IoMT-Driven eHealth: A Technological Innovation Proposal Based on Smart Speakers

David Domínguez[1], Leticia Morales[1(✉)], Nicolas Sánchez[1,2], and Jose Navarro-Pando[3]

[1] University of Seville, Escuela Técnica Superior de Ingeniería Informática. Web Engineering and Early Testing (IWT2) Group, Avda. Reina Mercedes S/N, 41012 Seville, Spain
davdomvaz@alum.us.es, {leticia.morales,nicolas.sanchez}@iwt2.org

[2] G7Innovations Company, Seville, Spain

[3] Inebir Clinic, Seville, Spain
jose.navarro@inebir.com

Abstract. Internet of Medical Things (IoMT) is a technological concept applied in healthcare contexts to achieve the digital interconnection of everyday objects with the Internet in order to make life easier for people. IoMT can help monitor, inform and notify not only caregivers, but provide healthcare providers with actual data to identify issues before they become critical or to allow for earlier invention. In this sense, this paper is contextualized in Assisted Reproduction Treatment (ART) processes to reduce the number of hospital visits, reduce healthcare costs and improve patientcare, as well as the productivity of the healthcare professional. So, we present an IoMT-based technological proposal to manage and control the prescription of pharmacological treatments to patients who are carried out ART processes. In this context, we propose the integration of iMEDEA (modular system specialized in the management of electronic clinical records for ART unit) and smart speaker devices (specifically, Amazon's Alexa), as well as the validation of our proposal in the real environment offered by Inebir clinic.

Keywords: Internet of Medical Things (IoMT) · iMEDEA · Alexa · Patientcare improvement

1 Introduction

Internet of Things (IoT) is a technological concept that emerged in the 90's in the field of sensor and radiofrequency technologies. Today, IoT aims to achieve the digital interconnection of everyday objects with the Internet in order to make life easier for people [1]. When the IoT concept is applied in healthcare contexts, it takes the name of Internet of Medical Things (IoMT) [2]. Also known as healthcare IoT, the IoMT comprises the medical devices and applications connected to healthcare information technology systems via the Web. Wi-Fi enabled devices facilitate machine-to-machine communication and link to cloud platforms for data storage. In short, IoMT is a concept that combines medical devices and software applications that can connect to healthcare information technology systems using networking technologies. The IoMT can help monitor, inform and notify not only caregivers, but provide healthcare providers with actual data to identify issues before they become critical or to allow for earlier invention.

In addition, the use of this technology allows to reduce unnecessary hospital visits and the burden on healthcare systems by connecting patients to their physicians and allowing the transfer of medical data over a secure network. IoMT also could reduce healthcare costs in the coming years.

In this context, this paper describes an IoMT-based technological proposal to manage and control the ingestion of pharmacological treatments to patients. More specifically, it is contextualized with the Assisted Reproduction Treatment (ART) processes [3], which have become a very used health service by more and more sentimental couple around the world because of problems such as fertility limiting pathologies, delay in the maternity age, single-parent couples, couples and women who wish to face maternity individually [4], among others. In fact, some epidemiological studies conclude that Infertility pathologies affect 15% of the population of reproductive age in Western countries (i.e., one in six couples) and this percentage is gradually increasing every year [5]. However, these data can be extrapolated to other countries.

Despite upward trends in the use of ARTs, these ones are expensive processes whose success depends on many factors [6]. One of them is the assimilation of pharmacological treatments that patients (usually women) have to take before, during and after carrying out the ART process.

In this context, we propose the integration of: (*i*) Hospital Information Systems (HIS), which are used by healthcare professionals to carry out the monitoring and control of ART processes, as well as the medication of the patients; and (*ii*) smart speaker devices, which is going to be located in the patient's home, it is going to notify when exactly each medication must be ingested, and it is going to receive the patient's response, storing it in the system to be checked by the healthcare professional. In addition, it is important to highlight that our technological proposal has been applied and validated in the real environment offered by Inebir Clinic [19] (Spanish assisted reproduction clinic). This collaboration has allowed us to obtain valuable feedback to improve our proposal and propose future work.

