Developing a Mobile COVID-19 Prototype Management Application Integrated With an Electronic Health Record for Effective Management in Hospitals

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Abstract—*This article aimed to develop a mobile application for the management of coronavirus disease 2019 (COVID-19). We analyzed the pilot version with satisfaction through a survey and an interview with health workers from Sidi Said, a local hospital located in Meknès, Morocco, which receives patients suffering from COVID-19. Methods: We have formed a team effort that involves health professionals, specialists from various fields and who participated in the design process of this project. It is a review of the existing literature and interviews with health professionals seeking to trace all the functions of this application. The user interface graphics, whether at the hospital or patient application level, were reviewed for effective usability by a multidisciplinary team. After having had to develop the pilot version of the application, the usefulness and the gratitude of the application were evaluated by eight patients and carers by means of a utility test, based on a real scenario, a utility survey. The objective is to ensure communication between the mobile application and the decision support application at the emergency services level to facilitate the detection of people who had developed COVID-19 as well as follow-up at home for detected patients. Results: The COVID-19 mobile management application provides capture functions and can afford information that helps in the prescription of appropriate drugs to patients at home. It is used to identify people who have been in contact with people who have tested positive for COVID-19, to carry out a large-scale screening by sending alert messages to these people, and to follow up via geolocation. There is also the possibility via Bluetooth, for the monitoring of patients without the activation of the Geolocation option. The approach adopted aims to reduce congestion in hospitals by identifying people suffering from respiratory illnesses or who may be contaminated, and monitoring them remotely. We offered six functions to achieve the objective of this project. Main: Respiratory crisis journal, medication recall, appointment, survey of people contacted, personal equipment and dashboard, daily traceability and monitoring, and geolocation. We have integrated the application of the electronic healthcare registration system in hospitals. To simplify usability, the frequently used functions, which are relatively important, can be found on the main page under the heading "COVID-19 monitoring" (in French: COVID-19 monitoring), and "Medication log" (in French: Journal medication). In addition, during graphic design, art therapy was used to improve the psychological stability of the patient. Eight participants were employed for the evaluation. For scenario-based tasks, out of ten tasks, all participants can record the entries in detail. The system use scale score was*

94 points, indicating that the system was satisfactory for the patients and the staff who tested and manipulated it. Conclusion: This article confirmed that patients were satisfied with the follow-up at home and with the caregivers of the hospital. In addition, this made it possible to accurately record their symptoms and, therefore, facilitated an early detection of COVID-19. This was very useful for analyzing crisis trends, responding to a broader detection, avoiding contamination within the same family and provide effective support for COVID-19 positive patients at home. Through integration with the electronic health record, patient health care information can be used by health care decision-makers to manage treatment plans and support medical interventions. Currently, all patients who have been followed remotely are cured. We intend to generalize this concept for the monitoring of other diseases than COVID-19 later.

Key words: Artificial immune system (AIS) techniques, coronavirus disease 2019 (COVID-19), decision support system, Electronic health record (EHR), mobile application

I. Introduction

ON January 30, 2020, the World Health Organization (WHO) designated an outbreak of a novel coronavirus not seen before in humans to be a “public health emergency of international concern”; this was followed by the declaration of a pandemic on March 11, 2020 [1], [2]. The pandemic traces its early beginnings to the report of a cluster of 27 unexplained pneumonia cases in late December 2019 originating from seafood and live animal market in Wuhan, Hubei Province, China [5]. Severe Acute Respiratory Syndrome coronavirus 2, previously referred to as 2019-nCoV, is the virus responsible for causing coronavirus disease 2019 (COVID-19) [3], [4]. In the case of Morocco, the Ministry of Health declared 1113 confirmed cases in Morocco having COVID-19. Given the increase in infection, a new approach has been proposed, which consists of reducing congestion at the level of emergency services by offering remote monitoring via a mobile application connected with the hospital. In this article, we discuss our approach, present the architecture of our mobile application, and illustrate the connection of our application to the electronic health record (EHR) of the patient.

