Developing and implementing an automated self-monitoring system during COVID-19 pandemic in Malaysia: The CoSMoS (COVID-19 Symptoms Monitoring System) study

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Abstract

Background: There was an urgent need of developing an automated COVID-19 symptom monitoring system during the COVID-19 pandemic to reduce the burden of the healthcare system and to provide better self-monitoring at home.

Objective: This paper aims to describe the development process of CoSMoS (COVID-19 Symptoms Monitoring System) and the lessons learned. We describe all the essential steps from clinical perspectives and technical approaches in designing, developing, and implementing the system during a pandemic.

Methods: CoSMoS was developed in three phases: (1) Requirement formation to identify clinical problems and drafting the clinical algorithm. (2) Development-testing iteration using agile software development method. (3) Implementation setup to design an effective clinical implementation workflow using repeated simulations and role plays.

Results: A total of 19 days was used to complete the development of CoSMoS. In phase 1 (requirement formation), we have identified three main functions: (1) daily automated reminder system for patients to self-check their symptoms, (2) safe patient's risk assessment to guide patient in clinical decision making, and (3) active telemonitoring system with in-time phone consultation. System architecture of CoSMoS involved 5 components: Telegram instant messaging, clinician dashboard, system admin (backend), database, and Develops infrastructure. The implementation setup of CoSMoS involved the consideration of the COVID-19 infectivity and patient safety.

Conclusions: Developing a patient's symptoms monitoring system within a short period of time during a pandemic is feasible using the Agile development method. Time factor and communication between technical and clinical teams were the main challenges in the development process. Lessons learnt from this development would guide the future development of eHealth innovation in a pandemic.

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Abstract

Background: There was an urgent need to develop an automated COVID-19 symptoms monitoring system during the COVID-19 pandemic to reduce the burden of the healthcare system and provide better self-monitoring at home.

Objectives: This paper aims to describe the development process of CoSMoS (COVID-19 Symptoms Monitoring System), which consists of a self-monitoring algorithm-based Telegram bot and a teleconsultation system. We describe all the essential steps from clinical perspectives and technical approaches in designing, developing, and integrating the system into the clinical practice during the COVID-19 pandemic and lessons learned from this development process.

Methods: CoSMoS was developed in three phases: 1) Requirement formation to identify clinical problems and drafting the clinical algorithm. 2) Development-testing iteration using the agile software development method. 3) Integration into clinical practice to design an effective clinical workflow using repeated simulations and role-plays.

Results: A total of 19 days was used to complete the development of CoSMoS. In phase 1 (requirement formation), we have identified three main functions: daily automated reminder system for patients to self-check their symptoms, safe patients' risk assessment to guide patients in clinical decision making, and active telemonitoring system with an in-time phone consultation. The system architecture of CoSMoS involved five components: Telegram instant messaging, clinician dashboard, system admin (backend), database, and DevOps infrastructure. The integration of CoSMoS in clinical practice involved the consideration of the COVID-19 infectivity and patient safety.

Conclusions: This study demonstrated that developing a COVID-19 symptoms monitoring system within a short time during a pandemic is feasible using the agile development method. Time factor and communication between the technical and clinical teams were the main challenges in the development process. The development process and lessons learned from this study can guide future development of the digital monitoring system in the next pandemic, especially in developing countries.

Keywords: COVID-19; coronavirus disease; home monitoring; symptoms monitoring; system; teleconsultation; development; ehealth; digital health; mhealth; health services research; telesurveillance; infectious disease; app.

Introduction

To combat COVID-19 pandemic, digital technology has been used extensively for health information dissemination, contact tracing [1], population surveillance and forecasting modelling [2]. It provides a platform for real-time updates of COVID-19 cases, performs modelling studies to forecast COVID-19 disease activity and disseminate public-health education [3]. However, there are issues related to technology use during a pandemic; there are occasions when urgency supersedes accuracy, which may compromise patient and public safety. The technology's accuracy and security must be considered carefully and scrutinized systematically to ensure patients' safety. Also, false information may cause unnecessary alarm and chaos in the population or fail to detect or monitor those at risk of infection [4]. Privacy and data protection concerns have been raised with large scale digital data collection during the pandemic [5]. Therefore, there is a need for research, risk assessment, and pilot study before technologies roll out to the public to avoid harms.

During the COVID-19 pandemic, several COVID-19 remote monitoring tools were developed and rolled out to reduce the burden of the healthcare system freeing up the hospital spaces. In France, Covidom, a web-based application was used as a remote surveillance tool for COVID-19 patients with mild-to-moderate symptoms to preserve medical resources for more severe patients and limit in-person interactions during the pandemic [6]. COVID-19 symptoms monitoring tools could potentially reduce the burden of the healthcare system. A practical and systematic structure is required to link the digital monitoring tools with the teleconsultation and local healthcare service system. However, a detailed description of the developmental process and practical operational steps in developing a digital monitoring system for urgent use in a pandemic was lacking in the current literature.

With increasing COVID-19 cases in Malaysia since March 2020, a total number of 70,236 confirmed COVID-19 cases in Malaysia (updated 5th December 2020). It is estimated that for every positive Covid-19 patient diagnosed, there are 16 other suspected Covid-19 patients, i.e. patients under investigation (PUI) and asymptomatic close contacts to be taken care of in Malaysia. These patients were quarantined and required daily follow-up [7]. In Malaysia, PUI and close contact of a confirmed case who was fit to be discharged home were given a home surveillance tool, a check-box list of COVID-19 symptoms [8]. Public health officers from the district health offices would call each patient via phone to monitor their symptoms daily for up to 14 days. This manual surveillance work is time-consuming and labour-intensive. Hence, there is an urgent need to use digital technology to monitor PUIs and close contacts during this COVID-19 to reduce the burden of the healthcare system in Malaysia.

