IEEE Journal of Translational Engineering in Health and Medicine

Received 15 July 2023; revised 10 February 2024; accepted 5 March 2024.
Date of publication 13 March 2024; date of current version 21 March 2024.

Digital Object Identifier 10.1109/JTEHM.2024.3377258

CHIVID: A Rapid Deployment of Community and Home Isolation During COVID-19 Pandemics

PARPADA PIAMJINDA[1,2], CHIRAPHAT BOONNAG[2], PIYALITT ITTICHAIWONG[1,3], SEANDEE RATTANASONRERK[1,4], KANYAKORN VEERAKANJANA[3], KHANITA DUANGCHAEMKARN[5], WARISSARA LIMPORNCHITWILAI[2], KAMONWAN THANONTIP[2], NAPASARA ASAWALERTSAK[6], THITIKORN KAEWLEE[1,2], AND THEERAWIT WILAIPRASITPORN[1,2], (Senior Member, IEEE)

[1]Sense AI Company Ltd., Rayong 21210, Thailand
[2]Bio-Inspired Robotics and Neural Engineering (BRAIN) Laboratory, School of Information Science and Technology (IST), Vidyasirimedhi Institute of Science and Technology (VISTEC), Rayong 21210, Thailand
[3]Siriraj Informatics and Data Innovation Center, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok 10700, Thailand
[4]Medensy Company Ltd., Bangkok 10900, Thailand
[5]Department of Pharmacy Practice, School of Pharmaceutical Sciences, University of Phayao, Mae Ka, Muang, Phayao 56000, Thailand
[6]Department of Biomedical Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom 73170, Thailand

CORRESPONDING AUTHORS: C. BOONNAG (c.boonnag@gmail.com), P. ITTICHAIWONG (piyalitt@gmail.com), AND T. WILAIPRASITPORN (theerawit.w@vistec.ac.th)

This work was supported in part by the IEEE Humanitarian Activities Committee/Special Interest Group on Humanitarian Technology (IEEE HAC/SIGHT), in part by the National Research Council of Thailand under Grant N35A650037, in part by PTT Public Company Ltd., and in part by The Siam Commercial Bank Public Company Ltd.

This work involved human subjects in its research. Approval of all ethical and experimental procedures and protocols was granted by the University of Phayao Human Ethics Committee in Thailand under Application No. UP-HEC 1.2/038/65.

This article has supplementary downloadable material available at https://doi.org/10.1109/JTEHM.2024.3377258, provided by the authors.

ABSTRACT *Background:* CHIVID is a telemedicine solution developed under tight time constraints that assists Thai healthcare practitioners in monitoring non-severe COVID-19 patients in isolation programs during crises. It assesses patient health and notifies healthcare practitioners of high-risk scenarios through a chatbot. The system was designed to integrate with the famous Thai messaging app LINE, reducing development time and enhancing user-friendliness, and the system allowed patients to upload a pulse oximeter image automatically processed by the PACMAN function to extract oxygen saturation and heart rate values to reduce patient input errors. *Methods:* This article describes the proposed system and presents a mixed-methods study that evaluated the system's performance by collecting survey responses from 70 healthcare practitioners and analyzing 14,817 patient records. *Results:* Approximately 71.4% of healthcare practitioners use the system more than twice daily, with the majority managing 1-10 patients, while 11.4% handle over 101 patients. The progress note is a function that healthcare practitioners most frequently use and are satisfied with. Regarding patient data, 58.9%(8,724/14,817) are male, and 49.7%(7,367/14,817) within the 18 to 34 age range. The average length of isolation was 7.6 days, and patients submitted progress notes twice daily on average. Notably, individuals aged 18 to 34 demonstrated the highest utilization rates for the PACMAN function. Furthermore, most patients, totaling over 95.52%(14,153/14,817), were discharged normally. *Conclusion:* The findings indicate that CHIVID could be one of the telemedicine solutions for hospitals with patient overflow and healthcare practitioners unfamiliar with telemedicine technology to improve patient care during a critical crisis.

INDEX TERMS COVID-19, pandemic, home isolation, telemedicine, remote healthcare.

Clinical and Translational Impact Statement— CHIVID's success arises from seamlessly integrating telemedicine into third-party application within a limited timeframe and effectively using clinical decision support systems to address challenges during the COVID-19 crisis.

I. INTRODUCTION

SINCE the beginning of the COVID-19 pandemic, Thailand has experienced about 4.7 million confirmed SARS-CoV-2 infections [1], resulting in patient overcrowding due to inadequate medical facilities relative to the size of the population. Therefore, prioritizing patients with critical conditions has been one of the most effective ways to optimize the use of medical facilities. The majority of SARS-CoV-2 infected patients experience mild to moderate respiratory illness and recover within two to three weeks without special treatment [2]. Thus, the Ministry of Public Health of Thailand recommended self-quarantining for patients with mild to moderate symptoms at home for 14 days to avoid hospital overcrowding [3]. However, the health situation of infected patients with mild or moderate symptoms could change at any time. People over 60 [2], [4] and those with underlying medical problems, such as cardiovascular disease, diabetes, chronic respiratory disease, and cancer [5], [6], [7], are more likely to develop severe illnesses and require special medical attention.

During crises, several countries implemented telemedicine solutions to provide patient care [8], [9]. Some systems developed new application systems, while others utilized existing digital care platforms or relied on social messaging apps to communicate with patients during the COVID-19 crisis [10], [11], [12], [13], [14], [15], [16], as indicated in Supplement Table 1. However, the monitoring systems share several functions, such as dashboards for monitoring vital signs or alarm systems to alert healthcare practitioners of anomalies. Nevertheless, the distinguishing factors between each system lie in the equipment used for measuring vital signs and the methods employed for data transmission. Some systems relied on standard equipment, requiring patients to input data manually, while others utilized Bluetooth-connected devices for automatic data transmission to the application system. Both approaches entail compromises in terms of expenses, user technical expertise, and data precision.

Before the COVID-19 outbreak, Thai hospitals lacked proficiency in telemedicine. Hospitals had adopted the LINE messaging application [17], Thailand's most popular instant messaging platform, to deliver medications and necessary quarantine items for prompt issue resolution. However, the existing telemedicine system employing the LINE application suffered from a lack of systematization, leading to the potential loss of patient conversations if healthcare practitioners inadvertently overlooked the chat box. Furthermore, patients often created online personas using profile names and photos that diverged from their actual identities, potentially leading to errors in patient identification. These issues could confuse healthcare practitioners, leading to delays in treating patients with severe symptoms.

To effectively address these challenges, the Community & Home Isolation-based electronic health record COVID-19 system, CHIVID,[1] was rapidly developed as a comprehensive telemedicine solution to deal with the intricate nature of non-systematic data collection and patient follow-up difficulties. This includes the specific challenges faced during the pandemic, such as technical aspects, privacy and data security, training of healthcare practitioners and patients, doctor-patient relationships, and potential acceptability and satisfaction [18]. This rapid response effectively managed and monitored isolated COVID-19 patients, offering a timely and robust solution to the multifaceted challenges.

