Functional and non-functional requirements of a smart triage system for Emergency Departments: the case of IntelTriage project

Antonis Billis[a], Evangelos Logaras[a], Maria Zouka[b], Nancy Karanasiou[c], Alexis Fourlis[c], Petros Nicopolitidis[d], Paraskevas Lagakis[a], John Gialelis[e], Dimitrios Kallergis[f], Georgios I Papadimitriou[d], Christos Douligeris[f], Theodosis S. Papavramidis[g], Maria Krizea[e], Panagiotis D. Bamidis[a]

[a] Lab of Medial Physics, Medical School, Aristotle University of Thessaloniki, Greece, [b] Department of Anaesthesiology and Intensive Care, AHEPA University Hospital, Greece, [c] VIDAVO S.A., Thessaloniki, Greece, [d] Department of Informatics, Aristotle University of Thessaloniki, Greece, [e] Industrial Systems Institute/ATHENA RC, Platani, Patras, Greece, [f] Department of Informatics, University of Piraeus, Piraeus, Greece, [g] 1st Propedeutic Department of Surgery, AHEPA University Hospital, Aristotle University of Thessaloniki, Greece

[a]{ampillis, bamidis}@med.augh.gr, [a]{evanlogar, parislagakis}@gmail.com, [b]mariazouka@gmail.com, [c]{nancy, afourlis}@vidavo.eu, [d]{petros, gp}@csd.auth.gr, [e]gialelis@isi.gr, [e]mariakrizea@gmail.com, [f]{d.kallergis, cdoulig}@unipi.gr, [g]papavramidis@hotmail.com

***Abstract*—Emergency Department (ED) overcrowding is a major global issue of public health concerning patients' safety and quality of care delivery, leading to increased mortality, increased costs due to prolonged in-hospital length of stay and readmissions The main goal of this paper is to present IntelTriage and its functional and non-functional requirements. IntelTriage is a smart triage system that automatically prioritizes ED's patients, continuously monitors their vital signs and also tracks their location through a wearable device and intelligent clinical decision support system.**

Keywords—Triage Algorithm, Medical Decision Making, Wearable Devices

I. INTRODUCTION

ED overcrowding has been a global issue of great concern among healthcare systems. Immature and underdeveloped primary care, imbalances between ED capacity and demand for patient triage, healthcare staff shortages and hourly delays for laboratory testing and imaging are only few of many identified causes of the problem [1]. ED overcrowding is considered to be "an emerging threat to patient safety and public health" [2]. Numerous studies have reported the negative consequences, including poor patient satisfaction, increased morbidity and mortality, treatment delays, prolonged in-hospital length of stay and hospital readmissions [1]. In Greece, according to data from a recent survey of the Pan-Hellenic Federation of Public Hospital Workers [3], the following statistics arise: i) patient arrivals at the outpatient clinics increased 40% over the past three years, ii) waiting time in many cases ranges from 5 to 8 hours and iii) large hospitals in Attica mediate up to 12 hours to drive a patient from the emergency room to another clinic.

Although the overcrowding phenomenon has been recognized for years, no measure implementation has been able to provide a robust and effective solution so far. Some investigators have proposed the "input-throughput-output" model of solutions, which provides a focused yet not ideal management policy towards ED patient flow according to the time course of events [1]. Electronic triage tools have been suggested and implemented as supplementary options in the ED setting in order to assist physicians manage the "input" and "throughput" phases. Such a solution seems promising, as reported results have shown less undertriage cases, shorter waiting times and facilitation of fast tracking. Moreover, compared to the Emergency Severity Index (ESI) [4], electronic triage has been reported to classify ESI level 3 patients more accurately and to emphasize the use of predictive analytics to support triage decision making [5], [6].

The main contribution of this paper is the description of an ongoing research project, namely IntelTriage. IntelTriage aims to go beyond current state-of-the-art solutions, by introducing more precise and personalized triage of incidents categorized as ESI 3, being an extremely heterogeneous group of patients, who require a continuous reevaluation of their status and real-time re-categorization for more efficient patient and healthcare system outcomes.