Conventionally, digital health systems are developed based on the Software Development Life Cycle (SDLC) models such as Waterfall, Spiral, V-shaped and Rapid Application Development models [9]. Agile model is preferred for this CoSMoS development because it uses an adaptive approach that easily adapts to changing requirements. This characteristic is important because the guidelines and clinical evidence of COVID-19 were changing rapidly, especially in the early phase of the pandemic, which would change the requirements (expressed as user stories) during the development. Agile method is more appropriate and feasible to develop a digital health application within a short period during a pandemic.

The development is a time-intensive process requiring the experts' commitment, and in this context, both the expert in digital software development and the healthcare professionals who are actively involved in providing care during the pandemic. This paper aims to describe the development process of a COVID-19 monitoring system using the agile model within a short period during the COVID-19 pandemic, and the lessons learned.

Methods

Overarching development framework and phases

This agile software development life cycle was used to develop CoSMoS because of its urgent need for COVID-19 suspected patients. The development of CoSMoS was divided into three phases: requirement formation; development-testing iteration and integration into the clinical practice. All requirements, development, and testing work were conducted online (via Zoom, WhatsApp, Slack, Trello and email). No physical meeting was held due to the COVID-19 movement control order (lockdown) in Malaysia. The whole development from study inception (21st March 2020) to the launching of CoSMoS (9th April 2020) took 19 days. The detailed timeline is shown in Table S1 (Multimedia Appendix 1). This study was approved by the University of Malaya Medical Center Medical Research Ethics Committee (MECID No. 202043-8434).

Development and research team

An interdisciplinary team-based approach, which was commonly used for mHealth solution in the literature, was adapted in the development of CoSMoS [10]. The core team, which was in charge of the overall study inception, development and execution, comprises primary care physicians (n=6) and computer science academicians (n=3), patient advocate (n=1), and an eHealth research fellow (n=1). The clinical team (six primary care physicians and eHealth research fellow) was responsible for the content of CoSMoS and the integration of CoSMoS into the clinical practice, including the workflow, monitoring and teleconsultation. The technical team who was in charge of the system development consists of the three computer science academicians, eHealth research fellow (n=1), students and graduates from the Faculty of Computer Science and Information Technology (n=26) and one user experience (UX) designer. The technical development process was led by an associate professor in computer science, the expert in software development and agile model, overseeing the development process, designing the system architecture, task and workforce management, and supervising the developers. A high number of technical team members volunteered to develop CoSMoS due to play a part contributing to combating the pandemic. The eHealth research fellow straddled across all teams and acted as the project coordinator between the clinical and technical teams. There were two postgraduate clinical master students in primary care medicine involved in integrating CoSMoS into the clinical practice (n=2).

Phase 1: Requirement Formation

Problem identification and requirements

The core team first met via Zoom to explore the problems in depth. This discussion was led by the clinical team, which consisted of a panel of seven experts in primary care health services, infectious disease, and health informatics. The panel obtained expert input from the district health officials and infectious control team from the University Malaya Medical Centre (UMMC) to have a clearer picture of the current COVID-19 situation.

The objectives of this discussion were to 1) identify the major problems in the process of home monitoring PUIs and close contacts and limitations of the existing system, 2) identify areas that digital technology could help to reduce the burden of the healthcare workers and to provide a better home monitoring service, 3) Identify the target users of CoSMoS system.

The problems identified were then converted to the requirement of the system, including the functions and features. The integration of CoSMoS into the existing clinical workflow was also discussed.

Algorithm and Content Drafting

With the list of requirements at hand, the clinical team started to draft the content and algorithm of CoSMoS. The clinical expert panel developed the clinical decision-making algorithm based on the World Health Organization (WHO) and the Malaysian Ministry of Health (MOH) guidelines of COVID-19 monitoring [7,8]. A decision tree method was used to develop the clinical algorithm, establish whether a patient is safe to continue home monitoring, or a patient should call the health care workers (HCW) for teleconsultation [11]. The panel selected the variables to be included in the decision tree and assessed the importance of each variable in clinical decision making. We also considered the selection of clinical relevance variables when developing the algorithm. After the variables were selected, a decision node was determined, representing a choice that would divide the patients into asymptomatic or symptomatic. An If-then-else rule was used to create a decision tree pathway. The clinical team tested the algorithm using different clinical scenarios and revise the algorithm iteratively.

Phase 2: Development-Testing Iteration

The requirements and the contents drafted were presented to the technical team. The technical team explored potential solutions to achieve the requirements. The technical team reviewed several software development platforms and tools, and selected the suitable ones based on their suitability to deliver the solution, availability of development resources including the teams existing skill sets, security, affordability to the end-users, and cost.

Continuous Integration Continuous Deployment (CI/CD)

The development of the CoSMoS system involved several short cycles comprising activities of elicit requirements – develop and test – review and feedback - revise requirements. To enable swift flow from one activity to the next within a cycle, uninterrupted integration of deliverable (software codes) of a cycle with deliverables of previous cycles, continuous testing by the core team and deployment of the tested system into the production environment, the CI/CD pipeline was used. CI/CD has two environments: staging (non-production) and production. Any changes requested will be first pushed to the staging environment for testing. Once the revision is tested and finalized, it will be pushed to the production environment swiftly.