[1]The term CHIVID means "life" in Thai.

CHIVID assesses patients' health conditions, analyzes associated risks, and promptly alerts healthcare professionals in high-risk cases through a chatbot. Moreover, during the crisis, the Thai government distributed standardized equipment without Bluetooth connection free of charge to COVID-19 patients in public hospitals. Consequently, to enable every patient to utilize the system without necessitating connected devices, we propose the integration of AI-based image extraction functionalities named PACMAN to facilitate patients by recognizing the number on the pulse oximeter screen, aiming to mitigate input errors inherent in manual data entry. Furthermore, the system was intentionally designed to be LINE-compatible, reducing development time and providing a user-friendly interface for Thai users. It effectively improved symptom recording and addressed patient identification issues by displaying relevant information or a unique identification number for verification.

This article describes the proposed system, developed under tight time constraints for hospitals that experience patient overflow and do not have their own telemedicine systems, to effectively address challenges arising during crisis periods. In addition to providing a comprehensive overview of the system, the article encompasses a study employing qualitative and quantitative methodologies. This mixed-methods study evaluated the system's performance by collecting survey responses from 70 healthcare practitioners and analyzing 14,817 patient records.

II. MATERIALS AND METHODS

A. SYSTEM OVERVIEW

The CHIVID system, as illustrated in Figure 1, served two main user groups: patients and healthcare practitioners (HCPs), which included physicians, nurses, and nursing assistants. For patients, the system served as a tool for collecting, recording, and transferring their health information. Upon COVID-19 diagnosis, patients with mild to moderate symptoms received a registration code and were provided with necessary quarantine items, including a thermometer, oximeter, and necessary medications. Then, they registered with the provided code through the hospital's official LINE account, verified their identity, and provided personal and health details. In daily monitoring, as shown in Figure 2a, patients had to submit progress notes at least twice daily, containing vital signs and symptoms. The system allowed patients to upload a pulse oximeter image automatically processed by the PACMAN function to extract oxygen saturation and heart rate values. However, other vital signs were optional. The collected data was analyzed to assess the severity of the patient's condition based on the clinical decision support system (CDSS). Once recovered, patients submitted their COVID-19 test results to healthcare practitioners,

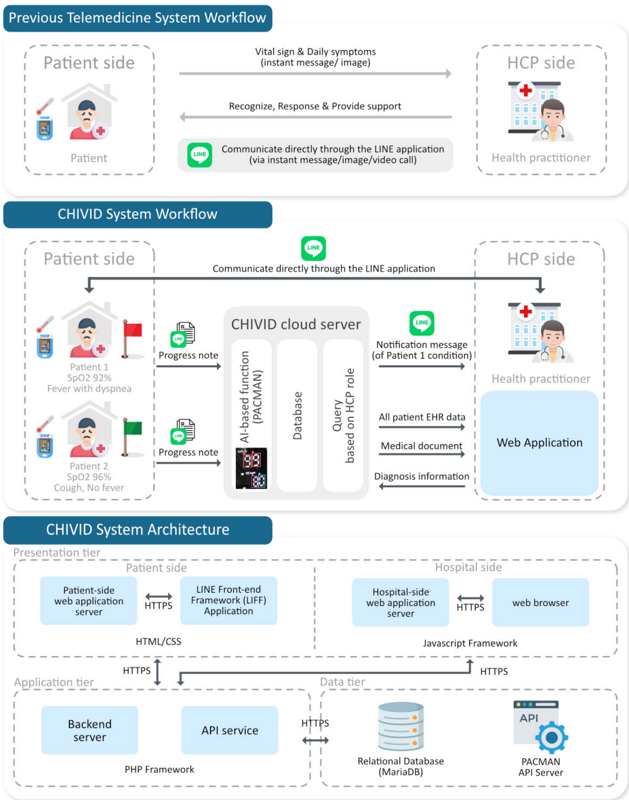
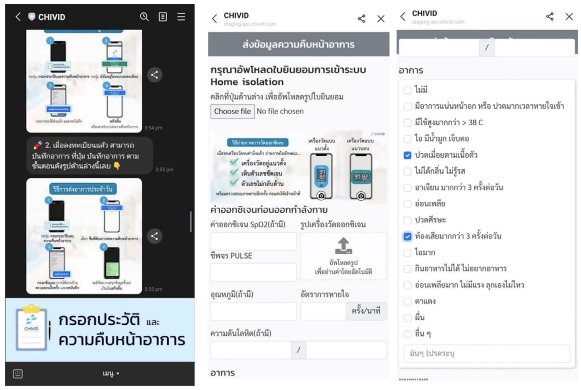


FIGURE 1. The previous telemedicine system workflow, the CHIVID system workflow, and the CHIVID system architecture design followed a three-tier architecture: the presentation tier for the user interface, the application tier for processing input, and the data tier for data storage.

and upon confirmation, the system updated their status to "discharged."

For healthcare practitioners, the primary usage was on the CHIVID web application, which had functions to facilitate healthcare practitioners, such as a summary dashboard (Figure 2b), automatic patient severity classification, prescribing medication and equipment, and generating medical documents. Moreover, the system promptly notified healthcare practitioners of patients' abnormal symptoms through the web application and also sent alerts to the healthcare practitioners' LINE group conversation through the chatbot. This two-way notification system ensured timely response and mitigated the likelihood of missed alerts.

The system architecture followed a three-tier structure comprising the presentation, application, and data tiers. The presentation tier included a web application for practitioners, utilizing JavaScript framework, and a mobile web application for patients, utilizing the LINE Front-end Framework (LIFF) [19]. The LINE Front-end Framework is a development framework provided by LINE Corporation, designed to facilitate the creation of seamless and interactive web applications within the LINE messaging platform. LIFF enables developers to integrate web content, such as HTML, CSS, and JavaScript, into the LINE messaging platform, allowing users to access external services or functionalities seamlessly from



(a) CHIVID system on the LINE platform and self-assessment page for the patients' end.

(b) The summary dashboard and patient information page for the healthcare practitioners' end.