To this end, IntelTriage system functionality is summarized as follows: i) it automatically prioritize patients within EDs, ii) it continuously monitors patients' vital signs and iii) it tracks patients' location during their stay in the ED or clinic. The continuous monitoring allows automatic evaluation and prioritization of level 3 incidents according to ESI while waiting in EDs but also upon their arrival. A tentative list of functional and non-functional requirements regarding the development of the proposed solution is presented, as part of the ongoing project work.

II. RELATED WORK

Similar computerized triage applications have already been developed [7], [8] and have demonstrated to be an effective approach for supporting the physicians and nurses in EDs with the patient prioritization. In [8] an electronic triage system was developed that could measure each patient's blood oxygen level and pulse rate by inserting their finger on a custom made electronic tag. Base stations were also developed for localization purposes, trajectory estimation and for supporting the wireless communication. A pilot test run at the ED in Juntendo University Urayasu Hospital for two years and showed the system's effectiveness. In [9] a similar system developed that consisted of a number of biomedical modules, a graphical user interface (GUI) and a triage decision making algorithm. Vital signs, syndrome and chief complaint were collected from patients. The acquired data were analyzed and the triage level of every individual patient was instantly reported. Average time for the triage level assessment by using the referent system was around 6 min. In [10], a computerized triage system was also integrated in hospitals' main system that was able to manage a number of variables (arrival time, acuity level, health risk indicators, gender, age, attending name, consultation, laboratory notification, radiology notification, etc.) and provide a real-time decision support for clinical, operational, educational, and financial activities, which can support decisions about ED's capacity and patient flow. A comparison of the aforementioned systems' main features with the proposed system is shown in Table I. Based on this initial benchmarking, it is shown that IntelTriage ambition is to provide a holistic approach towards the adoption of a smart solution for EDs overcrowding issue.

TABLE I. FEATURES COMPARISON

Feature	IntelTriage	[8]	[9]	[10]
Electronic biomedical modules	✓	✓	✓	
Medical decision support system	✓	✓	✓	✓
Interoperability with other systems	✓			✓
Patient tracking	✓	✓		
Triage algorithm usage	✓		✓	✓

III. INTELTRIAGE IMPLEMENTATION

A. The Triage Algorithm

The ESI was developed around a new concept for prioritizing patients in emergency clinics. In addition to the question "who should be preceded", the physician or the nurse should predict the expected number of resources (e.g., diagnostic examinations). However, according to the algorithm and in order to classify patients, the physician or nurse does not have to foresee more than two resources.

B. Portable Biosensors Subsystem and Tracking Devices

A list of critical vital signs that will be used for the evaluation of the status of each patient in ED's waiting area, has already been defined. The portable biosensor system will gather the biosignals and forward them to the stationary system. The stationary system will receive, store and present them to the medical staff. The measurements, will be received from fixed IEEE 802.11 Access Points (APs), which will be placed in the desired coverage areas. With this infrastructure, low cost and energy efficient patient tracking is feasible in the coverage area of the AP that serves it. This mechanism is considered sufficient for such applications, since the granularity of the tracking is spaces and not points. The power consumption is small, thus ensuring long autonomy of the device, while the extra cost is minimal.

C. Medical Data Mining & Discovery and Medical Decision Support Subsystem

Vital signs, location and patients' information will be analyzed in order to draw conclusions on the criticality of each incident. A Medical Decision Support System (MDSS) will be implemented to assist the physician with patient management. The MDSS will use machine learning algorithms and statistical models in order to monitor the progress of patients' health. Also, techniques like time series analysis and real-time changes detection will be used, aiming at optimal patients' prioritization.

D. Extensibility and Interoperability Assurance Subsystem

In order to support the exchange of medical data appropriate web services will be developed, which will ensure the interoperability, based on international e-health standards, such as Health Level 7 (HL7) and SNOMED. Data models relevant to IoT applications, such as Open mHealth, will be also integrated that will allow a seamless integration of the bio-parameters that will be collected.

