction, in terms of safe and efficient navigation in populated spaces and resolve deadlocks that involve humans.

C. Localization Methods

The development of robust localization methods for fleet tracking and supervision. The goal is an infrastructure-less indoor system that would minimize installation time and costs.

D. Cloud Services

The introduction of innovative cloud services which will combine existing solutions from the key industries (healthcare, robotics and logistics) and offer a new business model for indoor logistics with human interaction and higher data security standards.

E. Integration

The development of a modular, versatile and integrated e-diagnostic mobile station, that will integrate a set of non-invasive sensors, that will collect efficiently and cost effectively physiological signs from patients. These signs can be ECG, blood pressure, oximetry, etc.

F. Interdisciplinary Collaboration

Collaboration between various sectors and disciplines will ensure that these objectives are met. It will be achieved by coping with all the specific and challenging scientific and technological difficulties that will come across, by taking advantage of complementary competencies in the fields of robotics, machine vision, information technology, logistics and product design and engineering. The proposed solution with the ENDORSE concept will be modular, reconfigurable, customizable and hence applicable to a variety of fields and commercial spaces. Nonetheless, it will be focused and healthcare oriented, with the developed prototype piloted in the Fundació Ave Maria in Sines healthcare center.

III. CONCEPT

The ENDORSE project will achieve the above-mentioned objectives on the basis of four main pillars of innovation:

A. Infrastructure-less multi-robot navigation

Due to the novel internet based indoor localization technologies, the navigation of multiple robots will be enabled with minimal or even no installation of infrastructure. There will be minimum installation of sensors and communication buses, with no installation on building walls, ceilings and floors. Since there is a significant cost for typical sensors to be installed, with the additional expenses regarding integration and labor, the novel infrastructure-less navigation approach will reduce the cost and time considerably, especially for indoor logistic systems. The sensor technology that will be used will be of the latest technology and it will be fused with robust Simultaneous localization and Mapping (SLAM) algorithms. There is presently no open-source platform to seamlessly integrate fingerprint measurements from unique sorts of indoor localization technologies (e.g.: Wi-Fi, BLE, UWB, etc.) [6]. The purpose of the ENDORSE project is to extend the open-source Anyplace structure with components and specialized localization algorithms, so that infrastructure-free localization of IoT hardware will be allowed. More particularly, there will be redesign of algorithmic components that are necessary for indoor localization, estimation of the accuracy of indoor localization [7], API channel optimization techniques [1] and visual analytic cues to provide a rigorous Fingerprint Management Studio for crowdsourced indoor

signals. The infrastructure-less multi-robot navigation will be implemented through a software architecture that combines ROS (Robot Operation System) packages implementing RB1 base navigation and path planning with Java and JavaScript modules for the GUI and the implementation of the Fleet Management System.

B. Human-aware navigation for indoor logistic applications

The robotic revolution involves adapting the machines to both humans and themselves. This convergence requires intuitive human-robot interaction (HRI) so that non-trained staff in a healthcare center can interact with the robot to avoid deadlocks while simultaneously adapting the robot to the crowd and conducting human-conscious navigation. Safety is also an important issue, as with human-robot communication, the comfort of the person interacting with the robot, needs to be maximized. In order to achieve this, there will be features in the system, such as message activation, that will target at stress minimization. These features will be implemented by the ROS perception packages that will be running on the robot.

C. Reconfigurable and modular hardware architectures

The key innovations and tangible technical results of the project will be the development and testing of the modular interfaces and the integrated mobile e-diagnostic station on board of the mobile robot. They will be tested in real healthcare environment. Therefore, research and development in non-invasive sensors and devices (for ECG, blood pressure, oximetry, temperature) as well as dedicated software applications are required. Currently modular hardware interfaces (mechanical, electrical and data interfaces) mounted on the robot chassis (Robotnik 's commercially available RB1 base as in Figure 1) allow for easy swapping between them, but this would be the first time that a modular, interchangeable medical diagnostic functionality would be integrated on a mobile robot.

The mobile robot will serve as an e-diagnostic mobile station that will be able to produce a diagnostic examination report? This report will then be securely forwarded to update and complement the patient's cloud based electronic health record (EHR). The e-diagnostic mobile station software will be installed and running on the robot.