FIGURE 2. The example of the user interface for the patients' and healthcare practitioners' ends.

within the messaging interface. This framework enhances the overall user experience by enabling the integration of web-based features directly into the LINE app, ensuring a cohesive and user-friendly environment. Communication between components, including the LIFF-based mobile web app, was established through secure HTTPS protocols for reliable and encrypted data exchange. The application tier processed user input, such as progress notes, to determine the severity and detect abnormalities. It interacted with the data tier and utilized AI-based functionalities, presenting outputs to patients. PHP was used for development, and API calls facilitated communication with the database. The data tier served as the storage layer, utilizing MariaDB. Regarding system security, patient information was stored in a cloud

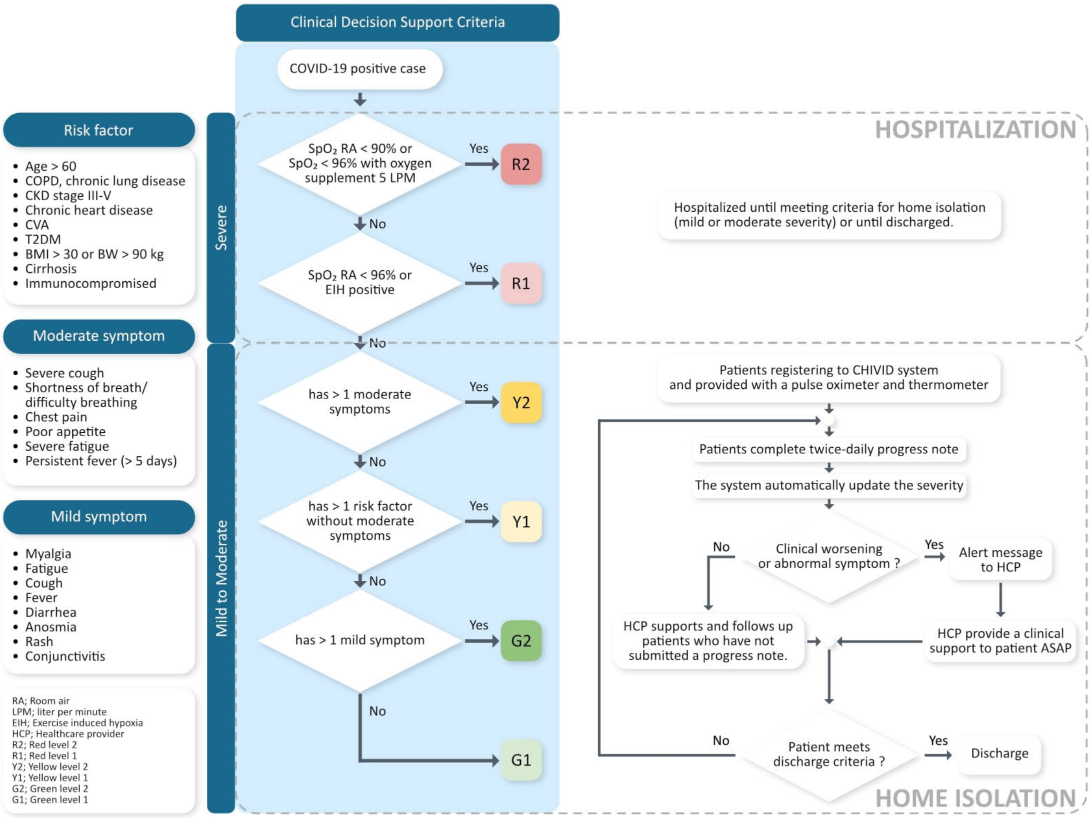


FIGURE 3. The automatic patient severity classification criteria.

database with restricted access permissions. Patients could only access their own data, and healthcare practitioners could only access patients' information under their care. API calls were secured through the OAuth2 protocol. Amazon AWS Firewall ensured network-level and server-level protection, which was reinforced by CSF and LFD Firewalls. SSL encryption was employed for secure communication between users and the server.

B. CLINICAL DECISION SUPPORT SYSTEMS (CDSS)

We developed the automatic patient severity classification function based on guidelines created by the Primary Care Hub's "ComCOVID-19 FM CoCare[2]" team. This working group, led by the Royal College of Family Physicians of Thailand, the Association of General/Family Practice Physicians of Thailand, and the Thai Society of Family Medicine, was dedicated to developing guidelines for addressing COVID-19 challenges and providing primary healthcare services in emergency situations [20].

The system followed this guideline in a rule-based manner, taking into account patients' daily symptoms, vital signs, and other risk factors to categorize them into groups with color-coded representations (Figure 3). This visual swiftly discerned patient severity using a color-coded representation from severe (red) to mild (green). This approach aided in efficiently prioritizing patient care during the challenges posed by the COVID-19 pandemic, eliminating the need for manual scrutiny of individual patient information.

CHIVID uses an AI-based function called PACMAN [21], which utilizes smartphone cameras to recognize digits on a pulse oximeter screen. PACMAN accurately identified and interpreted oxygen saturation and pulse rate numbers from real-world images, achieving an impressive accuracy range of 81.0%-89.5%. The top-performing model, YOLOv5, incorporated a digit auto-orientation and clustering algorithm, outperforming scaled YOLOv4, YOLOR, and commercially available OCR services.

CHIVID augments PACMAN's functionality, making it more accessible and user-friendly for both healthcare professionals and patients. By leveraging CHIVID, the pulse oximeter reading, interpretation, and data input process becomes more seamless, offering a practical and efficient solution for HCPs and patients in healthcare crisis management.

C. USABILITY EVALUATION ON HEALTHCARE PRACTITIONERS

We evaluated the CHIVID system by conducting a questionnaire-based survey among healthcare practitioners.

[2]Family Medicine COVID-19 Care.

The online survey included 16 questions divided into three sections, focusing on different objectives as follows:

- To indicate the general status of the respondents, including their location of employment (hospital), roles, and the number of patients under their care.
- To examine the healthcare practitioners' perspective on using the CHIVID system and their satisfaction and utilization level of the system and each function.
- To evaluate the performance of the new functions added to traditional telemedicine systems designed specifically for healthcare practitioners' end users, including the automatic patient severity classification function and abnormal condition alert function.

CHIVID served 11 Thai hospitals that lacked experience with telemedicine systems. The survey link was distributed to healthcare practitioners within these 11 hospitals (70 individuals). Subsequently, the survey responses were analyzed using descriptive statistics. To ensure the successful implementation and understanding of the CHIVID system, we initially provided training to at least one healthcare practitioner in each hospital. These trained individuals then acted as local trainers, capable of providing guidance and instruction to their colleagues as needed. This approach ensured optimal utilization of the system within the healthcare facilities.

D. USABILITY EVALUATION OF PATIENT DATA

We analyzed patient data from the CHIVID database to derive insights and patterns by using descriptive statistical analysis. The dataset comprised non-sensitive information that cannot be traced to a particular individual, including vital signs, symptoms, treatments, and clinical outcomes. Out of the 18,828 registered accounts, we excluded inactive accounts, those with missing progress notes, individuals under 18 years old, and cases with unknown program completion status. Our analysis focused on 14,817 users who met the inclusion criteria, ensuring the reliability and accuracy of our research, as illustrated in Supplement Figure 1.