Iterative Development-Testing Cycles

Among the technical team members, there were nine developers focusing on testing before CoSMoS was tested by the core team members in a daily manner. The core team members reviewed CoSMoS (Telegram Bot and Dashboard) in terms of its utility (e.g. accuracy of the algorithm, the wording of the content, timing of daily ping messages, correctness of patient categorization in the dashboard) and usability (e.g. button size and position, layout, the flow of content). The change requests with screenshots were compiled in a Word Document and sent to the technical team, who will implement the changes in the evening. Managing change requests was crucial in ensuring the requirements of CoSMoS were properly documented and updated.

Phase 3: Integration into the clinical practice

CoSMoS monitoring system was presented to the stakeholders, including the primary care clinic management team and clinicians, the hospital's COVID-19 task force committee and the emergency department. Live demonstrations of the system were used during these presentations, and the stakeholders could test out the CoSMoS Telegram Bot. Feedback from the stakeholders on the utility, usability, and feasibility of the system was collected to improve the system further. Medicolegal aspects of the clinical implication and teleconsultation were discussed.

Repeated simulations with different clinical workflows were tested to identify the most effective and suitable clinical workflow for CoSMoS integration. Role plays with clinic staff were done to test out the CoSMoS workflow in the actual clinic setting. Barriers and weaknesses in the workflow were identified. Careful consideration was done to reduce the physical contact between healthcare workers (HCW) and patients with suspected COVID-19. We finalized the clinical workflow for the integration of CoSMoS after several rounds of testing. Training was conducted for all clinic staff, including the objectives, functions, features, operational guides, and how to integrate CoSMoS into the existing workflow, teleconsultation guide and possible issues. Simulations were done during the training to ensure familiarity with the new workflow. We installed the CoSMoS Dashboard into the desktops in the clinic. The doctors used designated smartphones with installed CoSMoS Telegram bot for monitoring and teleconsultation. A technical helpdesk was set up to assist the doctors should any technical issues arise.

Records of patients recruited for CoSMoS would be kept in the hospital electronic medical record and the CoSMoS system. These data will be kept confidential. Only the researchers, research assistants and CoSMoS doctors have access to the medical record, using designated login credentials. Data is transmitted over the HTTPS secure communication protocol and stored on cloud storage with adequate security protection.

Results

Phase 1: Requirement formation

Problem identification and requirements

The expert panel has identified the target users and sites for the CoSMoS system. The target users were the PUIs and close contacts who attended the primary care clinic and emergency department in UMMC, and the healthcare providers who used the CoSMoS system to monitor the patients.

The expert panel has identified four main problems in the existing home monitoring system for PUIs and close contacts where digital innovation could solve (Table 1).

Table 1. Problems identified and proposed requirements for the CoSMoS system.

Problems	Requirements
There was a high workload for the district health officials in calling the patients to assess their daily symptoms.	A daily automated messaging and reminder system sends active reminders for patients to key-in their symptoms every day.
Issues of surveillance using phone calls, i.e. patients did not pick-up the calls, patients worried about scams calls, long phone conversation to assess each symptom.	To develop a simple system that is easy to use, secure, interactive and trustable.
Lack of coordinating and continuity of care for the PUIs and close contact, especially coordinating care between COVID-19 centres and district health officials	To develop a system to monitor patients with continuity of care.
The unnecessary clinic or emergency department visits due to change of symptoms or administrative issues (letter of quarantine) expose the patients and HCWs to COVID-19 infection risk.	An automated system performs safe patient's risk assessment and guides patients in clinical decision making, whether to continue home monitoring or to seek medical attention. A dashboard system provides active monitoring and facilitates the HCW to identify patients who required teleconsultation and unreported patients.

Besides the three main functionalities, the additional requirements proposed include 1) Materials to be sent to patients, i.e. privacy policy, user guide and educational materials. 2) Additional notes in the dashboard so that the CoSMoS system can be used independently without relying on electronic medical records. 3) Data export function in the dashboard for external data analysis. A storyboard on how CoSMoS will be used from enrollment to completion of monitoring was used to illustrate the system more clearly and thoroughly (Figure 1).

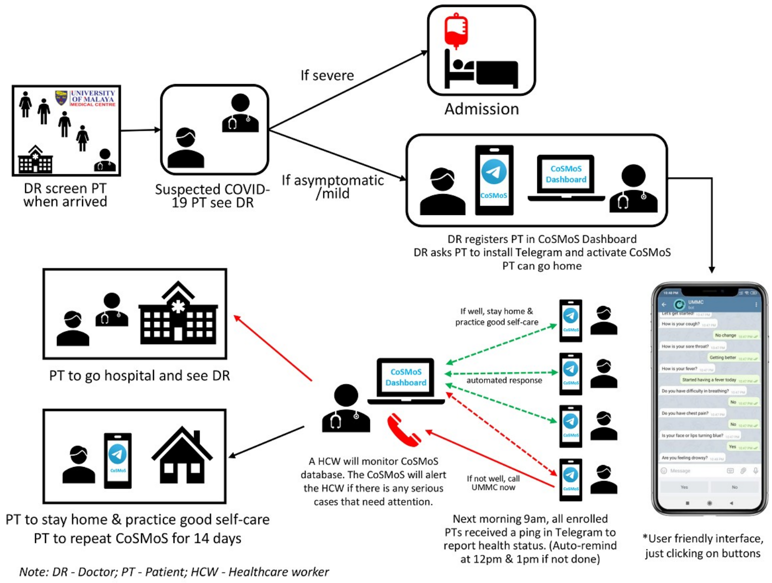

Figure 1. CoSMoS Storyboard

Algorithm and Content Drafting

A total of 13 iterative cycles (major and minor changes) were done to refine the clinical algorithm (Multimedia Appendix 2). The text for questions and answer options were refined so that they were easily understandable by the layperson. An end message will be sent to the patient automatically based on the algorithm to inform patients whether they could stay at home or call HCW for teleconsultation. A safety netting message advised the patients to attend to nearby healthcare facilities if they were unable to reach the HCW for teleconsultation. The algorithm had a lower threshold to prompt a patient to call HCW because patient safety was taken into significant consideration. A free-text remark was created as another safety netting measure for the patients. The algorithm was translated into Malay and Chinese languages to suit the local needs.