Finally, this paper is structured as follows. After this introduction, Sects. 2 and 3 explain the methodology used and the results obtained, respectively. Section 4 provides further discussion, and Sect. 5 states final conclusions and some future works.

2 Materials and Methods

As mentioned above, our IoMT-based technological proposal aims to improve the control and productivity of ART professionals when they prescribe pharmacological treatments to their patients. For this purpose, our proposal has been: (*i*) designed using model-driven methodologies and collaborative work techniques for product design; and (*ii*) carried out by integrating smart speakers with commercial HIS.

On the one hand, we have used the agile version of NDT (Navigational Development Techniques) [7] which is enriched with collaborative work techniques for product design (e.g., design thinking [8], sprint design [9], among others), providing a flexible, dynamic and powerful methodological environment. In addition, NDT is framed under the MDE paradigm (Model Driven Engineering) and it also offers its software toolkit (NDT-Suite [10]) to successfully apply NDT in practical environments. In fact, NDT-Suite has been satisfactorily applied in numerous contexts: aeronautics [11], software requirement management [12, 20], healthcare [13], software process management [14], functional software testing [21], among others.

On the other hand, our IoMT-based proposal has used iMEDEA [15] (innovative MEDical Engineering Assistance) system as data source and the integrated development environment offered by Amazon. iMEDEA is a HIS solution designed and developed by G7Innovations company [16] that provides a modular technological environment with advanced mechanisms for managing ART unit whereas Amazon provides smart speaker devices (Alexa [17]), Amazon's cloud-based voice services and toolkits to develop virtual assistant solutions using the Alexa Skills Kit (ASK) [18].

3 Results

This section describes our solution proposal to control and manage of pharmacological treatments to patients who are carried out ART processes. For this purpose, Sect. 3.1 describes the architecture of our IoMT-based proposal and Sect. 3.2 describes the workflow and communications when our proposal is used in practical environments.

3.1 Architecture of Our Technological Proposal

The proposal presented in this paper has been designed with a two-layer architecture (see Fig. 1): (*i*) «client/device layer»; and (*ii*) «cloud layer» . On the one hand, «client/device layer» contains patient's IoT devices (smart speakers) and client application (web browsers) of the healthcare professional.

On the other hand, cloud layer contains: (1) «Skill Alexa4iMEDEA» , which is am integration module between Alexa and the HIS used in our proposal (i.e., iMEDEA) that is deployed in Amazon's cloud (i.e., Amazon Web Services or AWS in Fig. 1); and (2) a submodule within iMEDEA and its «Integration and Interoperability Module» , which allows synchronizing the patient's instance with his/her user account on Amazon (this submodule is represented as a yellow box in Fig. 1 to avoid complications in the graphic representation of our architecture).

Regarding «Skill Alexa4iMEDEA», this one has been designed and developed with different cloud-based components which are coded in two different levels. The first one is the *client level* where the different interactions (i.e., voice commands) are created associated with our Alexa's skill. These voice commands are interpreted by Alexa engine (*server level*). The second level is the *server level* which could be hosted in AWS or in our server. It supports Node.js and Python languages. At *server level*, voice commands are managed in order according to the main configuration file (see Table 1) defined in our skill.