II. Clinical Presentation of COVID-19

The symptoms of COVID-19 are similar to other viral upper respiratory illnesses, which include fever, cough, fatigue, and dyspnea [7]. The differential diagnosis of COVID-19 should be tailored to the patients, their presenting symptoms and comorbidities. Influenza, respiratory syncytial virus, other viral illnesses, and bacterial pneumonia should be considered, as well as other pulmonary diseases (i.e., pulmonary embolism). Completing a thorough, yet focused history or physical examination and obtaining a collateral history from family members are vital. Aside from pulmonary symptoms, patients with COVID-19 positive may initially present, with more vague complaints including diarrhea, lethargy, myalgias, and nausea [11], [12]. Patients may also experience headache, confusion, vomiting, pleurisy, sore throat, sneezing, rhinorrhea, and nasal congestion [9], [10]. A case series of 41 patients (median age 49.0 years) with COVID-19 from Wuhan province, China, found the most commonly reported symptoms were cough (76%), fever (98%), or dyspnea (55%) [16]. In the same case series, patients also reported myalgias or fatigue (44%), productive cough (28%), headache (8%), hemoptysis (5%), and diarrhea (3%) [16]. In a nationwide study of COVID-19’s cases across China, the most common symptoms included cough (68%), fever (44%), fatigue (38%), sputum production (34%), and shortness of breath (19%) [11]. Fever was not a predominant symptom at the time of initial presentation. In patients with more severe disease, dyspnea may be present in 37% of patients and progress to acute lung injury in 15% of patients [17]. One study of 204 patients with confirmed COVID-19 suggests 48.5% of patients have gastrointestinal (GI) symptoms [18]. These symptoms may include anorexia (83.8%), diarrhea (29.3%), vomiting (0.8%), and abdominal pain (0.4%). Seven out of the 204 patients had only GI symptoms with no respiratory symptoms [7].

Three major trajectories for COVID-19 have been described: a mild disease with upper respiratory symptoms, nonsevere pneumonia, and severe pneumonia complicated by acute respiratory distress syndrome (ARDS) necessitating aggressive resuscitative measures [11]. Anywhere from 17% to 29% of patients may develop ARDS [11], [12]. Other complications of COVID-19 include secondary bacterial infection, acute kidney injury, septic shock, ventilator-associated pneumonia, and cardiac injury [7], [11], [12].

III. Disturbances in the Hospital Environment

The emergency department is one of the critical infrastructures of a hospital [13]. Often, it confronts events or exceptional situations, as the growing number of patients resulting epidemic episodes (e.g., natural disasters, terrorist attacks, accidents, and the like), reduction of resources, and appearance of complex pathologies requiring considerable time processing. The consequences of these disturbances on the hospital emergency services can vary from a simple peak of activity to a situation of crisis, passing through situations of tension [7].

IV. Situation of Tension in the Emergency Service

The situation of tension in an emergency service refers to an imbalance between the load flow in care and the capacity of care [14]. The load flow in care that is quantified by the number of patients entering, the number of patients leaving, and the number of patients abandoning emergencies without support. The capacity for care (or human and material resources) measured by the number of doctors, nurses or auxiliaries, and the number of boxes, beds, and the medical equipment. Three main identified factors can influence the balance between the load flow in care and the capacity of care. That is, first, factors influencing the number of admissions suchlike seasonal epidemics (e.g., influenza, colds, gastroenteritis, bronchiolitis, etc.), seizures, availability of upstream and downstream doctors (on days, nights, or holidays). Second, factors are influencing the speed of management and, therefore, the capacity to produce care (i.e., the speed of radiological examinations, the availability of resources, and so on). Finally, factors influencing downstream management (for example, internal and external transfer capacity, availability in downstream and outpatient care services and the like).

Different perspectives have also outlined situations of tension that are bounded by different factors. From the patient flow perspective, a tense situation in an emergency department refers to an imbalanced load out of the caring capacity of a facility, in which the marginal value exceeded. From these factors, the care load and the capacity of care depicted. Their definitions are as follows [15].