D. Cloud-Based services

Cloud Computing can be adapted to suit different levels of user load and is providing ubiquitous access to 24/7 software-based services (SaaS). Cloud services must guarantee what is known as a Service Level Agreement (SLA). Typically, SLA 's are usually specified as a percentage time during which the service functionality is available. Therefore, guaranteeing the SLA of a service is intimately linked to the management of the service life cycle and the events which drive it. These comprise of the initial deployment, the reconfiguration, the upgrade deployment, the fault handling, the re-scaling. Automation enables data centers to be managed in a cost-effective manner in order to deliver parts of themselves in the form of virtual machines and networks. By using cloud-based applications, business users are provided with high memory, data sharing and security service. Moreover, cloud servers can connect to

various applications and legacy enterprise systems. ENDORSE is proposing a cloud service that will contain a repository of data that will be fed by appropriate algorithms within the cloud, that will support the management of the fleet, including the tasks assigned to the robots, the queuing functions, the generation of dynamic routing and traffic control of the robots and the supervision of the execution of the fleet's tasks. Developing a cloud-oriented software platform will facilitate the development of APIs to integrate ENDORSE software with corporate ERP solutions and existing cloud health record systems. The ENDORSE applications will comply with the high standards of security for data sharing and data storage offered by the cloud infrastructure, as cloud services facilitate deployment of security updates, back up and replications of data. The user will interact with a web-based interface application.

IV. FUNCTIONAL ARCHITECTURE

Even during the operation of the system, five levels of supervision and control will arise naturally, depending on the time requirement (loop rates) and the abstraction level of the signals engaged. This will lead to a relational architecture consisting of levels for controlling wheel motors, robot modules, behaviors and tasks, and is described in the next sequence. At the lowest level of the hierarchy, the **Signal** level will involve the raw signal process and motor control (the wheel motors). The second level of the hierarchy will be the **Motion** level, which represents information about the module and its surroundings. Each controller of the module will accept asynchronous move and turn commands for a standard reference framework. The next level is the **Task** level which runs the software platform of the Fleet Management System (Task planner, dynamic robot routing, multi-map manager, elevator controller, etc.). Finally, the highest hierarchical level is the **GUI** level. The GUI level and the Task level can be grouped because they are both running on the cloud, whilst the rest is running on board.



Figure 1. RB1-base robot navigating in a healthcare environment

V. TECHNOLOGICAL SOLUTION

Cloud-based services: The project will create an API that will

incorporate logistic robotics into the facility's IT environment and will enable end-to-end automation (automatic traceability of the goods transferred, upgrading of ERP databases when transactions are carried out, etc.). Communication and safety standards will be examined so that data is securely transmitted from the robot to the cloud-based EHR of the patient through software integration based on ROS. All system modules will be defined by ROS packages and ROS nodes. Non-ROS modules (i.e., Java or JavaScript Applications) will have APIs able to create objects that can be translated into standard ROS objects (themes, services, actions, etc.).

Due to priority system requirements and the output of the implementation, an initial integrated software prototype will be developed that will then be incorporated in the cloud services. The evaluation will be carried out iteratively, leading to intermediate versions. Data relevant to the testing of healthcare APIs and applications will be dummy so no ethical concerns are therefore raised. The sensors used will be based entirely on embedded micro controllers processing units which will make the device compliant with most protocols and the device will be equipped with a measuring unit (IMU) enabling monitoring of activity and real-time orientation. Upon the installation of the diagnostic support module, the overall robot will actually serve as an e-diagnostic mobile station that can produce a diagnostic examination report that is securely sent to update and complement the cloud-based EHR of the patient.

Internet-based indoors localization technologies:

Localization solutions will allow virtually infrastructure-less multi-robot navigation, minimizing the installation process of infrastructure on building walls, ceilings and floors, lowering the cost and time required. The reliability of the SLAM techniques will be high so that the navigation capabilities of the fleet will be maximized.

Standard robot localization or localization tracking approaches are often based on state estimation algorithms working on a stochastic framework, they generally show poor performance when systematic errors or invalid model assumptions or data outliers appear of these approaches and require that the initial robot position is at least approximately known. The ENDORSE concept aims at developing an alternative, enriched with data fusion techniques, by the process of integrating multiple data sources to produce more consistent information, with methodologies that can function effectively with sporadic, asynchronous and heterogeneous measurements whilst being robust against the presence of non-consistent measurements, such as inconsistency in the modeling of the environment and drift and inaccuracy in the robot evolution model localization [8].

An analysis, comparison and selection of on-board sensors for localization will be carried out so that accuracy and stability of global localization are improved and so that SLAM's computational burden is reduced. IMU will be regarded for dead reckoning, cameras for a line or feature following and wheels encoders. In addition, the use of RSSI calculations

(existing Wi-Fi beacons or BLE or UWB deployment) will be reviewed. Preferably, only on-board sensors will be used.

After full integration and simulation, a vigorous state estimate will be carried out in the presence of data outliers, especially for the tracking of indoor human / robot localization tracking. The approaches will be adapted and expanded to update the location and mapping.