Phase 2: Development-Testing Iteration

Development platform

The technical team first proposed to employ WhatsApp as the platform to deliver the symptom assessment function as WhatsApp is widely used in Malaysia. However, the plan was halted as obtaining WhatsApp Business API required long approval time. The team then proceeded with

Telegram as it could provide the solution without complicated approval.

CoSMoS is hosted on the DigitalOcean cloud infrastructure. Github was used for code repository; Trello for task management; Slack for discussions on technical issues; WhatsApp for communication between core and technical teams. Development tools and language include React JS for the clinician dashboard; Go for the backend. Firebase was first chosen for database and Algolia for search engine, but it was switched to MongoDB due to performance and cost consideration. Docker Hub was used for container images, and the Sketch software was used to create CoSMoS's logo. Besides, FreshDesk was used to set up a technical help desk, through which the technical team received issues and reports from the clinical team. Kibana was used for logging server activities and auditing purpose. The CI/CD pipeline enables seamless integration of multiples tools used in the development CoSMoS.

System architecture

The architecture of CoSMoS is shown in Figure 2. From the user's end, the Telegram Bot retrieves PUI's records from the database through the backend. Ping messages are sent to the PUIs at 9.00 a.m., 12.00 p.m. and 1.00 p.m. daily to remind the patients to report their symptoms. The PUIs use Telegram Bot to report their daily symptoms. The symptoms are sent to the backend before being stored to the database—the HCWs monitor PUIs' symptoms through the clinician dashboard at 2.00 p.m. every day. PUIs' daily status was grouped into four main categories: A) Reported: Unstable and called HCW; B) Reported: Unstable but yet to call HCW; C) Reported: Stable; and D) Not Reported. For category A, the patient will be assessed immediately over the phone (teleconsultation) as they called the HCW. For category B and D, the HCW will contact patients at 2.00 p.m. during the clinical review. There is no need to contact the patients for category C unless the HCW identified serious comments in open-ended remark box during the review. The HCWs may update the PUIs' records such as changing a PUI's status from asymptomatic to symptomatic or completed monitoring, entering a PUI's swab test result, adding a note to a PUI's record. The HCWs can also export PUIs' records in comma-separated vector (csv) format. Retrieving, updating and storing PUIs' records between the dashboard and database is also done through the backend, preserving data security and integrity with mechanisms such as authentication, authorization, and validation.

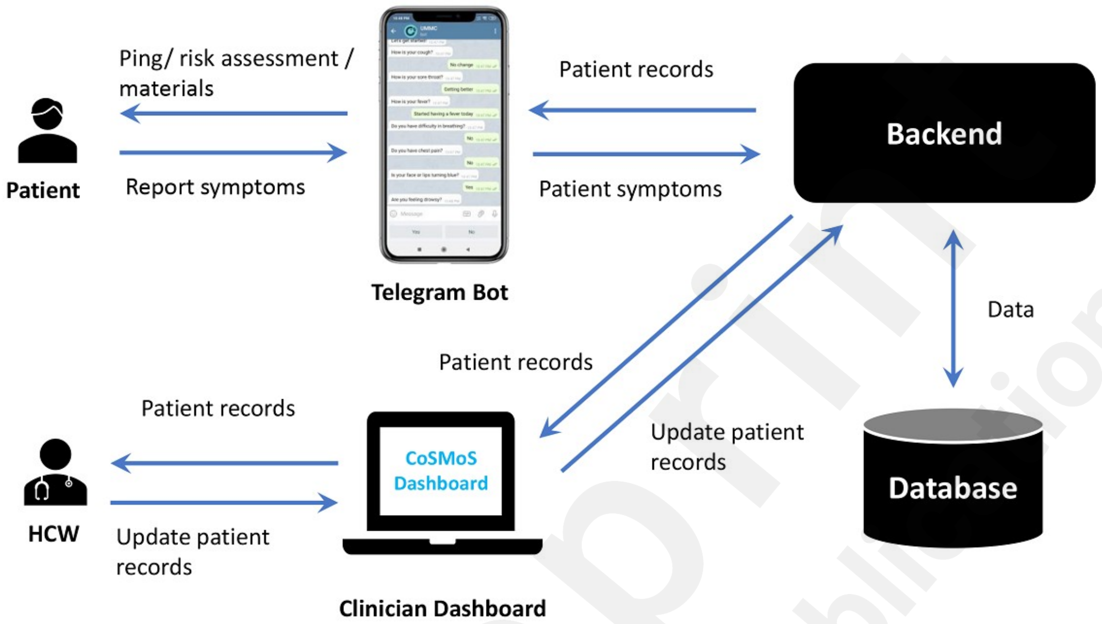

Figure 2. System architecture of CoSMoS

Iterative Development-Testing Cycles

There were many cycles of specify-develop-test-revise of the CoSMoS system as this study used the agile development method. The tester team (independent from the developers) documented test cases that were used and reused to ensure quality and efficiency of testing (example of test cases in Multimedia Appendix 3). The core team continuously gave feedback to the technical team after testing new deployment to the staging environment daily. However, there were three main prototype checkpoints (CoSMoS Prototype 1, CoSMoS Prototype 2, Finalized CoSMoS) to present major changes made to the system. Thus, it can be considered that the development process comprised three major agile cycles.