E. ETHICS

This study was approved by the University of Phayao Human Ethics Committee in Thailand (reference number UP-HEC 1.2/038/65). To preserve confidentiality, the data analyzed in this study did not contain any user identities or sensitive personally identifiable information, such as full name, identification number, social security number (SSN), and mailing address.

III. RESULTS

A. HEALTHCARE PRACTITIONERS' USABILITY

1) GENERAL STATUS OF THE RESPONDENTS

According to the responses, the 70 responses from all 11 hospitals represented an average of 6.36 responses per hospital. Among the respondents, 15.7% (n=11) were physicians, 51.4% (n=36) were nurses, and 32.9% (n=23) were nursing assistants. The first section of Table 1, which summarizes the percentage of patients under each type of healthcare practitioner's care, shows that most healthcare practitioners (34.3%) had between 1 and 10 patients under their care, while 11.4% had more than 101 patients.

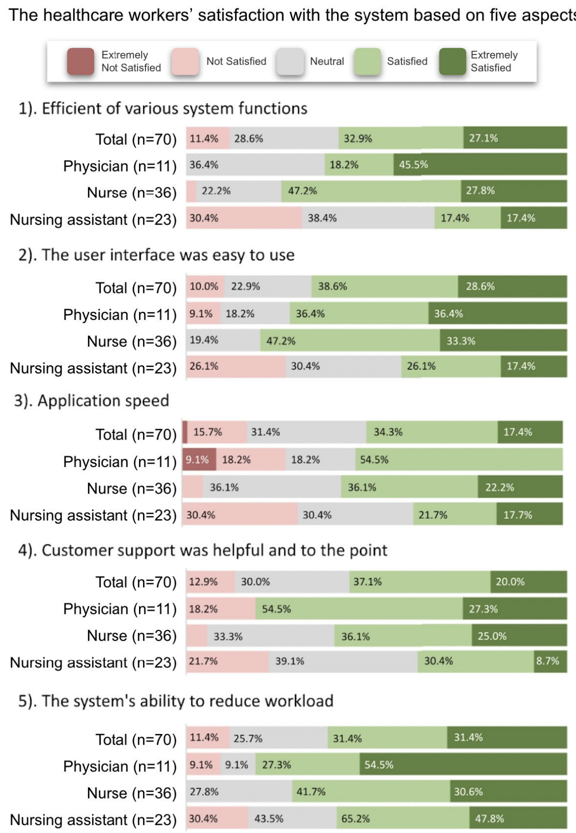


FIGURE 4. The healthcare practitioners' satisfaction with the system based on five aspects.

2) SATISFACTION AND UTILIZATION

The results presented in Table 1 indicate that the CHIVID system was frequently used by the respondents. Most (71.4%) used it more than twice daily, with others using it daily (14.3%), more than twice per week (11.4%), and once per week (2.9%). Physicians mainly used the system for patient monitoring (81.8%), while nurses and nursing assistants found it helpful in reducing paperwork (88.6% and 69.6%, respectively). Furthermore, the satisfaction levels of healthcare practitioners were assessed using a 5-point Likert scale, and the findings displayed in Figure 4 revealed that most respondents expressed satisfaction ranging from "satisfied" to "extremely satisfied" across different aspects of the system.

The study also investigated the usage frequency and satisfaction with ten essential system functions. Findings revealed that the progress note function was the most frequently used, with 87.1% of respondents indicating they always use it. Following that, the patient table function had a usage

TABLE 1. The healthcare workers' characteristics and their perspective regarding the system.

	Total (n=70)	Physician (n=11)	Nurse (n=36)	Nursing Assistant (n=23)
Patient under care – n (%)				
1-10	24 (34.3%)	1 (9.1%)	8 (22.2%)	15 (65.2%)
11-20	14 (20.0%)	7 (63.6%)	6 (16.7%)	1 (4.3%)
21-30	17 (24.3%)	2 (18.2%)	9 (25.0%)	6 (26.1%)
31-40	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
41-50	3 (4.3%)	0 (0.0%)	3 (8.3%)	0 (0.0%)
51-100	4 (5.7%)	0 (0.0%)	3 (8.2%)	1 (4.3%)
$\geq$ 101	8 (11.4%)	1 (9.1%)	7 (19.4%)	0 (0.0%)
Frequency – n (%)				
$\geq$ 2/day	50 (71.4%)	8 (72.7%)	27 (75.0%)	15 (65.2%)
1/day	10 (14.3%)	0 (0.0%)	5 (13.9%)	5 (21.7%)
2-3/week	8 (11.4%)	3 (27.3%)	3 (8.3%)	2 (8.7%)
$\leq$ 1/week	2 (2.9%)	0 (0.0%)	1 (2.8%)	1 (4.3%)
Purpose – n (%)				
Capable of monitoring patients more closely	47 (67.1%)	9 (81.8%)	24 (66.7%)	14 (60.9%)
Reduce paperwork	53 (75.7%)	6 (54.5%)	31 (88.6%)	16 (69.6%)
Increase the capacity to support patients	41 (58.6%)	6 (54.5%)	21 (60.0%)	14 (60.9%)
View patient overviews more easily	36 (51.4%)	5 (45.5%)	18 (51.4%)	13 (56.5%)
Reduce workload to follow up patient	37 (52.9%)	6 (54.5%)	22 (62.9%)	9 (39.1%)

TABLE 2. The suggestions of available functions and identified issues and recommendations for additional system features.

Themes	Total (n=70)	Physician (n = 11)	Nurse (n = 36)	Nursing Assistant (n = 23)	Representative quotes
The identified issues – n (%)					
System's speed	3 (4.3%)	2 (18.2%)	0 (0.0%)	1 (4.3%)	"It takes a long time to transition between window pages. For example, after signing the patient's medical certificate to discharge the patient and then returning to the discharge ist page to discharge another patient, the page will take a long time to load." (Physician)
User interface	10 (14.3%)	2 (18.2%)	6 (16.7%)	2 (8.7%)	"The patient's most recent vital signs should be displayed on the patient table page to make it easy to check." (Nurse)
Accuracy	7 (10.0%)	2 (18.2%)	5 (13.9%)	0 (0.0%)	"Occasionally, there was a problem when signing the medical certificate, such as the date or length of treatment time not being displayed." (Physician)
Incomplete understanding	10 (14.3%)	0 (0.0%)	7 (19.4%)	3 (13.0%)	"Need nursing notes feature" (Nurse)
Suggestions for improvement – n (%)					
Improve current functions	12 (17.1%)	4 (36.4%)	7 (19.4%)	1 (4.3%)	"Require an alert feature to notify the patient, one hour after the deadline, if daily progress notes are not submitted on time." (Nurse)
Develop new functions to expand coverage	26 (37.1)	2 (18.2%)	19 (52.8%)	5 (21.7%)	"I need the system to be able to restore discharge patient data back to the patient ward because readmitted patients are unable to access the system." (Nurse)

rate of 64.3% among the respondents. Conversely, the prescribing medication and equipment function was the least utilized, with 28.6% of respondents reporting never using it. Notably, a small percentage of nurses (5.6%) expressed dissatisfaction with this function. Regarding the summary dashboard function, which provides an overview of patients under care, it was found that 19.4% of nurses and 21.7% of nursing assistants expressed dissatisfaction and reported not using it. However, the respondents highly utilized the newly introduced functions, such as the automatic patient severity classification, abnormal condition alert, and PACMAN functions. The majority (57.1% to 52.9%) reported consistently using these functions, highlighting their importance and value in the telemedicine system during the pandemic.

