GEO-FENCING LOCATION TRACKING SYSTEM USING IOT AND LORA LPWAN FOR COVID-19 MANDATORY SELF-QUARANTINE MONITORING

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Article history

Received: 15 nov 2022

Received in revised form: 25 Nov 2022

Accepted: 1 Dec 2022

Published online: 10 Dec 2022

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ABSTRACT

Initially, quarantine for COVID-19 patients was carried out at specific quarantine centers; however, with large increases in COVID-19 individuals taxing the health system, a self-quarantine at home system was introduced. Nevertheless, self-quarantine at home creates other issues such as non-compliance to the self-quarantine directive and this has led to the spreading of COVID-19 in the community. In this paper, we propose CAGE (COVID-19 Adherence via Geo-fencing E-tracking), an electronic geo-fencing location tracking system using the Internet of Things (IoT) and Long Range Low Power Wide Area Network (LoRa LPWAN) to monitor and ensure adherence to the COVID-19 mandatory self-quarantine at home directive. CAGE incorporates an IoT-based geo-fencing tracking with location data obtained through GPS and the data is communicated to the authorities through LoRA. CAGE consists of a security fuse function that alerts the authorities if the patients have removed the device. CAGE runs on battery power for the whole self-quarantine period and is reusable where once the self-quarantine period is fulfilled; it can be returned and reprogrammed for the next users. Three versions of CAGE prototype have been developed to satisfy the requirements and they were built using off-the-shelf hardware which possesses the potential to integrate many more features with proper power characterization. In comparison to the first prototype, the second achieved the same geofencing performance while using 87% smaller in size and 65% less active current. This research focuses on design choices for Malaysia implementation and suggested multiple electronic prototypes to enforce strict adherence to Malaysia self-quarantine towards low power usage which can be monitored consistently by the authorities and will lead to breaking the chain of the relevant pandemic.

Keywords: *COVID-19, Internet of Things, self-quarantine monitoring, GPS, geo-fencing*

1.0 INTRODUCTION

It was first detected in Wuhan, China in December 2019, and in less than 6 months, has spread to almost all of the countries worldwide. The World Health Organization (WHO) declared COVID-19 a pandemic in March 2020 [1]. Since then, various COVID-19 variants have emerged that are even more highly infectious and can cause respiratory illness with symptoms such as coughing, fever, and, in severe cases, breathing difficulties that can lead to death [2]. COVID-19 is highly dangerous, especially to vulnerable groups such as the elderly and those with existing health conditions which has shown that for every 1000 infected elderly patients, 116 patients will die due to the virus [3]. Moreover, researches into the spread of COVID-19 has shown that it may be an airborne pathogen thus making it even more difficult to contain and stop the spread of the virus [4]. Up to four out of five people infected with COVID-19 have shown to be asymptomatic [5], and this poses a very difficult problem for authorities to track and identify these carriers. Even after starting the administration of COVID-19 vaccinations, it was meant for a mortality rate reduction, not for contagion prevention.

In order to halt the spread of COVID-19, Malaysia government enacted a number of regulations. The first was to implement an electronic check-in system via mobile applications such as the MySejahtera app to record people visiting places so that if a COVID-19 cluster is discovered there, all potentially infected people can be identified. This approach, however, was not well-implemented, especially in rural areas where not all are guarded to ensure that everyone checked in using the app. The second was to close all international and state borders initially and then allow only necessary travels through them. Individuals who travel internationally were then required to serve a quarantine period of 14 days or more which has effectively prevented virus spread [6]. Nevertheless, with the opening of travel allowances, high associated costs of quarantine locations and a high number of patients to be quarantined, the quarantine requirement is no longer strictly set at a quarantine center and it was expected that travelers and patients must undergo self-quarantine at home. To identify self-quarantine individuals, colour-coded wrist tags must be worn at all time for the community to recognize them. Unfortunately, there have been multiple cases of non-adherence where individuals have gone out into the community wearing the wrist tag unnoticed by hiding it under their clothes. The Sivagangga cluster is one highly unfortunate incident due to the non-compliance of the ruling [7].