The clinicians would be their main helpdesk contact person when patients have any technical issues. Patients could call the hotline directly to the clinician for technical issues. If the clinicians could not solve it, the technical issue would be channeled to the technical helpdesk system.

Phase 3: Integration into the clinical practice

Table 2 shows the technical and clinical implementation barriers identified during the simulation and role-plays. The workflow was improved by introducing new strategies such as refining the patient's recruitment criteria for CoSMoS and creating a communication script for HCW to explain CoSMoS to patients. We also prepared of patient's and doctor's guide to CoSMoS and Telegram Bot installation.

Table 2. Technical and clinical implementation barriers of CoSMoS.

Technical barriers	Clinical implementation barriers
Poor internet connectivity	Ineffective communication between HCW and patients (enrollment of CoSMoS)
Insufficient digital storage to download the Telegram app by the suspected COVID-19 patients	CoSMoS prolonged the consultation time (longer contact time between HCW and suspected COVID-19 patients) for enrollment and the installation of CoSMoS.
Inadequate mobile data quota to download an app	Patient factors (unfamiliarity with digital technology)

Because of the high infectivity of COVID-19 infection, necessary precautions were taken to ensure the safety of both patients and HCWs. Patient enrollment procedures, informed consent-taking and CoSMoS installation were done remotely by a CoSMoS doctor via phone call to reduce the physical contact time. Figure 3 shows the clinical workflow of integrating the CoSMoS system into clinical practice. The teleconsultation of CoSMoS was done following the Malaysian Medical Council advisory on virtual consultation [15]. The CoSMoS application served as a complementary service to the existing manual home monitoring system by the public health offices, not replacing it, to ensure that the patients' safety was not compromised.

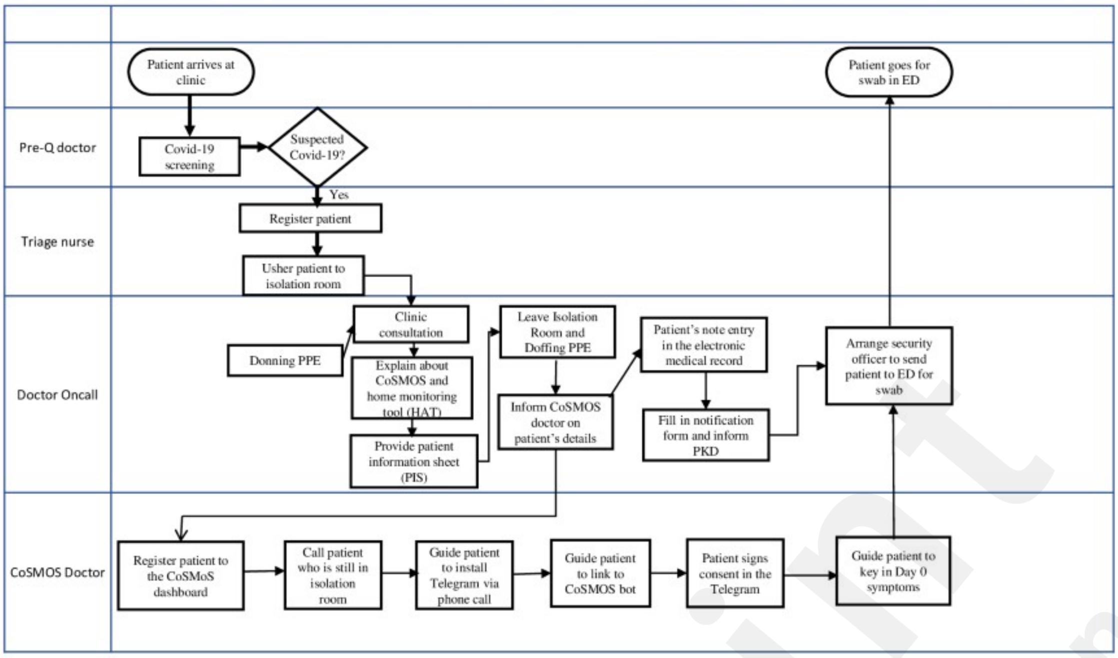

Figure 3. Integration of CoSMoS system in clinical setting.

Discussion

Principal findings

This paper presents the agile development process of a digital health innovation during the COVID-19 pandemic within a short period. CoSMoS was the first automated monitoring system aimed at the Malaysian population to provide home monitoring and phone consultation for patients with suspected COVID-19. There was an urgent need for CoSMoS to reduce the burden of the healthcare system while providing better home monitoring service to the patient in Malaysia. This paper reports a systematic approach to its development involving the clinical experts, evidence-based clinical guidelines, data security and privacy consideration, and real-life clinical integration of an eHealth app during a pandemic.