Additionally, we included open-ended questions in the survey to gather healthcare practitioners' suggestions and identify any problems they encountered while using the CHIVID system. The responses provided valuable insights and can be classified into two main categories: problems noticed and suggestions for improvement, as summarized in Table 2.

The problems noticed

(i) System's speed
4.3% of surveyed participants indicated occasional delays in loading windows. This phenomenon was attributed to the system's requirement to retrieve data afresh each time the page was altered or reloaded.

(ii) User interface
14.3% of all respondents encounter issues with the user interface, including requests for a simpler design, the addition or repositioning of elements, and the wish to adapt the interface for use on other platforms.

(iii) Accuracy
Accuracy was also a concern, with 10% of respondents reporting mistakes, such as errors in image processing by PACMAN (4.3% of respondents) and inaccuracies in the medical documents generated function (5.7% of respondents).

(iv) Incomplete understanding of all system functions
14.3% of all respondents proposed expanding coverage by enhancing existing functions and creating new ones. However, it was found that many of these suggestions were already present in the system or had been previously developed. This highlights an incomplete understanding of all system functions among some users, such as the nurse note function (unknown to 1.4% of respondents) and the rounded check function (unknown to 2.9% of respondents).

The suggestions for improvement

(i) Improve current functions
17.1% of the survey participants provided suggestions for enhancing current functions. These recommendations focused mainly on making the existing functions easier to use and more intuitive, such as making the progress note function retrieve more detail to enable a more accurate diagnosis and adding a reminder function for patients who forgot to send their daily progress notes. Additionally, some respondents (2.9% of all respondents) recommended including the reason for changes in the patient's severity level for the automatic patient severity classification function to decrease inaccuracies.

(ii) Develop new functions to expand coverage
35.7% of the respondents suggested the exciting idea of developing new functions, such as functions related to medicines (for example, whether they have taken or not, when to take, how much to handle, etc.), developing a system to connect to the hospital database and export the data as an Excel file for convenient use. Moreover, they suggested critical functions we overlooked, such as bringing a discharged patient back to the treatment process to allow readmitted patients access to the system and the quarantine notification function, which automatically calculates the discharge date of each patient and notifies staff at the due date.

3) PERFORMANCE OF THE AUTOMATIC PATIENT SEVERITY CLASSIFICATION FUNCTION AND ABNORMAL CONDITION ALERT FUNCTION

Most respondents reported changing patient information one to three times for the automatic patient severity classification function. The primary reason for these manual changes was the presence of inaccuracies or omissions in the patient information. Regarding the abnormal condition alert function, 51.4% of respondents utilized the alert message function within the LINE clinician group chat, and 52.8% of group chat participants reported consistently checking the message every time it was notified. Of these, the majority (41.7%) indicated they responded to the message immediately.

B. PATIENTS' USABILITY

1) PATIENT CHARACTERISTICS

According to patient data derived from the CHIVID database, there will be 14,817 cumulative patients who met the inclusion criteria, as shown in Table 3. Regarding the severity on the first day of treatment, the percentage of mild patients in the system is 64.1%, followed by moderate patients at 34.4% and severe patients at 1.6%. Among all patients, 58.9% (n=8,724) are male and aged between 18 and 34 (49.7%; n=7,367). The average length of isolation of all patients was 7.6 days (CI 90.0%; 7.5-7.7 days), which was by government quarantine criteria that required patients to complete seven days of treatment. Among all patients, 3,616 (24.4%) have an underlying disease, the most common being hypertension, diabetes, and dyslipidemia. The most commonly reported daily symptoms were cough, myalgia, and headache.

The graph presented in Figure 5 depicts the severity levels of patients and their clinical outcomes during a 14-day period. The data is consolidated twice daily into a single data point, utilizing symptom data documented as being more severe on that specific day. For example, if the symptoms are mild in the morning and become moderate in the evening, the overall condition of the day is classified as moderate.

The clinical outcomes consist of three categories: "Home," which refers to patients who were discharged in a normal state; "Refer," which indicates patients who were transferred to private or other public hospitals that do not use our system; and "Hospitalize," which represents patients who were admitted for in-hospital care. The patients categorized as mild, moderate, and severe on day 14 imply that they have not been discharged and have remained in the home isolation program for more than 14 days.

The graph reveals that over 95.52% (n=14,153) of patients exhibited clinical outcomes categorized as "Home." However, several patients were quickly discharged after the initial phase of the isolation program. This was primarily because their registration to the system did not occur on the first day of their infection, and they could be in the advanced stages of recovery, resulting in their short duration in the system.

Furthermore, an analysis of the data reveals that most patients marked as severe in the system continued

TABLE 3. The patient characteristics.