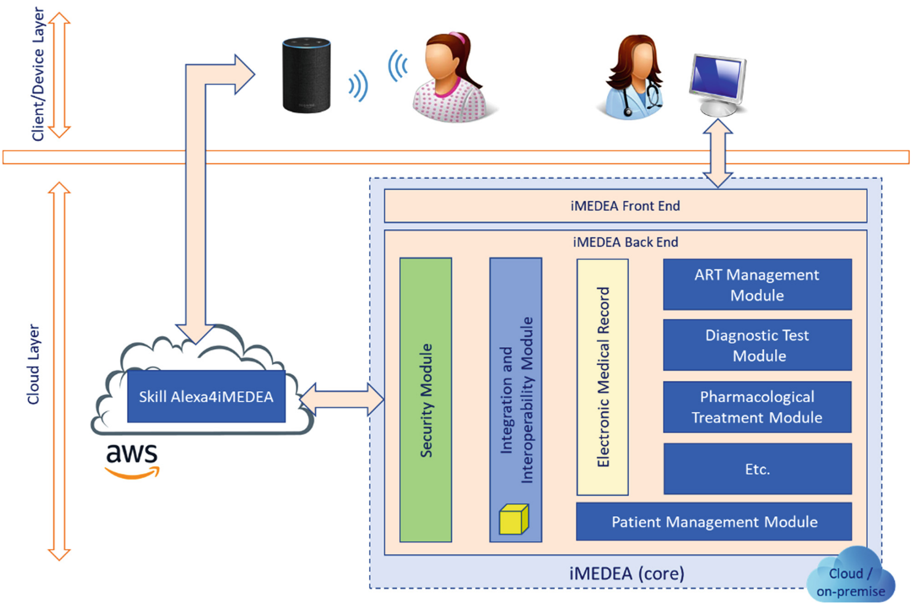

Fig. 1. Architecture of our IoMT-based proposal. (Color figure online)

Table 1. Main configuration file to manage each interaction (voice command) in our skill.

```
sb = SkillBuilder()

sb.add_request_handler(LaunchRequestHandler())
sb.add_request_handler(GeneralInteractionIntentHandler())
sb.add_request_handler(reminderInteractionIntentHandler())
sb.add_request_handler(CancelOrStopIntentHandler())
sb.add_request_handler(SessionEndedRequestHandler())
sb.add_request_handler(HelpIntentHandler())

sb.add_exception_handler(CatchAllExceptionHandler())
lambda_handler = sb.lambda_handler()
```

Each mentioned instruction in Table 1 represents the definition of a Python class in our skill to manage each voice command. For example, Table 2 shows the Python class associated with the first interaction which allows initiating the communication of our solution for Alexa.

These class contains two main functions. The first one is *can_handle* and its objective is to check if this class has to be executed. The second function is *handle*, which contains the logic of the interaction. This function returns a set of actions predefined by Alexa: speak, that is a phrase to be reproduced by Alexa; *ask*, which allows to activate our Skill (listening mode) to identify any command indicated by the user; *response*, that returns the *response object* to be sent to the Alexa device; *AskForPermissionsConsentCard*, that manages request permissions.

Table 2. Code to start communication with Alexa

```
class LaunchRequestHandler(AbstractRequestHandler):
   def can_handle(self, handler_input):
      return
      ask_utils.is_request_type("LaunchRequest")(handler_input)

   def handle(self, handler_input):
      speak_output = "Hola, ¿Que necesitas?"
      return (handler_input.response_builder.
                 speak(speak_output).ask(speak_output).response)
```

3.2 Communication Flow

Once the architecture is defined in the previous section, we are going to explain what the communication flow when our proposal is used. In this sense, we have created three on-demand interactions (voice command) to interact with Alexa: (1) *«start interaction»* ; (2) *«get active pharmacological treatments»*; and (3) *«create reminders associated with treatments»*. The behavior of these commands is shown in Fig. 2 using an UML (Unified Modeling Language) sequence diagram. However, Fig. 2 only shows the first and last interaction because the second one is very similar, and the sequence diagram could be very extensive.

It is important to mention that, before using our «Skill Alexa4iMEDEA» , it is necessary a configuration step (see at the top of Fig. 2) which is performed by the healthcare professional and consists of enabling the communication of the patient with iMEDEA using Alexa (this action automatically generates a security token by IMEDEA; this token is used in subsequent transactions). Once the patient is enabled, s/he can configure his/her Alexa device with his/her own iMEDEA's security token and start interacting with Alexa.

Once the user has been activated, patient can interact with Alexa and IMEDEA using voice commands. As mentioned above, the first interaction shown in Fig. 2 is *«start interaction»* which allows to initiating communications and, subsequently, interact using next commands. In this sense, Alexa communicates with «Skill Alexa4iMEDEA» module (into AWS) and these one communicates with «Security Module» of iMEDEA to authenticate the patient. This security module responds with rejected or successful authentication (the communication flow continues if authentication is successful).