For the scope of this project, we aim to make use of an electronic tracking method that is tamper-proof and is able to communicate the adherence to self-quarantine to the authorities. The objectives of our proposed device, CAGE (COVID-19 Adherence via Geo-fencing E-tracking) are:

1. Geo-fencing of the self-quarantine individual to ensure that they stay within their quarantine centers.
2. Periodically check the location of the individual and alert authorities of any non-compliance.
3. The device will be operating on battery power for the duration of the recent quarantine period.

PERINTIS eJournal, 2022, Vol. 12, No. 2, pp. 56-68

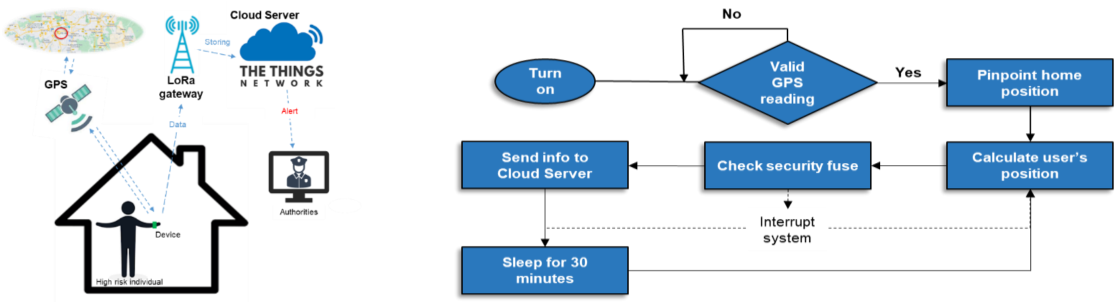
Other countries have also implemented an electronic tracking device to ensure that COVID-19 patients adhere to their quarantine directive. However, the majority of the other solutions require a secondary device to connect to the internet via cellular or Wi-Fi to update the authorities such as [8], and require multiple procedures to be performed manually on a regular basis for quarantine management such as [9]. Others require that the device be recharged twice a day for it to be constantly connected. Although the effectiveness of the previous work is recognized in their respective countries, their benefits appear to be limited in Malaysia. Therefore, it is sensible to modify the electronic devices in order to improve their usability, reliability, and flexibility within the Malaysian environment by introducing LoRa-based geofencing electronic device for self-quarantine monitoring. Table 1 indicates the detailed features of the devices implemented in different countries as reported in global news.

Table 1: Examples of electronic tracking devices of other countries for COVID-19 quarantine measures.

Country	Ref.	Device	Features
Hong Kong	[10]		• Equipped with GPS module. • Assisted by phone app for mapping out home location. • Need QR code to be scanned by phone regularly to update wear-status. • Not suitable for low internet coverage area. • Need a smartphone connection (secondary device).
Abu Dhabi	[11]		• Waterproof design. • Alert authorities if the band is removed. • Needs charging twice a day. • Predetermined fixed home position. • High energy usage and low battery capacity.
Belgium	[12]		• Equipped with SOS button, health monitoring, GPS, GSM and WiFi • Only monitors location, not for geo-fencing • No authorities alert for non-compliance

2.0 MATERIALS AND METHODS

The proposed device prototype for COVID-19 mandatory self-quarantine monitoring was developed through the use of geofencing using IoT and LoRa. The combination of IoT and LoRa communication has the valuable advantage of being scalable, easy to deploy and having a wide reach. IoT has shown to have exponential growth in the industrial, agriculture, and medical healthcare sectors and is a platform that can be useful to develop COVID-19 monitoring solutions [13]. The system architecture of the proposed system can be seen in Figure 1(a) as Malaysia is the case study. The system consists of a standalone wearable electronic device, GPS and LoRa-IoT communication, and a cloud server (The Things Network). The flowchart of the developed system is depicted in Figure 1(b).



(a) (b)

Figure 1: (a) System architecture; (b) System flowchart.

2.1 Location and Coordinates Detection for Geo-fencing

In order to ensure that the COVID-19 individual adheres to the self-quarantine at the home directive, the location and coordinates of where the individual will be serving the self-quarantine period have to be determined. The coordinates can be obtained through Global Positioning System (GPS). GPS was used because it is low cost, can be easily integrated, and can constantly detect the location of the individual anywhere unlike WiFi and Bluetooth which require a modem nearby and have a shorter range, and cellular network which is costly and high-power consumption.