1) Care load: is based on numbers of the entering and the outgoing patients, runaways, and the number of untreated patients leaving emergency services.
2) The capacity of care represents the emergency department patients' number being held during a given period, considering human and material means. This includes the number of doctors, nurses, and care auxiliaries, number of boxes, beds and medical equipment that is estimated by emergency department employees. Concerning the capacity of the care, the following two types of capacity are defined.
   – The required capacity: the gain of the resource working with maximum capacity.
   – Available capacity: the capacity of the resource subtracting from the times of dysfunction.

Furthermore, the main factors that can affect balance include the following.

Table 1. WHO Case and Contact Definitions for Global Surveillance of COVID-19.
Suspected case A. A patient with acute respiratory illness (fever and at least one sign/symptom of respiratory disease, e.g., cough, shortness of breath), AND a history of travel to or residence in a location reporting community transmission of COVID-19 disease during the 14 days prior to symptom onset. OR B. A patient with any acute respiratory illness AND having been in contact with a confirmed or probable COVID-19 case (see definition of contact) in the last 14 days prior to symptom onset. OR C. A patient with severe acute respiratory illness (fever and at least one sign/symptom of respiratory disease, e.g., cough, shortness of breath; AND requiring hospitalization) AND in the absence of an alternative diagnosis that fully explains the clinical presentation. Probable case A. A suspect case for whom testing for the COVID- 19 virus is inconclusive. OR B. A suspect case for whom testing could not be performed for any reason. Confirmed case A person with laboratory confirmation of COVID-19 infection, irrespective of clinical signs and symptoms. See laboratory guidance for details: https://www.who.int/emergencies/diseases/novel-coronavirus- 2019/technical guidance/laboratory-guidance. Contact A contact is a person who experienced any one of the following exposures during the 2 days before and the 14 days after the onset of symptoms of a probable or confirmed case. • Face-to-face contact with a probable or confirmed case within 1 m and for N15 min. • Direct physical contact with a probable or confirmed case. • Direct care for a patient with probable or confirmed COVID-19 disease without using proper personal protective equipment. OR • Other situations as indicated by local risk assessments.

9Note: Sources: www.who.int/publications-detail/global-surveillance-for-human-infection-with-novel-coronavirus-(2019-ncov).

– Factors affecting the number of inflows (patient flows): seasonal epidemics (influenza, colds, gastroenteritis, bronchiolitis, etc.), accidents (works, factories, and road accidents).
– Factors influencing fast care and, therefore, the capacity to produce cares, as such the nursing staff competencies (experience feedback, etc.), internal and external transfer capacity (availability of downstream care services).

The application we offer for remote monitoring of patients will reduce the load on the emergency department and allow doctors to work in less stressful conditions.

V. Initial Approach to COVID-19 in the Emergency Department

An emergency medicine approach to COVID-19 should focus on identifying and isolating patients at risk for infection, informing hospital infection prevention and local public health authorities, and engaging infectious disease and other specialists early in care [19]. The WHO has established case and contact definitions for COVID-19 to standardize global surveillance (see Table 1). Most patients with confirmed COVID-19 have had a subjective or confirmed fever and/or symptoms of acute respiratory illness (e.g., cough, difficulty breathing) [12], [18]. In concert with clinician judgment regarding patient presentations compatible with COVID-19, CDC guidelines prioritize patients from defined populations for further evaluation and testing as persons under investigation [7] (see Table 2). These criteria are not exhaustive, and patients with an unestablished etiology or equivocal history of exposure may be considered for further testing on an individual basis [12]. Confirmed local COVID-19 cases in the setting of known community transmission should reduce the threshold for further COVID-19 evaluation in the ED. Collaboration with local and state public health departments is strongly recommended [11], [12].

It is in this context, our approach aims to make an early detection. The application will make it possible to detect people who have been in contact with people detected positive.

Those people who have no symptoms will be monitored via the developed application.