Moreover, the second interaction shown in Fig. 2 is *«create reminders associated with treatments»* which allows creating automatically reminders. For this purpose, the patient only has to say: *«create reminders for my treatments»* (voice command). It is necessary that the patient indicates the number of days in which reminders should be created and the time of the first dose (if this is not done, Alexa ask for this information). Subsequently, «Skill Alexa4iMEDEA» module (into AWS) checks if the user is authenticated («Security Module» of iMEDEA) and obtains the list of their active treatments («Integration and Interoperability» and «Pharmacological Treatment» modules of iMEDEA).

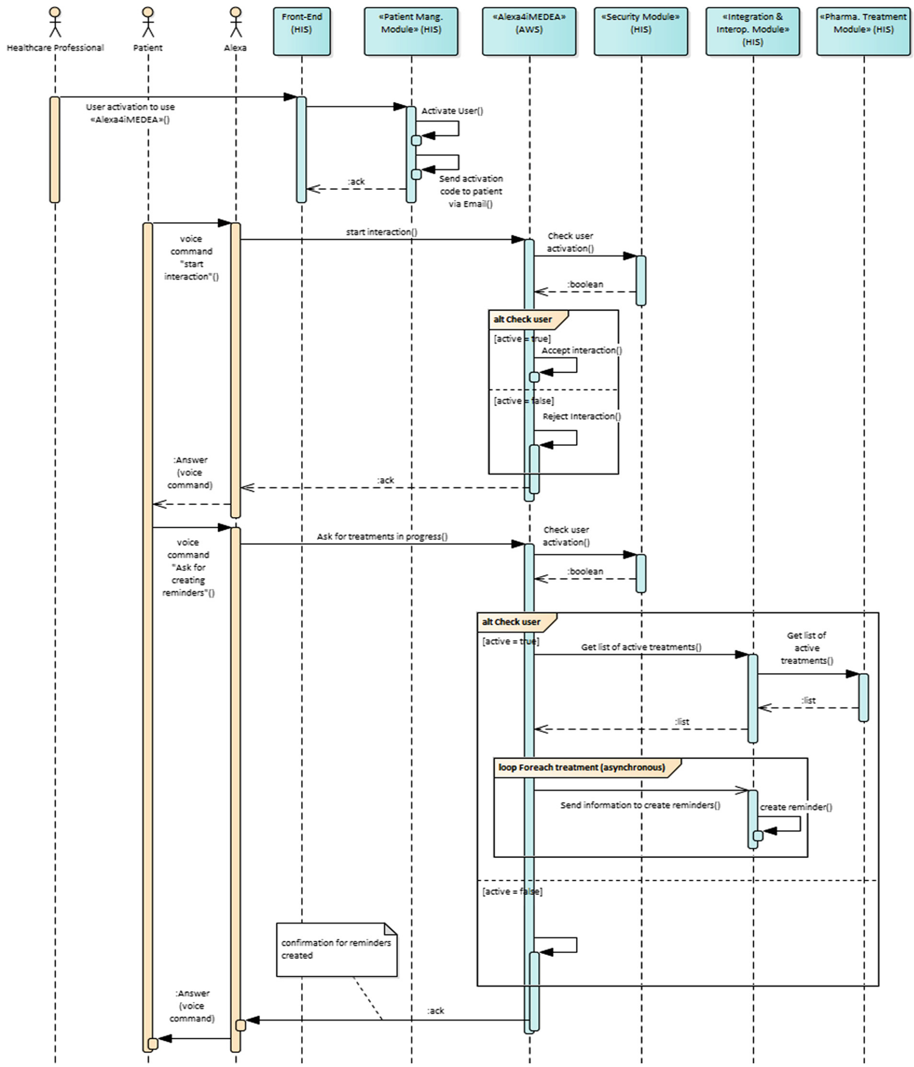

Fig. 2. Communication flow of our IoMT-based proposal and representation.

Once the request is completed, «Skill Alexa4iMEDEA» retrieves the patient's active treatments. Finally, it sends an order with all the information to create the reminders in an asynchronous way and tells the patient that soon they will be created.

4 Discussion

Once our proposal has been designed and developed, we have managed to apply and validate it in the real environment offered by Inebir clinic [19]. This validation has been carried out using the case-studies method as *proof-of-concept*.