Several COVID-19 symptoms monitoring systems were developed and deployed in developed countries such as France, China and Korea [6,12,13]. Covidom, a web-based application developed in France, was used on a large scale for home-monitoring patients with COVID-19 [6]. A similar approach was used in China, where the telemedicine system was developed based on popular social media, WeChat, to monitor those who need home quarantine [12]. In this study, the CoSMoS symptoms monitoring bot was delivered via the Telegram app, a commonly used app among Malaysians as the government ministries and agencies were disseminating the COVID-19 news and health awareness via the Telegram. Using the existing digital platform would be more user-friendly for patients as they are familiar with the application. In the Korean military hospitals, similar COVID-19 symptoms monitoring application was developed with an additional model prediction programming interface to predict whether a patient requires attention from healthcare professionals [13]. This function was not developed in CoSMoS because of limited time, data and resources to accurately predict the patients' outcomes. The automated COVID-19 symptoms monitoring system was useful to alleviate the burden of the healthcare system, reduce the physical contact, and reduce the risk of delayed hospitalization [6,12]. The detailed developmental process described in this present paper could be transposed to other developing countries where resources are limited to engaging commercial developers. Using the existing local expertise and available resource, developing a digital solution for COVID-19 symptoms monitoring system is feasible and applicable for the urgent use in the local setting.

The time factor was the most critical challenge to the development of CoSMoS because the automated COVID-19 home monitoring system was in great urgent need in the healthcare system to combat the COVID-19 pandemic. Compared to the usual developmental process of a monitoring system for chronic diseases [14-16], conducting a detailed patients' need assessment was not feasible during the COVID-19 pandemic due to Malaysia’s movement control restriction situation. Hence, the initial Phase 1 requirement formation was done with the input from clinical experts who would be the users for the system and review the existing guidelines for COVID-19 home monitoring. We would be able to develop the CoSMoS in 19 days because many experienced developers organized into specialized teams according to their expertise (front-end, backend, Telegram bot, infrastructure) and led by computer science academicians with long working hours. Each development task was systematically delegated to the designated team using a task management tool (Trello). Each task was granular enough to be executed by a team member for accountability. Progression of the task to completion is also monitored using Trello. Thus, the development project was adequately managed amid changing requirements. Using an existing application (which is a Telegram in this study) reduced the development time instead of developing a new bot system. CoSMoS is an independent system that does not require integration into the existing electronic medical record, its development and deployment into the clinical practice are simpler.

This study recognized that the successful development of CoSMoS required effective communication between the technical and clinical teams. Communication and cooperation challenges are common in the development process of an eHealth project, especially involving experts from different working cultures and backgrounds [17]. In this CoSMoS project, the communication was conducted via virtual meetings (Zoom) and electronic platforms such as chat group and emails due to the movement control restriction in Malaysia. However, the communication was effective as both clinical and technical teams understood each others' languages and terminologies, work process, work practice and limitations as the team collaborated for a few years. The team leaders and patient advocate in the development team also played a prominent role in coordinating the collaboration. The change request of the CoSMoS system was made via virtual meetings at the initial development phase using the agile development method. The communication method has changed from virtual meetings to Helpdesk method after the CoSMoS has been developed for a more proper management and documentation of system evolution.

The consequential feature of CoSMoS system development was the concept of combining home-monitoring application and teleconsultation with doctors. Consideration of patient safety was of utmost importance, especially in designing the decision-making clinical algorithm and the active telemonitoring system that would help the patients be safely monitored at home [18]. There were several challenges in the integration of this interactive and real-time patient monitoring system in clinical practice. Given the high infectivity of COVID-19 infection, research and clinical ethics were considered in the clinical workflow process. The enrollment process was done via phone call to reduce the patient and the doctor's exposure time to prevent transmission of the COVID-19 infection to the healthcare providers. Several rounds of role-playing between the CoSMoS core members and the clinic staff provided useful feedback and change requests to improve the CoSMoS app and dashboard. The role-play managed to streamline the integration process, identify technical problems, and reduce the risks. To ensure patients' safety, the clinical workflow of CoSMoS was parallel to the usual care provided by the district health officer so that the care of patient would not be compromised with the introduction of new technology. Patient data privacy and confidentiality is often a main concern, especially during a pandemic [19]. There was social stigma towards patients with confirmed COVID-19 infection [20]. For CoSMoS, privacy and data protection were ensured in the CoSMoS system by applying authentication and authorization mechanisms. Thus, only authorized personnel will be granted access to the data according to their rights of access. Each of the healthcare providers has their own access identity and passwords to assess the CoSMoS Dashboard. The data of CoSMoS would not be shared with other party or service setting. Data is transmitted over the Internet using HTTPS secure communication protocol, Telegram messages are encrypted end-to-end, while the database is hosted on a trusted cloud infrastructure provider (DigitalOcean) with clearly defined privacy and security policies. Internally, the technical team also sets a security policy to control access to the patients' database.

Strengths

The strength of this paper includes a full description of the development process of CoSMoS, which could be replicated for future health system development during a pandemic. We used a patient-centred care approach in the development process to consider its integration in clinical practice. The development process of CoSMoS prioritized the health safety of patients and healthcare providers.

Limitations

Limitation of this development process was that usability testing was only done among computer science students and healthcare providers. It was a clinical challenge to test on the real patients given the infectivity of COVID-19 and researchers' safety. The usability testing reported in this present paper did not represent the target population. The usability and utility evaluation using a qualitative study was conducted separately.

Conclusions

In view of the urgent need of a COVID-19 symptom monitoring system during the COVID-19 pandemic, it can be developed systematically and practically within a short period using the agile model. With effective communication between the technical and clinical teams, developing a digital healthcare monitoring system is feasible and practicable without compromising patient safety. The development process described in this paper and the lessons learned would guide the development of a digital monitoring system during the next pandemic.