E. Security

Handling sensitive medical information makes the security of the system a critical factor to its overall quality. In the proposed triage system, a horizontal approach to applying the neccessary security rules is used, where each data interaction between subsystems is evaluated and secured if the need arises, in order for the system to comply to international standards and regulations in regards to integrity, safety and privacy of the information.

F. Implementation considerations

The design of the proposed system will take into account the needs of end-users (hospital, medical and nursing staff and patients). In particular, a series of interviews with medical personnel was carried out and as a result a list of patient cases were produced. In what follows a detailed description of these scenarios and their translation into functional and non-functional requirements for the development of the technical system are provided.

IV. SCENARIOS

Two indicative patient scenarios have been documented to identify the workflow of a typical triage process and evaluation carried out by the personnel in Emergency Departments based on ESI protocol. Specific points in this process, that, ideally, IntelTriage would fit for improving the patient outcomes are included.

A. First scenario

A male bicycle driver, arrives at the ED with his right hand tied up with a piece of cloth soaked in blood. He states that his bike was overturned due to bad driving from a driver that was coming against him. He landed on his right hand, which hurts a lot at the wrist and carries a deep trauma that bleeds on the right forearm. In addition, it carries abrasions and bruises in the right upper abdomen without intense pain. "Fortunately I wore a helmet," he says.

The patient will need right wrist-forearm x-ray and squeezing of the traumatic wound (2 resources). Upper abdominal ultrasound (1 additional resource) may also be required. Its vital signs are fixed. Therefore, due to the fact that he is stable and that he will need 2 or more resources he is classified in category 3 ESI. However, due to the objective findings in the region of the right upper abdomen he is candidate for a closed liver injury, so he needs a continuous reassessment of its vital signs with the portable electronic device.

Approximately 45 minutes later, and while the patient has been evaluated by surgeons, he becomes anxious and hurts a lot. At the same time, the screening physician receives an appropriate notification on the monitoring device. He reevaluates the patient and discovers that symptoms have worsened and decides the patient's classification in ESI category 2 and his immediate transfer to the rejuvenation chamber. There, it is found that the patient's blood pressure is below the normal limits, indicating that according to the rest of his clinical picture he advocates a possible hollow entrails rupture. A quick reassessment by the surgeons follows and it is decided to transfer him to the surgical room for further investigation and treatment. The screening physician removes the wearable device from the patient and states the end of the emergency incident.

B. *Second scenario*

"My left foot is swollen and my hump is hurting enough," says a 47-year-old with obesity arriving at the ED on an electric wheelchair accompanied by her daughter. Her medical history mentions arterial hypertension and type 2 diabetes. Vital signs are: AP 158/82 mmHg, HB: 78 beats/min, breaths 24/min, SpO_2 at 98%, temperature 37.5^{o}C.

The patient will need at least 2 resources (hematological examination, Doppler of the lower limb), so the incident is classified in ESI category 3. Her vital signs do not worry the screening staff, but as there is suspicion of deep vein thrombosis, a condition dangerous for pulmonary embolism, the patient should be re-evaluated regularly for possible dyspnea and tachycardia.

According to the IntelTriage protocol, the patient wears the device for the continuous assessment of vital signs and the monitoring by the physician of the screening starts. After some minutes, the screening physician receives a notification for 125 beats/min tachycardia and a SpO_2 drop at 87%. The patient is directly led to the rejuvenation chamber and is rapidly evaluated by a cardiologist. It is necessary to perform spiral CT, through which it is confirmed the possible diagnosis for pulmonary embolism. The physician removes the patient's electronic device and the patient is led to the coronary unit for thrombolysis.

V. RESULTS

A. *Initial list of functional requirements*

Based on the above scenarios and after an extensive literature review, the initial list of functional requirements is shown in Table II.