In this sense, we have designed 7 cases of study to evaluate the performance and efficacy of our skill in the creation of reminders according to different pharmacological treatment settings. Specially, for each case study, we have conducted tests varying the number of treatments from one to three; and for these treatments we have changed the frequency of the doses between 2 h and 12 h. Also, we have modified the end date of the treatments in order to finish them during the requested days.

Figure 3 shows all cases of study and their variations, according to the number of reminders created in each case (X-axis represents the combination of the amount of treatments with their dosage frequency).

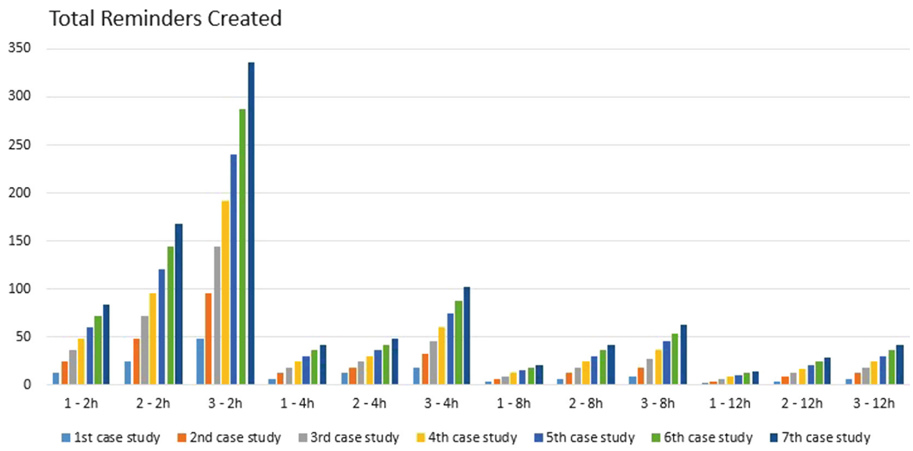

Fig. 3. Total reminders created in each case of study.

Figure 3 shows that cases where the dosage frequency is 2 h, a lot of reminders can be created. However, for all other frequencies it does not exceed 100 reminders because of issues of our preliminary design. Although user experience has been successful, we have received comments to improve the usability of voice commands between patient-Alexa to promote more human communication (question-answer). From a technical perspective, we have identified some limitations. The main one is related to the existence of limitations in the number of transactions that can be issued by our Skill.

5 Conclusions and Future Works

This paper describes an IoMT-based technological proposal to manage and control the prescription of pharmacological treatments to patients who are carried out ART processes. Our proposal aims to reduce the number of hospital visits, reduce healthcare costs and improve patient care, as well as the productivity of the healthcare professional. In this context, we propose the integration of iMEDEA (modular system specialized in the management of electronic clinical records for ART unit) and smart speaker devices (specifically, Amazon's Alexa), as well as the validation of our proposal in the real environment offered by Inebir clinic.

Finally, after carrying out this proposal, some future works are proposed: optimization of our Skill Alexa for iMEDEA through concurrent algorithms; mechanisms to facilitate the daily work of health professionals when they manually enter information into their HIS (we will consider using voice commands with Alexa); alert notifications (via voice commands from Alexa) when an critical error has been detected that could compromise the success of the ART processes; integrate our proposal into the design and development of ART processes using process modeling languages [22, 23], among others.

However, we have already started new research lines related to our proposal. Specifically, we are defining generic and abstract models that allow the design of technological solutions that are independent of the IoT device. In this sense, we could define abstract models and automatically (using model-to-text transformations) generate code associated to specific technologies (such as, Alexa, LG smart speakers[1], among others). In addition, from perspective of software product design, we plan to improve the NDT methodology when this one is used to design products with IoT device. These improvements will be related to the incorporation of prototype-driven mechanisms to facilitate the communication of users and software engineers during the design of these technological solutions.

Acknowledgments. This research has been supported by POLOLAS project (TIN2016-76956-C3-2-R) of the Spanish Ministry of Economy and Competitiveness (Spain) under ERD funds and SocietySoft project (AT17_5904_USE) of the Regional Ministry of Economy, Knowledge, Business and University (Andalucía, Spain).