Characteristic	Total (n=14,817)	Mild (n=9,490)	Moderate (n=5,096)	Severe (n=231)
Age – n (%)				
18-34	7,367 (49.7%)	5,482 (57.8%)	1,808 (35.5%)	77 (33.3%)
35-49	4,277 (28.9%)	2,760 (29.08%)	1,459 (28.6%)	58 (25.1%)
50-64	2,416 (16.3%)	1,241 (13.1%)	1,113 (21.8%)	62 (26.8%)
65-74	536 (3.6%)	3 (<0.1%)	513 (10.1%)	20 (8.7%)
$\geq$ 75	221 (1.5%)	4 (<0.1%)	203 (4.0%)	14 (6.1%)
Sex – n (%)				
Male	8,724 (58.9%)	5,778 (60.9%)	2,800 (55.0%)	146 (63.2%)
Female	6,051 (40.8%)	3,682 (38.8%)	2,284 (44.8%)	85 (36.8%)
Missing	42 (0.3%)	30 (0.3%)	12 (0.2%)	0 (0.0%)
BMI – n (%)				
Underweight	718 (4.9%)	579 (6.1%)	130 (2.6%)	9 (3.9%)
Normal weight	6,880 (46.4%)	5,444 (57.4%)	1,329 (26.1%)	107 (46.3%)
Overweight	3,643 (24.6%)	2,529 (26.7%)	1,052 (20.6%)	62 (26.8%)
Obesity Class I	1,735 (11.71%)	21 (0.2%)	1,680 (33.0%)	34 (14.7%)
Obesity Class II	531 (3.6%)	2 (<0.1%)	520 (10.2%)	9 (3.9%)
Obesity Class III	205 (1.4%)	0 (0.0%)	202 (4.0%)	3 (1.3%)
Missing	1,105 (7.5%)	915 (9.6%)	183 (3.6%)	7 (3.0%)
Pregnant – n (%)	40 (0.3%)	20 (0.2%)	19 (0.4%)	1 (0.4%)
Length of isolation– avg. days	7.6 days	7.9 days	7.2 days	7.7 days
Oxygen saturation– n (avg %spo2)	12,483 (98.2%)	8,260 (98.3%)	3,992 (98.0%)	231 (96.7%)
Clincal presentations – n (%)				
Conjunctivitis	358 (2.4%)	196 (2.1%)	155 (3.0%)	7 (3.0%)
Rash	384 (2.6%)	226 (2.4%)	152 (3.0%)	6 (2.6%)
Anosmia	2,139 (14.4%)	1,388 (14.6%)	717 (14.1%)	34 (14.7%)
Diarrhea	808 (5.5%)	399 (4.2%)	395 (7.8%)	14 (6.1%)
Fever	1,081 (7.3%)	655 (6.9%)	404 (7.9%)	22 (9.5%)
Cough	1,0995 (74.2%)	6,410 (67.5%)	4,386 (86.1%)	199 (86.2%)
Severe cough	1,978 (13.4%)	759 (8.0%)	1,173 (23.0%)	46 (19.9%)
Fatigue	4,009 (27.1%)	2,186 (23.3%)	1,736 (34.1%)	87 (37.7%)
Severe fatigue	154 (1.0%)	43 (0.5%)	109 (2.1%)	2 (0.9%)
Myalgia	5,269 (35.6%)	2,979 (31.4%)	2,175 (42.7%)	115 (49.8%)
Loss of appetite	938 (6.3%)	285 (3.0%)	627 (12.3%)	26 (11.3%)
Headaches	4,785 (32.3%)	2,796 (29.5%)	1,896 (37.21%)	93 (40.3%)
Shortness of breath	517 (3.5%)	192 (2.0%)	311 (6.1%)	14 (6.1%)
Vomit $\geq 3days$	188 (1.3%)	93 (1.0%)	89 (1.8%)	6 (2.6%)
Underlying diseases (UD) – n (%)				
Obesity	20 (0.1%)	11 (0.1%)	9 (0.2%)	0 (0.0%)
Hypertension	1,012 (6.8%)	529 (5.6%)	462 (9.1%)	21 (9.1%)
Diabetes	752 (5.1%)	344 (3.6%)	392 (7.7%)	16 (6.9%)
COPD	17 (0.1%)	11 (0.1%)	6 (0.1%)	0 (0.0%)
Asthma	239 (1.6%)	134 (1.4%)	101 (2.0%)	4 (1.7%)
Dyslipidemia	618 (4.2%)	307 (3.2%)	301 (5.9%)	10 (4.3%)
Coronary Artery Disease	195 (1.3%)	92 (1.0%)	101 (2.0%)	2 (0.9%)
Cirrhosis	18 (0.1%)	11 (0.1%)	7 (0.1%)	0 (0.0%)
Immunocompromised	96 (0.6%)	42 (0.4%)	53 (1.0%)	1 (0.4%)
Other UDs	609 (4.1%)	345 (3.6%)	258 (5.1%)	6 (2.6%)
No known UD	8,111 (54.7%)	5,410 (57.0%)	2,541 (49.9%)	120 (52.0%)
Missing	3,130 (21.1%)	2,234 (23.5%)	846 (16.6%)	50 (21.7%)
Patient cohort – n (%)				
Kratumban Hospital	20 (0.1%)	13 (0.1%)	7 (0.1%)	0 (0.0%)
Bang Pakong Hospital	1 (<0.1%)	1 (<0.1%)	0 (0.0%)	0 (0.0%)
SUT Hospital	2,315 (15.6%)	1,915 (20.2%)	396 (7.8%)	4 (1.7%)
Queen Sirikit Hospital	7,851 (53.0%)	4,498 (47.4%)	3,284 (64.4%)	69 (29.9%)
Lopburi Ramesuan Hospital	2 (<0.1%)	1 (<0.1%)	1 (<0.1%)	0 (0.0%)
Fort Ingkhayut Hospital	2,282 (15.4%)	1,726 (18.2%)	523 (10.3%)	33 (14.3%)
Fort Wiphavadirangsit Hospital	119 (0.8%)	83 (0.9%)	32 (0.6%)	4 (1.7%)
Fort Wachirawut Hospital	1,139 (7.7%)	590 (6.2%)	432 (8.5%)	117 (50.7%)
Fort Thepsatsrisunthon Hospital	9 (0.1%)	9 (0.1%)	0 (0.0%)	0 (0.0%)
Fort Senanarong Hospital	476 (3.2%)	313 (3.3%)	159 (3.1%)	4 (1.7%)
Banyayda Health Promoting Hospital	603 (4.1%)	341 (3.6%)	262 (5.1%)	0 (0.0%)

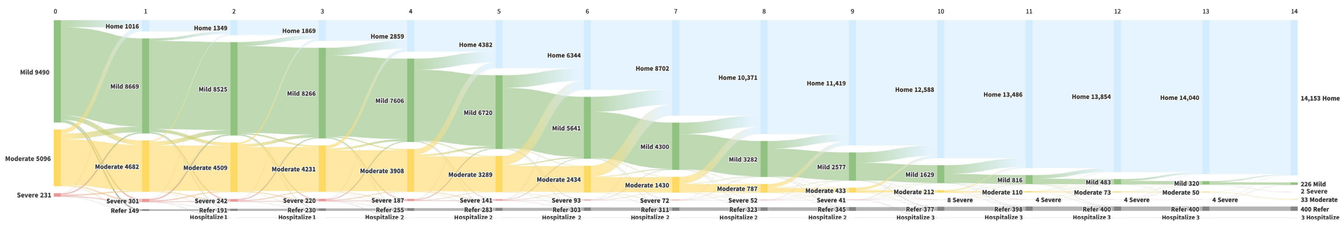


FIGURE 5. The longitudinal healthcare data, revealing evolving severity levels within the assessed patient cohort.