TABLE II. INTELTRIAGE INITIAL LIST OF FUNCTIONAL REQUIREMENTS

No	Functional requirement	Description	Ref.
1	Recording data from a biosensor device	The type of vital signals to be recorded from the device is the number of heart beats per minute and the oxygen saturation in the blood.	[11]
2	Algorithmic breathing rate calculation	The respiratory rate of the patient will be calculated algorithmically as a function of tightness and oxygen saturation in the blood.	[12]
3	Local storage of data in the biosensor device	Local data storage in the device offers the possibility of later sending data to the hospital's server, if for any reason there is a failure to send in the first attempt.	[13]
4	Function of wireless device when out of range	It is necessary to determine how the device will operate if it is not within the wireless network.	[13]
5	Encoding data to be send	Encoding algorithms will be deployed for the data to be sent from the device communication channel to the application.	[14]
6	Frequency of data transmission	The frequency of data transmission should ensure that no critical event is lost and also that it should be optimized regarding energy consumption.	[15]
7	Methods to reduce energy consumption	Activation of peripherals (eg screen, biosensors, electronic circuitry) at specific times. Low-power microprocessor modes (idle, sleep mode). Selective data delivery algorithms.	[15]
8	Patient tracking	Continuous tracking of the patient's location during his/her stay at the Emergency Department or during his/her stay at the Surgical Clinic for the first 48 hours.	[13]
9	Automatic recognition of abnormalities in vital sign measurements	Continuous monitoring of respiratory rate, heart rate, oxygen saturation, and statistical processing to detect abrupt changes of signals based on the patient's previous history levels.	[15]
10	Set a threshold for acceptable values of vital signs and the permitted time interval	The physician has the ability to set the upper/lower limit for acceptable values of vital signs, as well as the maximum permitted time that the values can be out of that range.	[16]
11	Send notifications to the physician about the worsening of the vital signs of the patient under monitoring	Any recognition of variations in vital sign values (i) based on the patient's reference level; or (ii) on the basis of the acceptable limits set by the medical practitioner, results in a notification to the physician's application, concerning the patient's ID and his current location within the hospital.	[16]

12	Visualization of the movements of patients under monitoring in an analytical visual form	The physician will be able to visualize, setting a scale of time of his/her choice, several parameters concerning the patients' stay in the individual departments of the hospital, as well as the individual transitions between the departments.	[15], [16]

B. Non-functional requirements

IntelTriage puts emphasis on the non-functional requirements that are shown in Table III.

TABLE III. LIST OF NON-FUNCTIONAL REQUIREMENTS

No	Non-functional requirement
1	Unobtrusiveness of the wearable system
2	Increased user acceptance
3	Robustness of the network infrastructure and topology
4	Security policy application that responds to the needs of critical environments, such as hospitals (cyber and physical)
5	App's usability as far as the ease of use and learnability is concerned (user-friendly design)
6	Maximum efficiency even in cases of increased load
7	Data integrity ensuring the accuracy and consistency of data over their transmission and their entire life-cycle
8	App's future extensibility and scalability if needed (adding new features)
9	Software easy test ability by supporting testing in a given test context
10	Interoperability with other hospital's systems and applications

VI. CONCLUSIONS

IntelTriage, is a system that aims to address issues in current EDs and to improve patient traffic handling. Main contribution of IntelTriage is the development of a medical decision support solution towards more precise triage in EDs and in particular for the heterogeneous population of incidents that are categorized as ESI category 3. It consists of various subsystems that implement improved patient prioritization, patient monitoring, patient location tracking, as well as provide useful business intelligence analytics and insights for the ED. The purpose of this paper, is to present its main subsystems, functional and non-functional requirements, and explain the logic behind this specific selection through senarios and reviewing current literature.

ACKNOWLEDGMENTS

The IntelTriage (Intelligent triage system for hospital emer-gency departments and clinics) project has received funding from the Ministry of Economy & Development, Special Sec-retary for ERDF & CF, Managing Authority of EPAnEK Competitiveness Entrepreneurship Innovation operational program, under grant agreement No. T1EΔK-02489.

REFERENCES

[1] C. Morley, M. Unwin, G. M. Peterson, J. Stankovich, and L. Kinsman, “Emergency department crowding: A systematic review of causes, consequences and solutions”, PLoS ONE, https://doi.org/10.1371/journal.pone.0203316, 2018.

[2] S. Trzeciak, and E. P. Rivers, “Emergency department overcrowding in the United States: an emerging threat to patient safety and public health”, Emerg. Med. J., vol. 20, pp. 402 – 405, 2003.