2.2 Wireless Communication for Communicating the Status of Individual

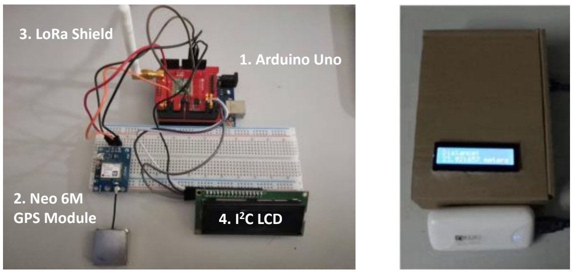
There have been many cases where individuals hide their COVID-19 status colour band and this had led to numerous clusters spreading throughout the community. Therefore, it is imperative that the status of the location of the individual can be monitored and constantly communicated to the authorities. LoRa was used to facilitate communication. LoRa is an upcoming open standard communication protocol that is useful for industrial applications enabling devices to send small amounts of data over great distances with low power consumption for remote applications. Despite the data transfer amount limitation, the requirement of only needing to send data of the individual's adherence to self-quarantine is suitable for our particular device application. In comparison with WiFi and Bluetooth, LoRa appears to be more cost-effective for communication when installed especially across rural areas due to the larger coverage of its gateway.

2.3 Ensure that the device is never removed – security fuse

There have been many cases of individuals removing their COVID-19 colour-coded bands and this was less monitored by the authorities. To improve individual adherence even further, a method must be implemented to ensure that if the individual removes the device, the authorities are automatically notified. To ensure that the device is never removed, we implement a security fuse function in our device. The security fuse is connected and activated once it is turned on and if the device is removed, an alert will be sent to the authorities. The status of the security fuse cannot be reset by the individual and this will ensure that the user never removes the device. In comparison to [8], users must manually scan the QR code provided on the bracelet to update their wear status.

3.0 RESULTS

Our prototype for CAGE was developed to solve the issues associated with monitoring the self-quarantine directive. The initial CAGE prototype was developed with the discrete components shown in Figure 2.



(a) (b)

Figure 2: (a) Initial prototype development for CAGE using discrete components of Arduino Uno, LoRa shield, NEO 6M GPS module, and an I2C LCD; (b) Simple box case for the first CAGE prototype powered by a 5200 mAh power bank.

3.1 Geo-fencing through GPS signal location

The CAGE prototype would start up and initialize by checking for a GPS signal availability received by Neo 6M GPS module. When the GPS signal is available, it would then store the current coordinates as the home location position and calculate the allowable geo-fence area. CAGE would then periodically check the current GPS coordinates and by using the Haversine Equation (1), the distance between the current coordinates and the stored home location can be calculated. The Haversine equation is an accurate method of determining the distance between two co-ordinates on a sphere and is useful for small angles and distances. The distance calculated via the Haversine formula is expressed as:

$$a = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi_2 \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right),$$
$$c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{1-a}), \quad (1)$$
$$distance = R \cdot c,$$

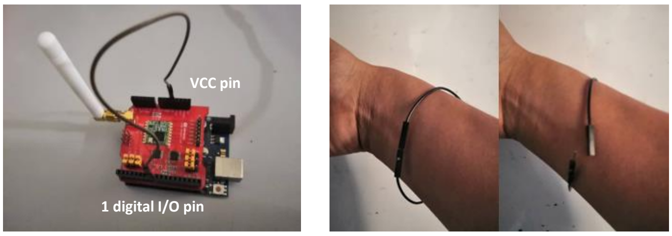
where φ is latitude, λ is longitude and R is Earth's radius.

Using the Haversine equation, if the current coordinates were found to be within the geofenced area, it would send a signal through LoRa that the user is located within the boundary. In our use case, we set the geo-fenced boundary to be within 30 m of the individual home location to cater to different sizes of Malaysian houses and the accuracy of the GPS signal. If the current GPS coordinates were outside of the geo-fenced area, it would then send an alert through LoRa indicating that the user has moved out of the geofenced area. The user can also monitor their position from the home position using the provided LCD interface to avoid accidental non-adherence.