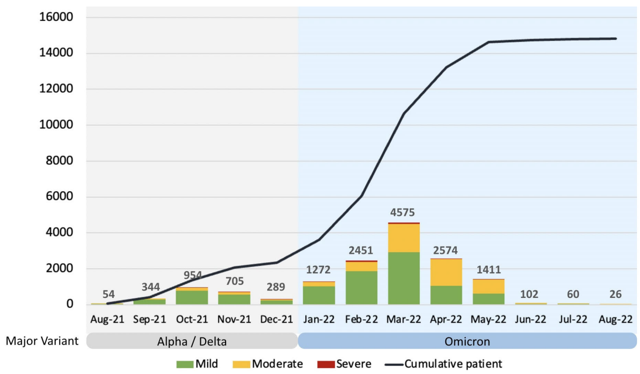


FIGURE 6. The cumulative patients and registered patients each month.

participating in the home isolation program without being hospitalized as in the criteria. This phenomenon was attributed to the crisis period, during which hospital bed capacity reached full capacity, rendering hospitals unable to admit patients. Consequently, patients marked as severe were necessitated to stay within the isolation program, undergoing regular monitoring. However, as illustrated, the severity progress of patients within the system emphasizes the comprehensive and accessible care they receive.

Moreover, Figure 6 depicts a notable surge in patient admissions during March 2022, reaching a peak with a record-breaking total of 4,575 registered individuals, coinciding with the emergence of the Omicron variant in Thailand. Nevertheless, the system lacks specific data on each patient's individual variants. Consequently, the researcher inferred their variants based on the registration date [22] recorded in the system.

2) PROGRESS NOTE UTILIZATION

According to the data presented in Table 4, patients submitted daily progress notes approximately twice a day, adhering to the daily progress note submission criterion. The average submission rates across different age groups and severity levels appear relatively similar, with no significant differences between groups. However, a slight trend indicates that patients aged between 35 and 49 had a slightly higher average submission rate than those in other age groups, while those aged 65 and above had the lowest average submission rate.

3) PACMAN UTILIZATION

Since the launch of the PACMAN function, the system has processed 43,444 image submissions. During the peak of the Omicron strain outbreak, patients on the system utilized the PACMAN function more frequently. Utilization rates varied based on age and severity. Specifically, patients aged 18-34 had the highest utilization rate (34.6%), while those aged 65-74 had the lowest (14.9%). Moreover, severe patients had significantly higher utilization rates than other severity groups. However, their accuracy rates were lower, averaging 68.7%.

IV. DISCUSSION

In order to address the challenges highlighted in this study, it is crucial to consider the broader implications and potential generalizations for countries confronting analogous healthcare crises. Rapid integration with widely adopted social messaging platforms, such as LINE in Thailand, in other countries presents a pragmatic solution [11]. This approach proves particularly advantageous when the creation of a novel application or service from the ground up is unfeasible amid a pandemic characterized by constrained time and resources.

Moreover, leveraging extension frameworks from social messaging platforms with third-party customization features, such as LINE Front-end Framework (LIFF), enhances the efficiency in managing data compared to typical messaging platforms. This inclusive strategy contributes to a more streamlined approach to handling unsystematic information on messaging platforms. However, this approach may be impractical in countries without popular chat platforms or facing restrictions. In such cases, rather than create a new application, we recommend utilizing the existing digital care platform [10], [13] or the web application with short messaging service (SMS) integration from telecom services for patient notifications and remote health monitoring offering a viable alternative in the absence of suitable messaging platforms. This approach ensures scalability and practicality without requiring a significant amount of time for development.

Although our survey indicates that our system has the potential to reduce the healthcare practitioners' workload, save time, and be user-friendly, certain functions such as the summary dashboard, prescribing medication and equipment, and PACMAN have been underutilized. Despite being provided with training and user manuals, healthcare practitioners

IEEE Journal of Translational Engineering in Health and Medicine

TABLE 4. The patient progress note submission and PACMAN function utilization.

	Total (n=14,817)	Mild (n=9,490)	Moderate (n=5,096)	Severe (n=231)
Progress note function				
Age – avg. submissions per day (SD)				
18-34	1.9 (0.9)	1.9 (0.9)	2.0 (0.9)	1.9 (0.8)
35-49	2.1 (1.0)	2.1 (1.0)	2.2 (1.1)	1.8 (0.9)
50-64	2.0 (1.2)	1.9 (0.9)	2.0 (1.1)	2.6 (4.2)
65-74	1.8 (0.9)	1.26 (0.2)	1.8 (0.9)	1.83 (1.84)
≥ 75	1.8 (1.1)	1.7 (0.5)	1.8 (1.1)	2.1 (1.4)
Total – avg. submissions per day (SD)	2.0 (1.0)	2.0 (1.0)	2.0 (1.0)	2.1 (2.3)
Utilization of PACMAN function				
Age – %utilization				
18-34	34.6%	33.7%	36.1%	70.1%
35-49	30.8%	29.9%	31.2%	60.3%
50-64	21.5%	20.2%	21.8%	43.6%
65-74	14.9%	<0.1%	13.3%	40.0%
≥75	24.0%	<0.1%	22.2%	57.1%
Total – %utilization	30.5%	30.8%	28.7%	57.1%
Overall accuracy of PACMAN function	72.6%	71.7%	74.6%	68.7%

remain unfamiliar with the system unfamiliar with the system, resulting in a lack of utilization and understanding of all system functions. The numerous functions designed for healthcare practitioners and the training section were insufficient, resulting in diminished comprehension of the system, in contrast to the uncomplicated functionality provided to patients who merely need to report their daily symptoms. Enhancing the accessibility of explanations and optimizing training methods are vital measures in tackling these challenges.

Furthermore, as healthcare practitioners typically administer medications through their existing hospital information system, the utilization of the medication prescribing function in the CHIVID system may lead to redundancies in patient record-keeping. Moreover, during times of crisis, the CHIVID system's prescribing function is limited to the option of Favipiravir, contributing to healthcare practitioners' underutilization of this function. A crucial aspect of future development strategy involves the capability to link hospital information systems seamlessly to optimize the system's functionality.

Interestingly, the patient data demonstrated that severe patients used the PACMAN function more and submitted more progress reports than patients with milder conditions. This behavior can be attributed to the need for severe patients to closely monitor symptoms and track their progress for informed treatment decisions. In contrast, mild or moderate-intensity patients may perceive their symptoms as less severe and show less motivation to utilize the system's tracking functions. Despite the higher usage rate among severe patients, their accuracy in data entry was lower than other severity groups, suggesting the presence of barriers affecting data quality. Further investigation is necessary to identify and address these barriers to ensure accurate data entry and enhance data quality in this patient group.

Due to CHIVID's original design not being intended for research purposes, our study relied on post-crisis data analysis, which revealed limitations in utilizing patient data for retrospective analysis. Some hospitals implemented the system before the research plan was finalized, resulting in missing crucial information for symptom analysis and inaccurate recording of clinical outcomes. Additionally, incomplete patient discharges and government quarantine regulations mandating a minimum treatment duration posed challenges in determining accurate recovery durations. Moreover, reliance on patient self-assessment introduced potential inaccuracies and incomplete data, highlighting the need for improved data collection processes in healthcare systems during pandemics to ensure more reliable research outcomes.