Electronic Health Records: The European Union has identified the advancement of eHealth and mHealth systems and services as a main priority for improving the quality of healthcare, thus improving the quality of life of patients while saving substantial healthcare costs [9] [10]. Towards this direction, the European Commission Decision 2015/1302 of July 2015 recommended 27 IHE - Integrating the Healthcare Enterprise [11]- profiles describing the different layers of interoperability at a European level. The current CEF cross-border healthcare program, which is being established simultaneously in 17 Member States, will promote the exchange of a minimum Patient Summary (PS) between countries, while accommodating electronic prescription (ePrescription) and dispensing (eDispensing) functionality, adopting the Directive 2011/24/EU [12], by 2020.

In the context of the ENDORSE project, the aim is to increase our existing EHR system to meet the interoperability requirements [13]. To this end, the necessary APIs will be developed using the Fast Healthcare Interoperability Resources [14], the most widely used standard for the development of mobile smartphone applications today [15]. Lightweight processes will obtain data from multiple sensors at pre-set sampling rates, e-diagnostic module, and assemble them into JSON or XML as the format to communicate them to the cloud-based EHR

Appropriate security and device authentication procedures will be installed, while the EHR system will provide appropriate auditing schemes for the registration of each communication and data update session. The latter functionality entirely depends on the accumulated knowledge of FISTAR (Future Internet for social and technological alignment) and the resulting FIWARE specific enablers developed in the past. Extra functionality of the EHR system will enable the generation of directly relevant reporting documents, utilize statistical analysis and support export functions for further data analysis.

Diagnostic Support Module: The diagnostic support module will be installed on the robot chassis, allowing the entire robot to become a mobile e-diagnostic station and equipped with a set of non-invasive sensors / devices (ECG, blood pressure, oximetry, temperature) in order to make possible medical examinations, generate diagnostic reports and transmit them safely. All the module's embedded sensors will be already powered and available which is not the case when all medical devices are left on a trolley. The e-Diagnostic module offers a real service innovation providing several advantages regarding:

1) Organizational impact

The robot moves up to the healthcare professional. The e-health information collection module provides diagnostic aid permitting patient management in all circumstances to be faster and more efficient.

2) *Economic impact*

Many hospitals suffer from budget restrictions. Rather than purchasing multiple medical devices for the very same service, the e-diagnostic module collects them all in one place.

3) *Human impact*

The e-Diagnostic module provides practicality and less physical exertion, as it moves up to the requester when called.

How will it come? A probable architecture for the diagnostic support module is a plug-in device that will be robot powered and will consist of a set of non-invasive medical sensors attached to a control unit. It will manage and handle the sensors, but will also act as a preprocessor for medical data and a gateway to the cloud-based EHR of the patient. The supervisory unit should be able to broadcast diagnostic reports to the cloud-based EHR using this interface.

The architecture can be divided into three global subsystems:

1) *Acquisition*

A medical data acquisition module (sensors and the supervisor)

2) *Communication*

A communication module (heterogeneous networks both intrinsic to the sensors and more generally between the various components of the system).

3) *Consultation*

A consultation module (analysis and diagnosis of results).

VI. FUTURE RESEARCH

ENDORSE is an ongoing EU project ending in September 2021, with a three- year timeframe. Throughout that period, many aspects of the use of indoor logistic robots in hospital environments are expected to be addressed. More specifically ENDORSE will:

- Compare use in commercial spaces of robots with use in fields such as warehouses and acquire know-how. The study of the analogy between these two environments, would be of considerable interest and could uncover potential robot navigation problems.
- Calculate the economics of robotic implementation in hospitals. Large hospitals and especially tertiary referral hospitals, necessitate many person-hours per week, which amount to a significant cost (depending on the country in which the hospital is located), as stated in the introduction.
- Examine the safety and security of both the goods transported and the professionals and the precise and on-time delivery.

VII. CONCLUSION

The actual implementation of this project in the Marie Skłodowska- Curie Action (MSCA)- Research and Innovation

Staff Exchange Framework (RISE) Horizon 2020 will provide a unique opportunity for knowledge exchange and know- how and experience between the SMEs and creative academic groups of the ENDORSE consortium with the ultimate goal of successful business, thanks to a challenging R&D project that intends to address one of the major topics in the industry in general and the health care provision in particular: The Human Robot Interfaces. With regard to future work, the defined research strategy will be implemented to achieve the goals of the project and to identify the tools and methods to be used.. Later, the implementation of artificial intelligence tools, could offer new services such as disease surveillance, medical decision-making support, statistics or more broadly big data analytics.

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