3.2 Security fuse with an interrupt system function

In order to ensure that CAGE is always worn by the individual and is never taken off, a security fuse function is implemented in the prototype. The security fuse uses one digital I/O port of the Arduino Uno which is connected to a wire. The initial prototype of the security fuse function as shown in Figure 3(a) would detect if the wire is disconnected from the I/O port and would send a message through LoRa indicating that the user has removed CAGE. This status is not resettable by the user even if the wire is reconnected again.

In addition, the function is also programmed with an interrupt system rather than a polling system. The difference between the two systems is that the interrupt can respond at any time once the interrupt signal is sent to the microcontroller, whereas polling periodically monitors the device status and only executes tasks when certain conditions are met, strictly adhering to the system workflow. As a result, CAGE can track changes even when it is in sleep mode



(a) (b)

Figure 3: (a) Security fuse implementation on the CAGE initial prototype and (b) how the security fuse can be applied around the individual's wrist.

because when the security fuse is disconnected, the device directly notifies the microcontroller and switches to active mode to capture data instead of waiting for the active mode and missing out on data.

3.3 Status communication to the authorities

The status of whether the individual is within the geo-fenced boundary or out of the geo-fenced boundary along with the status of the security fuse must be communicated to the authorities in order to ensure that the self-quarantine directive is adhered to. In order to achieve this, we make use of the LoRa communication to send the status of the individual to the authorities. The Dragino LoRa shield in our initial CAGE prototype contains the necessary radio and antenna to enable LoRa communication at 907.5 MHz. In our testing, a distance of 5 km is achievable where CAGE is connected to a single channel Raspberry Pi based LoRa gateway. We expect that a further improvement in distance is achievable with the use of a dedicated LoRa gateway. Figure 4 shows how both data are experimentally sent to the cloud server for a specific device ID respectively.

Figure 4: The Things Network graphical user interface (GUI) and how data is sent to it. The first column shows the time stamp, the second column shows the number of detections and the last column shows the encoded and decoded messages.

For confidentiality, all detailed data are processed on the device and only status is communicated via LoRa to the cloud server which is The Things Network, and this approach is known as a Boolean-based algorithm based on [15]. Position status only highlights ‘IN’ or ‘OUT’ and wear status only highlights ‘CONNECTED’ or ‘DISCONNECTED’ as presented in Figure 4. Thus, the user's personal privacy will not be exposed to the public throughout the application.

3.4 Power characterization

CAGE aims to operate for the whole quarantine period which is approximately 10 to 14 days without charging needed. Therefore, the system is developed with two modes in order to satisfy the requirement which are active mode and idle mode where it will check, display and transmit position status and wear status and then, sleep for 30 minutes respectively. CAGE majorly operates at low power consumption as well as allows longer battery life. Furthermore, the considerations for battery selection and system power consumption to run the entire quarantine period are based on Equation (2).

$$\begin{gathered} P = V \times I, \\ E = V \times I \times T, \\ E = V \times Q, \\ Q = I \times T, \end{gathered} \tag{2}$$

where Q is the battery capacity needed in amps hours, I is the expected current of the device in amps and T is the expected device operating time in hours.

CAGE v1 generates 0.20 A and 0.13 A in active and idle modes, respectively. As previously stated, the device operates primarily in idle mode; thus, the calculation for idle mode is prioritized. Given that the initial prototype has a 5200 mAh power bank and 0.13 A current consumption,