In the next stage of our project, we aim to advance the development of a telemonitoring system designed for the continuous tracking of bedridden patients, which has been driven by the policy of the Bangkok governor. By utilizing the expertise of healthcare practitioners and the findings from the studies discussed in this research, we endeavor to enhance the efficiency of patient data collection by incorporating more stringent measures. Our focus is on obtaining accurate and comprehensive patient information. Moreover, we have implemented additional functionalities tailored to remote monitoring of the bedridden, such as augmenting the processing capabilities for collecting blood pressure data.

V. CONCLUSION

CHIVID effectively manages and monitors patients remotely, reducing transmission risks and overcrowding. Healthcare practitioners can remotely monitor vital signs and symptoms through a user-friendly app, triggering alerts for abnormalities. Although the system meets user needs and satisfies healthcare practitioners, minimizing data errors is crucial for improved effectiveness and research purposes. Despite limitations, CHIVID can significantly manage COVID-19 patients, especially in resource-constrained areas and with healthcare professionals unfamiliar with telemedicine. In light of the COVID-19 crisis, it is crucial to reflect on the use of telemonitoring systems and other innovations that could be integrated into an enhanced health information system in the future [23].

REFERENCES

[1] S. Triukose et al., "Effects of public health interventions on the epidemiological spread during the first wave of the COVID-19 outbreak in Thailand," *PLoS One*, vol. 16, no. 2, Feb. 2021, Art. no. e0246274.

[2] F. Zhou et al., "Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: A retrospective cohort study," *Lancet*, vol. 395, no. 10229, pp. 1054–1062, Mar. 2020.

[3] N. Nittayasoot, R. Suphanchaimat, C. Namwat, P. Dejburum, and V. Tangcharoensathien, "Public health policies and health-care workers' response to the COVID-19 pandemic, Thailand," *Bull. World Health Org.*, vol. 99, no. 4, pp. 312–318, Apr. 2021.

[4] F. Perrotta et al., "COVID-19 and the elderly: Insights into pathogenesis and clinical decision-making," *Aging Clin. Experim. Res.*, vol. 32, no. 8, pp. 1599–1608, Aug. 2020.

[5] M. R. Mehra, S. S. Desai, S. Kuy, T. D. Henry, and A. N. Patel, "Cardiovascular disease, drug therapy, and mortality in COVID-19," *New England J. Med.*, vol. 382, no. 25, p. e102, Jun. 2020.

[6] Y. Zhou, J. Chi, W. Lv, and Y. Wang, "Obesity and diabetes as high-risk factors for severe coronavirus disease 2019 (COVID-19)," *Diabetes/Metabolism Res. Rev.*, vol. 37, no. 2, p. e3377, Feb. 2021.

[7] Y.-D. Gao, "Risk factors for severe and critically ill COVID-19 patients: A review," *Allergy*, vol. 76, no. 2, pp. 428–455, 2021.

[8] F. Ye et al., "A framework for infectious disease monitoring with automated contact tracing—A case study of COVID-19," *IEEE Internet Things J.*, vol. 10, no. 1, pp. 144–165, Jan. 2023.

[9] A. Alboksmaty et al., "Effectiveness and safety of pulse oximetry in remote patient monitoring of patients with COVID-19: A systematic review," *Lancet Digit. Health*, vol. 4, no. 4, pp. 279–289, Apr. 2022.

[10] T. Annis et al., "Rapid implementation of a COVID-19 remote patient monitoring program," *J. Amer. Med. Inform. Assoc.*, vol. 27, no. 8, pp. 1326–1330, Aug. 2020.

[11] S. Q. Ko et al., "Remote monitoring of marginalised populations affected by COVID-19: A retrospective review," *BMJ Open*, vol. 10, no. 12, Dec. 2020, Art. no. e042647.

[12] L. Wang et al., "Large-scale implementation of a COVID-19 remote patient monitoring program," *Western J. Emergency Med.*, vol. 24, no. 6, pp. 1085–1093, Nov. 2023.

[13] S. Talha et al., "Early hospital discharge using remote monitoring for patients hospitalized for COVID-19, regardless of need for home oxygen therapy: A descriptive study," *J. Clin. Med.*, vol. 12, no. 15, p. 5100, Aug. 2023.

[14] H. Gruwez et al., "Remote patient monitoring in COVID-19: A critical appraisal," *Eur. Respiratory J.*, vol. 59, no. 2, Feb. 2022, Art. no. 2102697.

[15] H. Patel, A. Hassell, B. Cyriacks, B. Fisher, W. Tonelli, and C. Davis, "Building a real-time remote patient monitoring patient safety program for COVID-19 patients," *Amer. J. Med. Qual.*, vol. 37, no. 4, pp. 342–347, 2022.

[16] D. Wurzer et al., "Remote monitoring of COVID-19 positive high-risk patients in domestic isolation: A feasibility study," *PLoS One*, vol. 16, no. 9, Sep. 2021, Art. no. e0257095.

[17] Electronic Transactions Development Agency. (2016). *The Development of E-Commerce in Thailand: Challenges and Opportunities*. [Online]. Available: https://unctad.org/system/files/non-official-document/dtl_eweek2016_ETDA_IUP_en.pdf

[18] R. Ftouni, B. AlJardali, M. Hamdanieh, L. Ftouni, and N. Salem, "Challenges of telemedicine during the COVID-19 pandemic: A systematic review," *BMC Med. Informat. Decis. Making*, vol. 22, no. 1, pp. 1–21, Dec. 2022.

[19] LINE Corporation. 2024. *LINE Front-end Framework (LIFF) Overview*. [Online]. Available: https://developers.line.biz/en/docs/liff/overview/

[20] P. Kietdumrongwong, "Recommendations for emergency management of severe communicable disease-lesson learned from the emergency medical service management of COVID-19 epidemic in Thailand," *J. Emergency Med. Services Thailand*, vol. 2, no. 1, pp. 90–97, 2022. [Online]. Available: https://he03.tci-thaijo.org/index.php/Jemst-01JHS/article/view/317

[21] C. Boonnag et al., "PACMAN: A framework for pulse oximeter digit detection and reading in a low-resource setting," *IEEE Internet Things J.*, vol. 10, no. 15, pp. 13196–13204, Aug. 2023.

[22] Department of Disease Control. 2023. *COVID-19 Situation Administration—Thailand*. [Online]. Available: https://covid19.ddc.moph.go.th/

[23] E. Negro-Calduch, N. Azzopardi-Muscat, D. Nitzan, R. Pebody, P. Jorgensen, and D. Novillo-Ortiz, "Health information systems in the COVID-19 pandemic: A short survey of experiences and lessons learned from the European region," *Frontiers Public Health*, vol. 9, Sep. 2021, Art. no. 676838.