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Authors' contribution

All the authors participated in the conceptualization and design of the study. HML and CHT contributed to developing the research proposal, conceptualization and writing of this manuscript, and literature review. CJN and TKC led the research and development of the CoSMoS and was involved in all phases. AA, WLN and HH contributed towards writing, and critically revising the manuscript. TKC, CSL and CSC critically revised the manuscript for the intellectual content. All authors read and approved the final manuscript.

Conflicts of Interest

None to declare

Multimedia Appendices

Multimedia Appendix 1. Table S1. Development timeline of CoSMoS

Multimedia Appendix 2. Table S2. Clinical algorithm.

Multimedia Appendix 3. CoSMoS test cases.

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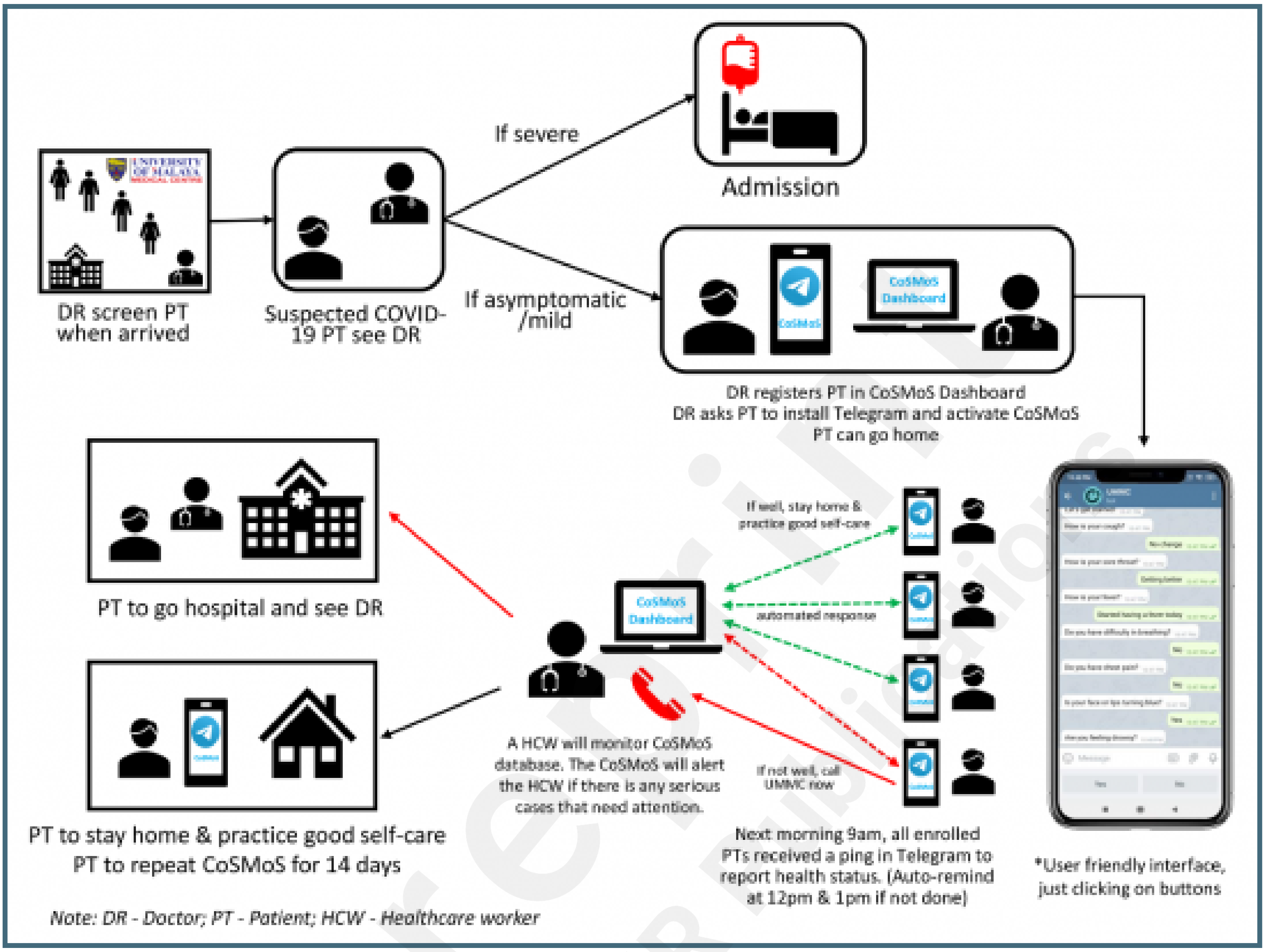
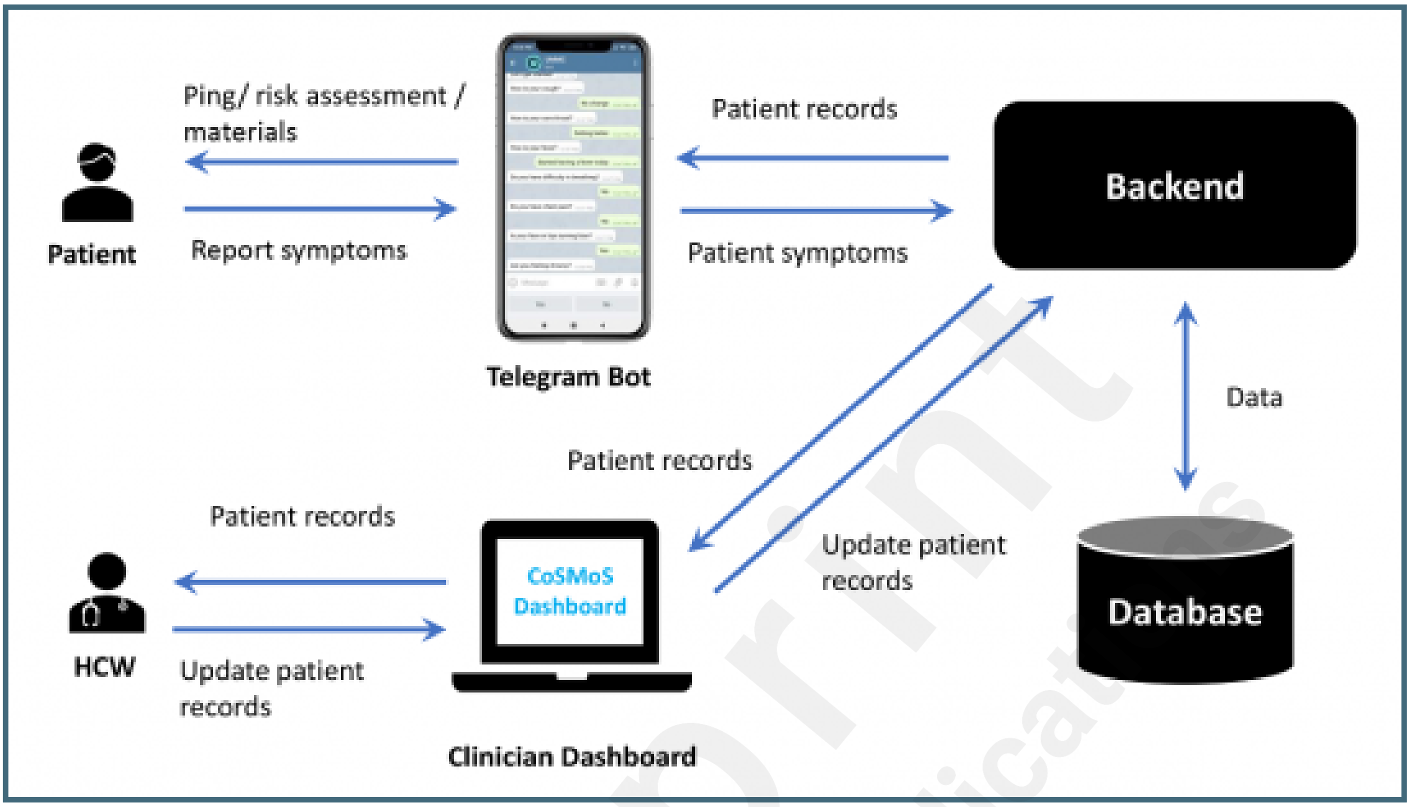
Supplementary Files