$$T = Q \div I,$$
$$T = 5200\ mAh \div 130\ mA,$$
$$T = 40\ hours,$$

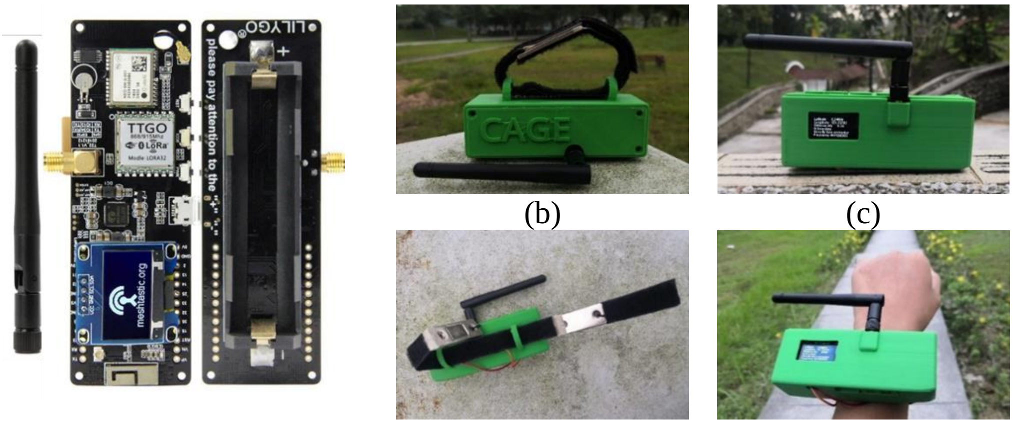
CAGE v1 can only run for about 1.7 days which is not suited for our objective. As a result, it must be improved further for the selection of electronic components to reduce power consumption and battery selection for higher capacity.

3.5 Improvement of prototype system – CAGE v2

Another main objective of CAGE was that it should be battery-powered throughout the entire duration of the self-quarantine period. For the initial prototype version of CAGE using the standalone components, it was evident that these components were not optimized to be used in a battery-operated device. The second version of CAGE (CAGE v2) was then developed with battery life considerations in mind and was constructed using a TTGO T-Beam development board. CAGE v2 consists of an ESP32-based microcontroller with a built-in NEO 6M GPS module and LoRa communication. The security fuse was embedded into the strap and attached to the magnetic clasp for detection. CAGE v2 has a smaller dimension for a wearable device and consumes less power, allowing it to survive for 10 to 12 days in a row. The developed CAGE v2 with a 3d-printed wearable case and how the security fuse wrist band is implemented are shown in Figure 5.

4.0 DISCUSSION

In order to ensure that the objectives of CAGE are met, it is necessary to ensure that the co-ordinate of the COVID-19 individual is correctly identified and to identify the lifetime of CAGE running on battery power. An improvement to the first prototype was also completed which results in CAGE v2 as will be described in the following section.



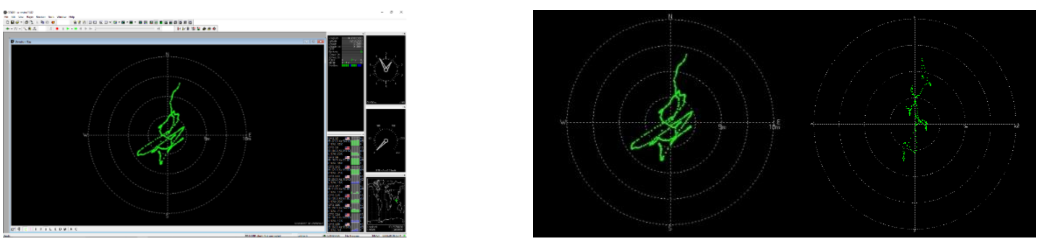
(b) (c)

(a) (d) (e)

Figure 5: (a) TTGO T-Beam ESP32 LoRa GPS development board with integrated battery slot, OLED, and rigid antenna; (b) CAGE v2 developed with 3D-printed case and security fuse strap; (c) CAGE v2 shown with the OLED screen showing status information and LoRa antenna; (d) Wearable security fuse strap connected to CAGE v2; (e) Example of how CAGE v2 can be worn on a wrist of the COVID-19 individual.