References

1. Qian, Z., Wang, Y.: IoT technology and application. Acta Electronica Sinica **5**, 026 (2012)
2. Joyia, G., Liaqat, R., Farooq, A., Rehman, S.: Internet of Medical Things (IOMT): applications, benefits and future challenges healthcare domain. J. Commun. **12**(4), 240–247 (2017)
3. Zegers-Hochschild, F., et al.: The international committee for monitoring assisted reproductive technology (ICMART) and the world health organization (WHO) revised glossary on ART terminology, 2009. Hum. Reprod. **24**(11), 2683–2687 (2009)

[1] https://www.lg.com/us/smart-speakers

4. Matzuk, M.M., Lamb, D.J.: The biology of infertility: research advances and clinical challenges. Nat. Med. **14**(11), 1197 (2008)
5. Skakkebaek, N.E., et al.: Male reproductive disorders and fertility trends: influences of environment and genetic susceptibility. Physiol. Rev. **96**(1), 55–97 (2015)
6. Vaegter, K., Lakic, T.G., Olovsson, M., Berglund, L., Brodin, T., Holte, J.: Which factors are most predictive for live birth after in vitro fertilization and intracytoplasmic sperm injection (IVF/ICSI) treatments? Analysis of 100 prospectively recorded variables in 8,400 IVF/ICSI single-embryo transfers. Fertil. Steril. **107**(3), 641–648 (2017)
7. Escalona, M.J., Aragón, G.: NDT. A model-driven approach for web requirements. IEEE Trans. Software Eng. **34**(3), 377–390 (2008)
8. Design thinking (2020). http://www.designthinking.es/inicio/
9. Banfield, R., Lombardo, C. T., Wax, T.: Design Sprint: A Practical Guidebook for Building Great Digital Products. O'Reilly Media, Inc. (2015)
10. García-García, J.A., Escalona, M.J., Domínguez-Mayo, F.J., Salido, A.: NDT-Suite: a methodological tool solution in the model-driven engineering paradigm. J. Softw. Eng. Appl. **7**(04), 206 (2014)
11. Salido, A., García, J.A.G., Ponce, J., Gutierrez, J.: Tests management in CALIPSOneo: a MDE solution. J. Softw. Eng. Appl. **7**(06), 506 (2014)
12. García-García, J.A., Escalona, M.J., Ravel, E., Rossi, G., Urbieta, M.: NDT-merge: a future tool for conciliating software requirements in MDE environments. In: 14th International Conference Information Integration and Web-based Applications Services, pp. 177–186 (2012)
13. García-García, J.A., Escalona, M.J., Martínez-García, A., Parra, C., Wojdyński, T.: Clinical process management: a model-driven tool-based proposal (2015)
14. Garcia-Garcia, J.A., Enríquez, J.G., Garcia-Borgoñon, L., Arévalo, C., Morillo, E.: A MDE-based framework to improve the process management: the EMPOWER project. In: IEEE 15th International Conference on Industrial Informatics, pp. 553–558 (2017)
15. IMEDEA Suite (2020). http://g7innovation.com/imedea-suite/
16. G7Innovations company (2020). http://g7innovation.com/
17. Alexa (2020). https://developer.amazon.com/en-US/blogs/alexa
18. Alexa Skills Kit (2020). https://developer.amazon.com/es-ES/alexa/alexa-skills-kit
19. Inebir clinic (2020). https://inebir.com/
20. Escalona, M.J., Urbieta, M., Rossi, G., Garcia-Garcia, J.A., Luna, E.R.: Detecting web requirements conflicts and inconsistencies under a model-based perspective. J. Syst. Softw. **86**(12), 3024–3038 (2013)
21. Cutilla, C., et al.: Model-driven test engineering: a practical analysis in the AQUA-WS project. In: 7th International Conference Software Paradigm Trends, pp 111–119 (2012)
22. García-García, J.A., García-Borgoñón, L., Escalona, M.J., Mejías, M.: A model-based solution for process modeling in practice environments: PLM4BS. J. Softw. Evol. Proc. **30** (12), e1982 (2018)
23. Garcia-Garcia, J.A., Meidan, A., Carreño, A.V., Risoto, M.M.: A model-driven proposal to execute and orchestrate processes: PLM 4 BS. In: International Conference on Software Process Improvement and Capability Determination, pp. 211–225 (2017)