Figures

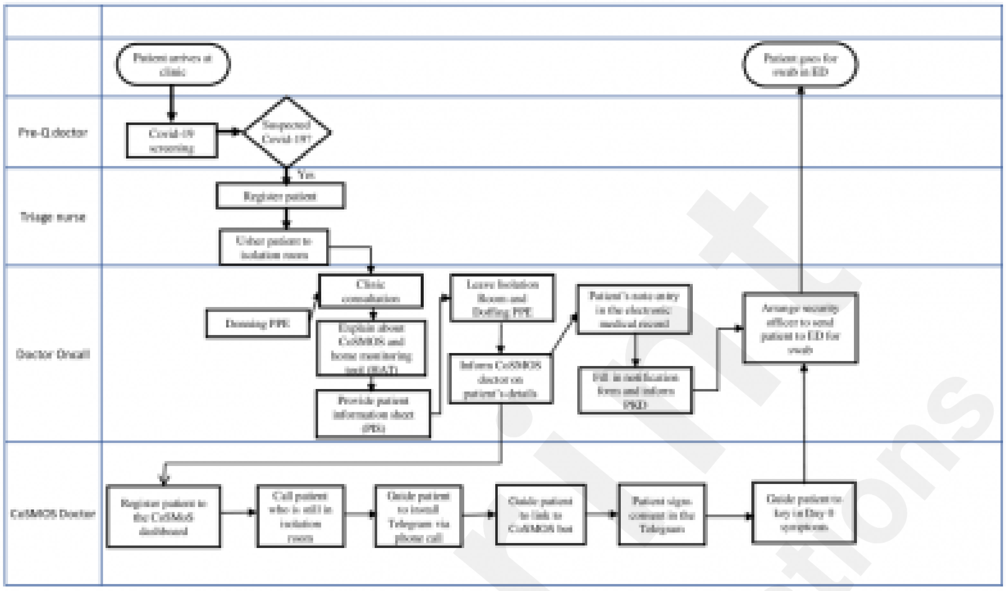
CoSMoS Storyboard.



System architecture of CoSMoS.



Integration of CoSMoS system in clinical setting.



Multimedia Appendixes

Table S1. Development timeline of CoSMoS.
URL: https://asset.jmir.pub/assets/5b4174cfec862fc3b7c076014fb97dc9.png

Table S2. Clinical algorithm.
URL: https://asset.jmir.pub/assets/690ff126248ac989f4e74e926aaa8320.pdf

CoSMoS test cases.
URL: https://asset.jmir.pub/assets/32fc51d067e2ba1fd684369d8d50afbc.pdf