4.1 Accuracy of GPS coordinate location for geo-fencing

The geo-location of the individual is obtained through GPS to ensure that COVID-19 patients are staying within the geofenced area. To test the accuracy of the GPS location obtained, the GPS signal was monitored in four indoor environments are standalone house, a double-storey terrace house, a dormitory on the ground floor, and a dormitory on the top floor. The accuracy was tested by recording the GPS reading using U-center software without moving. The green dots indicate the movement of the device from the geo-fence center. The ideal result is that the green dots should always be in the middle of the radar. However, the results were found to be typically accurate to within a ±5 meters range and occasionally the GPS reading would deviate up to ±7 meters within densely indoors as shown in Figure 6(b) such as at the second and third



(a) (b)

Figure 6: (a) U-center software from u-blox.com is used to track the accuracy of geolocation; (b) Accuracy of GPS signal obtained indoors showing the received GPS signal to be within ±7 meters where the middle circle to the outer circle is between 0 meter and 10 meters.

location. Moreover, CAGE also takes a longer duration to lock the GPS data at both locations. In the CAGE prototype, we set the geo-fencing boundary to be within 30 meters which would include the accuracy discrepancy. If the need arises to further reduce the geo-fenced area, the current accuracy of the GPS enables us to further reduce the geo-fenced area down to 10 meters. On the other hand, to cope with the issue, the device was included with a display for users to monitor accordingly.

4.2 Battery life consideration for self-quarantine period

One advantage of CAGE v2 is that during idle times, it can be put into sleep mode which turns off non-required components and thus reduces the current consumption. The sleep mode duration can be set to enable longer battery life to accommodate the self-quarantine requirements. In terms of battery life expectations, a comparison between the initial CAGE prototype and CAGE v2 is shown in Table 2 using a 3000 mAh battery as the power source and a sleep mode duration of 30 mins.

Table 2: Active and idle currents for CAGE and CAGE v2 along with the expected battery life using 3000 mAh battery capacity

Version	Active current, A	Idle current, A	Expected battery life (days)
CAGE	0.20	0.13	1
CAGE v2	0.07	0.01	12.5

In order to further extend battery life for CAGE v2, we can make use of a higher capacity battery such as a 7800 mAh 18650 Rechargeable Li-ion Battery or further increase the sleep mode duration to cater to the self-quarantine period. We expect CAGE to run on battery power for the duration of the self-quarantine period. Once the self-quarantine period is fulfilled, CAGE can then be returned and reprogrammed for the next self-quarantine patient to use making it highly reusable.

4.2 Battery life consideration for self-quarantine period

CAGE v3 was proposed to improve the dimension of the previous version by considering a smaller microcontroller which is Heltec ESP32 LoRa development board and will be integrated with Neo 6M GPS module and flexible antenna. Compared to the previous version, CAGE v3 antenna can be accommodated into the wristband as it is flexible. The developed CAGE v3 prototype and how the antenna is integrated is as shown in Figure 7.

Consequently, we developed three versions in order to achieve them and reduce the limitations encountered. Table 3 shows the features comparison of each CAGE version. Despite the initial cost of CAGE hardware shown in Table 3, the reusability of CAGE over multiple individuals can lower the costs of implementation.

(a) (b) (c)

Figure 7: (a) Heltec ESP32 LoRa development board with integrated OLED and flexible antenna; (b) CAGE v3 developed with additional NEO 6M GPS module and 1000 mAh LiPo battery as well as handmade case; (c) Security fuse and flexible antenna integrated into the wristband.

Table 3: Feature comparison of all CAGE versions

Version	Cost	Dimensions, cm	Weight, grams
CAGE v1	150 MYR	16 x 11 x 6	300
CAGE v2	140 MYR	10 x 4 x 3.5	130
CAGE v3	95 MYR	7.5 x 4 x 3	66

5.0 CONCLUSION

We have developed CAGE which enables monitoring the self-quarantine of COVID-19 individuals and reporting any non-adherence. The use of LoRa enables CAGE to communicate the device position status and wear status with the authorities. CAGE is reusable for next users and is fully battery-powered throughout the self-quarantine period. If there are any changes to the self-quarantine duration, the battery capacity can also be easily expanded, or the communication interval can be optimized to cater to the required battery life. It is hoped that developing CAGE will provide a low cost for long-term implementation and will be feasible in both rural and urban areas, accordingly, breaking the chain of any contagious infections, particularly COVID-19.

Acknowledgement

The authors would like to acknowledge Keysight Technologies for the IoT training and technical discussion and CREST for the grant to develop the CAGE prototypes in the year 2021.

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