[3] Pan-Hellenic Federation of Public Hospital Workers, “Μεγάλη έρευνα της ΠΟΕΔΗΝ κατάσταση σε τμήματα επειγόντων περιστατικών 61 Νοσοκομείων,” 2016. [Online]. Available: https://www.poedhn.gr/deltia-typoy/item/2023-megali-erevna-tis-poedin-katastasi-se-tmimata-epeigonton-peristatikon-61-nosokomeion---synthikes-polemou-epikratoyn-sta-tep. [Accessed: 20-Nov-2018].

[4] D. R. Eitel, D. A. Travers, A. M. Rosenau, N. Gilboy, and R. C. Wuerz, “The Emergency Severity Index triage algorithm version 2 is reliable and valid,” Acad. Emerg. Med., vol. 10, no. 10, pp. 1070–1080, 2003.

[5] A. F. Dugas, T. D. Kirsch, M. Toerper, F. Korley, G. Yenokyan, D. France, D. Hager, and S. Levin, “An electronic emergency triage system to improve patient distribution by critical outcomes”, J. Emerg. Med., vol. 50, no. 6, pp. 910 – 918, 2016.

[6] S. Levin, M. Toerper, E. Hamrock, J. S. Hinson, S. Barnes, H. Gardner, A. Dugas, B. Linton, T. Kirsch, and G. Kelen, “Machine-learning based electronic triage more accurately differentiates patients with respect to critical outcomes compared with emergency severity index”, Annals Emerg. Med., vol. 71, no. 5, pp. 565 – 574, 2018.

[7] Dominik Aronsky, MD, PhD, Ian Jones, MD, Bill Raines, Robin Hemphill, MD, MPH, Scott R Mayberry, MS, Melissa A Luther, and Ted Slusser, “An Integrated Computerized Triage System in the Emergency Department”, AMIA Annu Symp Proc. 2008; 2008: 16–20.

[8] Teruo Higashino, Akira Uchiyama, Keiichi Yasumoto, “eTriage: A Wireless Communication Service Platform for Advanced Rescue Operations”, ACM IoTSP 2011, December 6, 2011, Tokyo, Japan.

[9] H. A. Chong, K. B. Gan, “Development of automated triage system for emergency medical service”, 2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES), Putrajaya, Malaysia, 2016.

[10] Dominik Aronsky, Ian Jones, Kevin Lanaghan, Corey M Slovis, “Supporting Patient Care in the Emergency Department with a Computerized Whiteboard System”, Journal of the American Medical Informatics Association, Volume 15, Issue 2, March 2008, Pages 184–194.

[11] J. Welch, B. Kanter, B. Skora, S. McCombie, I. Henry, D. McCombie, R. Kennedy, and B. Soller, “Multi-parameter vital sign database to assist in alarm optimization for general care units,” J. Clin. Monit. Comput., vol. 30, no. 6, pp. 895–900, 2016.

[12] J. Hernandez, D. McDuff, and R. Picard, “BioWatch: Estimation of Heart and Breathing Rates from Wrist Motions,” Proc. 9th Int. Conf. Pervasive Comput. Technol. Healthc., 2015.

[13] M. P. Farry, “Sensor networks for social networks,” Ieee Trans. Instrum. Meas., pp. 1–9, 2006.

[14] W. Guédria, E. Lamine, and H. Pingaud, “Enterprise Interoperability,” vol. 144, 2013.

[15] O. S. Albahri, A. S. Albahri, K. I. Mohammed, A. A. Zaidan, B. B. Zaidan, M. Hashim, and O. H. Salman, “Systematic Review of Real-time Remote Health Monitoring System in Triage and Priority-Based Sensor Technology: Taxonomy, Open Challenges, Motivation and Recommendations,” J. Med. Syst., 2018.

[16] A. P. Monitoring, T. Gao, T. Massey, W. Bishop, D. Bernstein, L. Selavo, A. Alm, and D. White, “Integration of Triage and Biomedical Devices for ’ T ’,” Pulse, pp. 34–39, 2006.K. Elissa, “Title of paper if known,” unpublished.