The application will recommend to these patients the drugs to be followed with their doses according to the protocol adopted by Morocco, as well as the food supplements that must be taken to strengthen the immune system.

A. Overview of the AIS Techniques

The AIS field, being inspired by the natural immune system of several species, helps ambitious practitioners to develop systems that operate within environments facing similar constraints that natural immune system deals with biologically. In this context, De Castro and Timmis define the AIS as “the adaptive systems, inspired by the theories of the immunology, as well as the functions, the principles and the immune models, to be applied to the resolution of problems. . .” [20]. The immunity is subdivided into two distinct systems: the innate immune system and the adaptive immune system. The adaptive immune system has three principal processes: negative selection, clonal selection, and immune network [21], whereas natural dendritic cells are the link between the innate and adaptive immune system.

B. Immune Memory

Many theories were proposed to explain the immune memory [18], [21]–[23], [29]. Two theories are adopted. According to one of the theories, the adapted memory cells are long-lived, surviving for up to the lifetime of the organism [23]. The other theory postulates that the adapted B-cells are constantly restimulated by traces of antigens that are retained in the body for years [29], [32]. Memory cells are reactivated upon detection of pathogens, which are structurally similar or identical to those that led to their creation [32].

C. Negative Selection

The purpose of negative selection is to provide tolerance for self-cells, wherein, the thymus is a gate against the non-self-antigens, and the T cells representing non-self-antigens, are destroyed in this organ. All the T-cells retiring of the thymus and circulating in the body are set tolerantly toward the self [22], [32].

The analogy between the immune system and the proposed decision support system, which will communicate with the mobile

Table 2. Analogy Between the Natural Immune System Principle and the Developed System of COVID-19 Management.

Natural immune system	AIS applied in our hospital emergency context
Body	EHR
Self	Normal pathway of patient
Infected Cell	Disturbed pathway
Non-self (antigen) antibody	False pathway
Lymphocyte (B)	Control decisions
	Combination of control decision for detected disturbance
Affinity	Adequacy between the correction actions and disturbance
	Data base
Memory cells Response strategy	Immune memory based algorithm

application, is detailed in the following section.

VI. Biological and AISs

It is assumed that the purpose of a biological immune system is to protect its host organism from toxic substances and to do so in a way that minimizes harm to the body and ensures its continued functioning [28]. From an artificial intelligence point of view, biological immunity has many interesting features. The biological immune system is an intrinsically distributed system, with no central command organ (distribution feature). It accomplishes detection, identification, reaction, and evaluation functions (integration feature) to defend the body against a great variety of threats based on a limited number of concepts and mechanisms (genericity feature) [28]. It can memorize disease-causing elements (learning feature), and to reuse this knowledge during a future encounter with similar or identical substances (adaptation feature). These features are achieved based on several immune mechanisms, which involve detection of harmful elements, stimulation of immune cells, self-tolerance, coordination, adaptation, optimization, and memorization of responses [32].

VII. System Overview

The main objective of this article is to develop a vital supporting tool for hospital decision-makers to strengthen the quality of their decisions for patients who may be carriers of COVID-19.

A. Global Architecture The basic idea is that communication will be made between a decision support system implemented in the hospital and a mobile application for individuals.

The case of Morocco and other countries that have made containment as a means of limiting contamination gave rise to the outbreak of COVID-19 within families prompted us to think about a tool that will help to provide early detection and follow-up both at home.

The principle is that patients who probably have COVID-19 after entering their symptoms on the application will receive several directives that allow their isolation (see Figure 1).

Remote monitoring may be carried out. And prescriptions of advice on

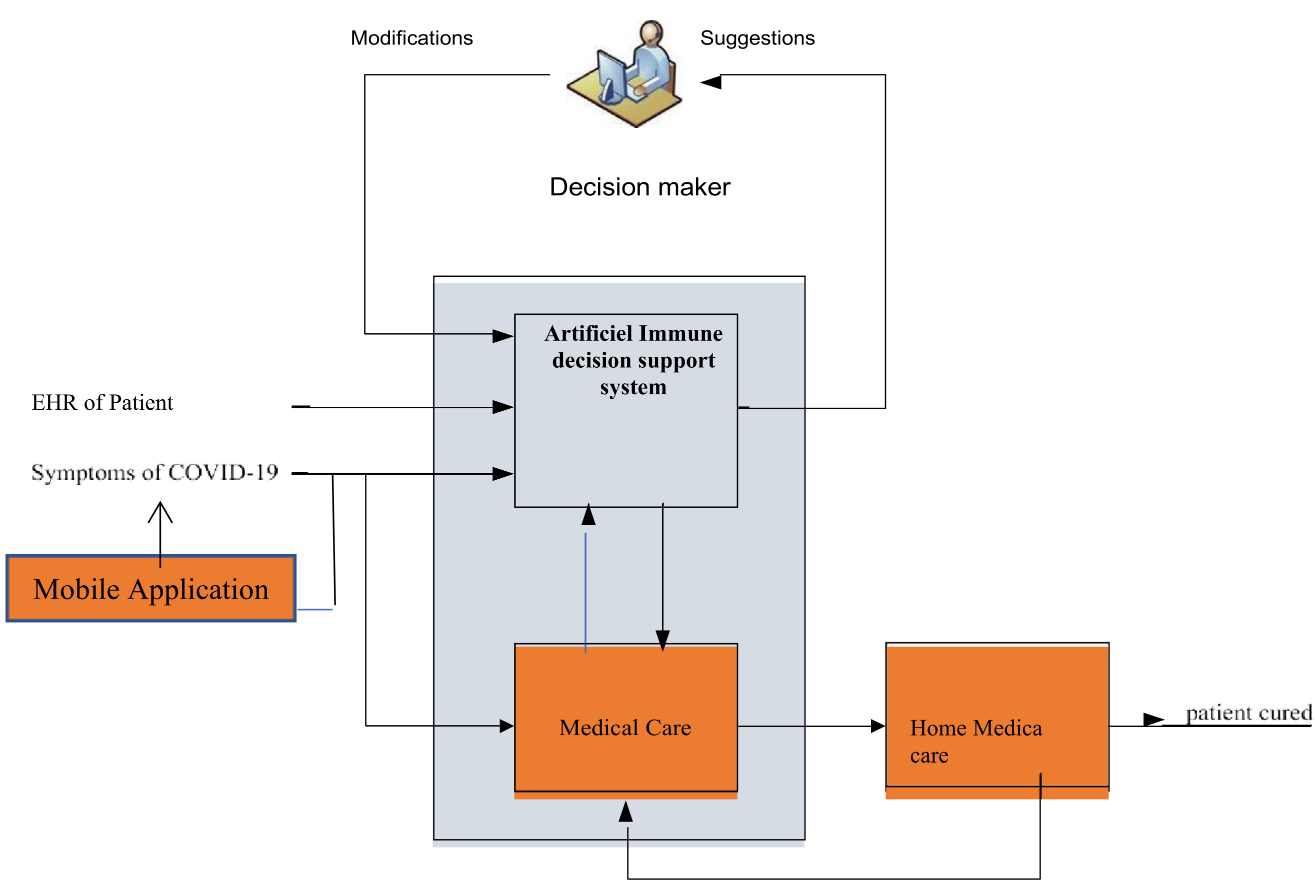

Figure 1. Position of an immune decision support system suggested in a control system architecture for patients with COVID-19.

medications and food may be provided (protocol adopted in Morocco). More detailed description of the foods and supplements that should be taken.

The objective is to describe a method of hygiene for patients and early detection for them to isolate them and limit contamination.

The main objective of this article is to develop a vital supporting tool for hospital decision-makers to strengthen the quality of their decisions due to the massive flow of patients with positive COVID-19. The fundamental idea is to detect traces in the patient record.

B. Self-Cell Representation Self-cells represent normal situations of EHR. In this article, we suggest a model to represent and structure knowledge related to normal situations of EHR. The model includes five attributes as presented in the following equation:

$$E = \{Fj, Cj, Fj, SBj, STj, Cvj\} \quad (1)$$

where

Fj flu;
Cj cough;
Fj fever;
SBj shortness of breath;
STj sore throat;
Cvj recent contact with person with COVID-19.

Consequently, we present a route proposal that shows how our application may develop its responsibility to contribute to the early detection and appropriate referral of possible cases of the COVID-19, with the goal to contribute to prevention of the overall community spread of the virus in Morocco (see Figure 2).

C. Antigen Representation A disturbance is any kind of event that affects a pathway of patient. We characterize a disturbance as a vector of patient *i* with *j* attributes describing the affected pathway

$$Vi\{\text{Flu Cough Fever Shortness of Breath Sore Throat contact with person with COVID-19.} \quad (2)$$

Our goal is to identify common sequences from data that can constitute clinical pathways. To do this effectively, we introduce an element called immune memory and negative selection to represent unique visitor content. For each patient we will have a unique combination: {Flu Cough Fever Shortness of Breath Sore Throat contact with person with COVID-19}.

D. Representation of B Cells The control strategies are represented by the "B cells" that allow the recognition process and neutralize the antigen

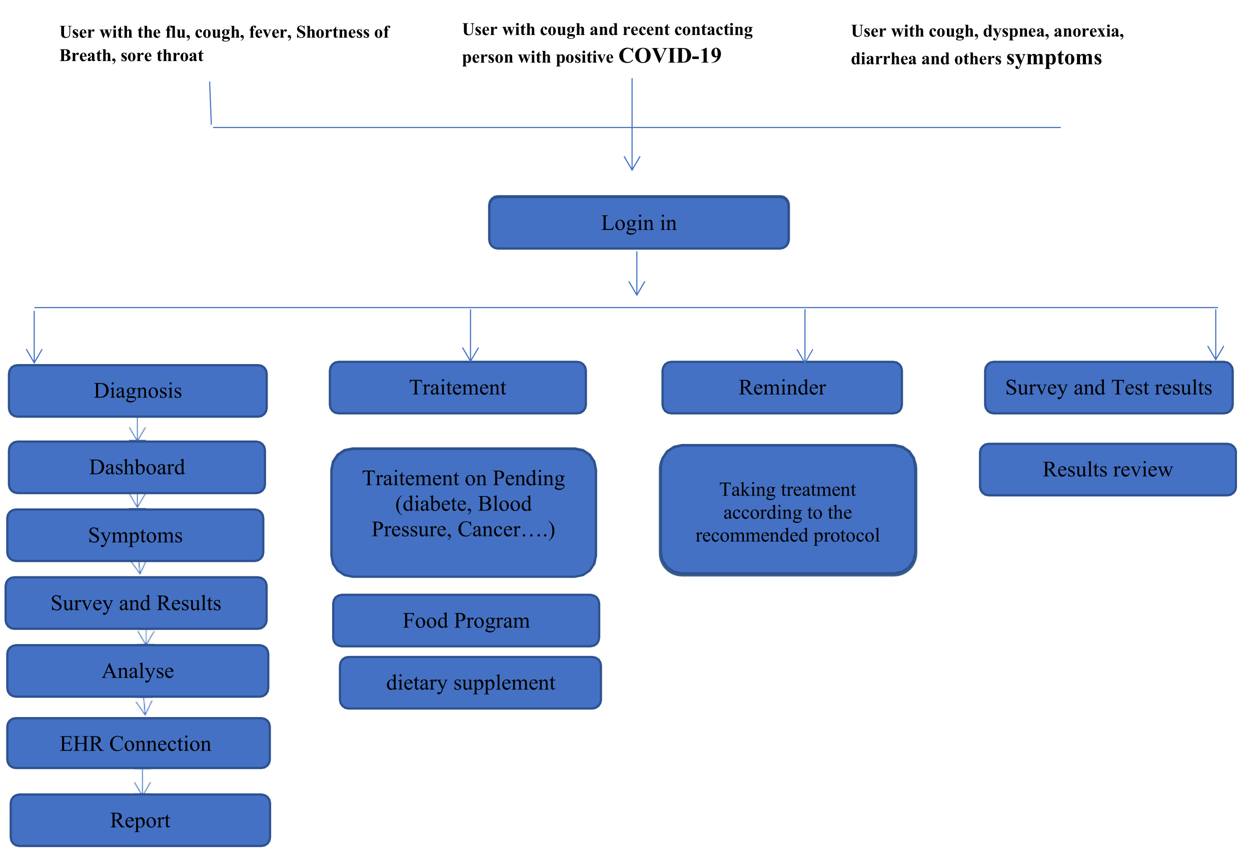

Figure 2. Route of attention in the mobile application of users with suspicion of COVID-19 in the community.

detected in the sphere concerned. They aggregate with one or more decision controls (antibodies) that react each time the disturbance occurs. Therefore, the system must create a B cell identical to each detected antigen. Equation (1) illustrates the definition of independent B-cells that receptors are a prerequisite that has the structure similar to that of the antigen that has been described below [see (3)]. The set of receptors, epitopes, and antibodies is equal to the B cells. According to the model suggested in, a control decision can have the value 0 or 1. Whether the antibody is operated or activated, the similar epitope indicates the value 1 and the value 0 is assigned to it otherwise. Epitopes are the activators of antibodies in these cases.

1) Learning:

This step aims to produce sets of non-self-cells using periodic comparisons between normal situations (self-cells) and the state of the new patient with probably COVID-19. We highlight matching ratios to quantify existing distances in given situations, using data collected from the facts. These measures are designated by *Pi* and the elements of

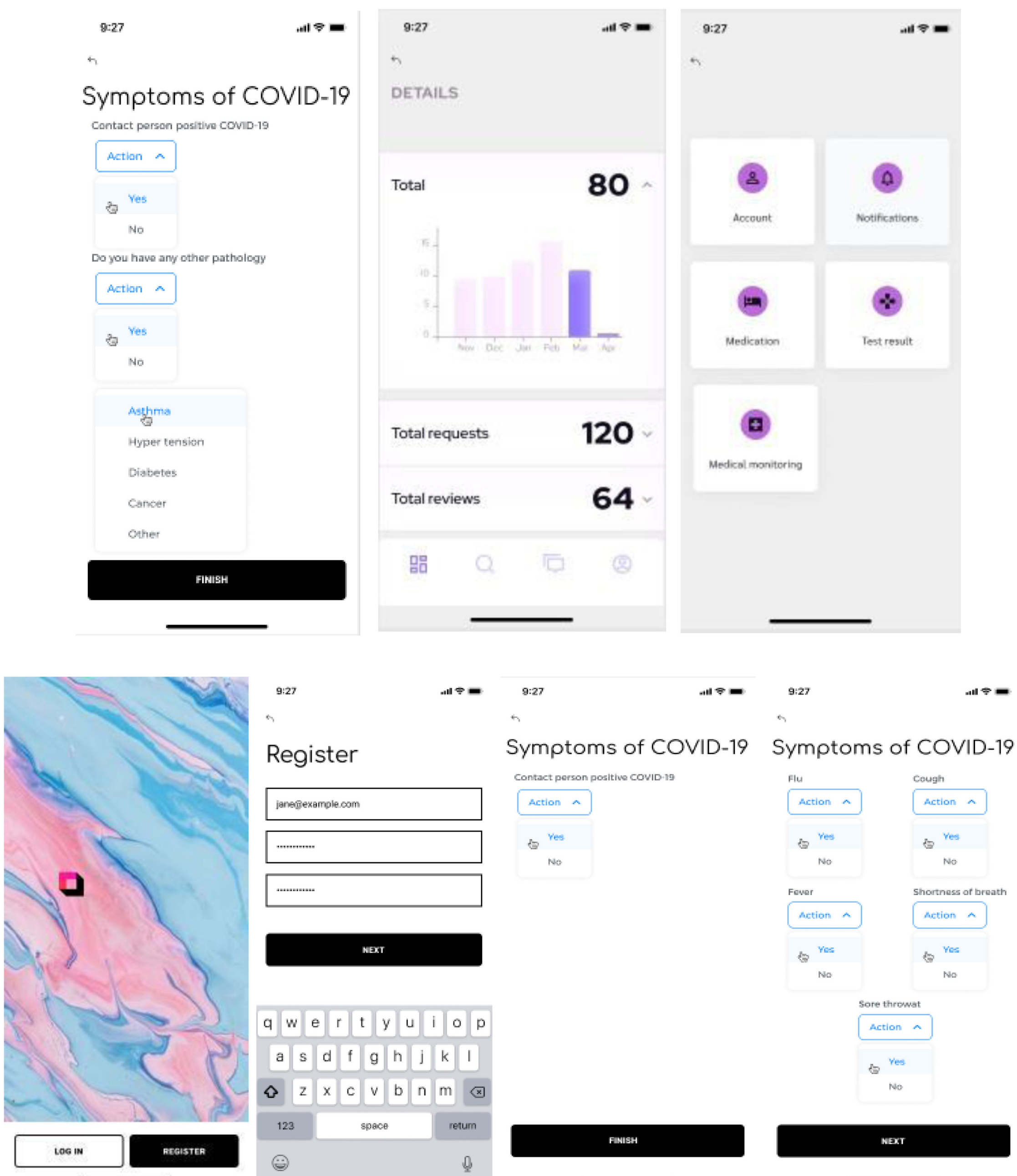

Figure 3. COVID-19 screening application interfaces.

the set *P* with respect to testing their similarities. The matching rate is calculated mathematically by adapting the following equation:

$$\text{Mat}(Pi, P) = \frac{100}{6} \times \sum_{1}^{6} \alpha i. \quad (3)$$

Here, the "Mat (*Pi, P*)" represents the corresponding percentage (%). The "*Pi*" indicates a normal patient among the set "*P*." *Pi* determines a situation. Attribute values are extracted from the database. ***αi*** is calculated using the following method:

$$\alpha i = \begin{cases} 1 \text{if} P^j = p_i^j \\ 0 \, \text{else} \end{cases}. \quad (4)$$

The "P^j" is the "*j*"th attribute of a "*P*" situation captured from the database. The ≪ *Sij* ≫ is the "*j*"th attribute of a "*Pij*" situation captured from the database. When the adequacy rate is lower than the coverage already fixed "1"e; therefore, the situation is classified as abnormal and will then be added to the *R* set of patterns. To close this process, the set *R*, this includes various types of deviant symptoms, displays the most significant abnormal patients. In fact, it is used in the next steps to identify the patient that has occurred.

The problem in Morocco as well as in other countries is the limited number of places in COVID-19 services in hospitals. The objective is to ensure the follow-up of patients at home via our application, to patients who do not have breathing difficulties or who do not require care.

The other advantage is the information via a message on the mobile phones of the patients who have already contacted people detected positive so that they remain confined at home, in order to avoid the contamination of other people and to limit the perimeter of the contamination. This strategy will allow a reduction in contamination and early detection of COVID-19 in its early stages to facilitate its treatment and reduce contamination. The illustrations of the interfaces of the mobile application setup to ensure isolation and early detection for patients are presented in Figure 3.

The advantage of our application is that it gives the user the choice for monitoring not only just on the geolocation function but also by ensuring the correct activation of his Bluetooth if he does not wish to activate his position to ensure the information security.

VIII. Conclusion

COVID-19 is a novel coronavirus that has affected an unprecedented number of people to date. Patients typically present with a combination of fever or cough and have a history of exposure to either a close contact with COVID-19 or travel to an affected geographic area.
The applications implemented are used to early recognition and isolation of a patient with COVID-19 at home and in the ED may help decrease exposure to other patients and healthcare personnel. Future research is necessary to expand our collective knowledge of COVID-19 and optimize patient outcomes.

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