Pothole Detection System (PoDS) with Computer Vision and Internet of Things (IoT)

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Abstract: Pothole is one of the key factors that lead to road accidents in Malaysia each year. In this paper, a Pothole Detection System (PoDS) is developed where machine learning algorithm, computer vision and Internet of Things (IoT) play an important role in detecting potholes. The project is divided into two parts, the first part is focused on object detection with the application of YOLO (You Only Look Once) algorithm which involves labelling of pothole dataset, training the pothole detection AI model through Google Colab (Google Colaboratory) and testing the pothole detection AI model. For the computer vision to work in this system, NVIDIA Jetson Nano Developer Kit, a single board computer, is connected with a web camera to detect the potholes. Another part of this project involves the IoT implementation where a GPS module is used to identify the pothole locations in real time whereas NodeMCU functioned as the microcontroller along with a Wi-Fi module. These two components are integrated in order to obtain the location data of potholes and which is then saved into the ThingSpeak cloud database. Field tests are carried out to test the general performance of the PoDS system. The results obtained are very positive as it detected most of the observable potholes. The success rate under different situations was studied and it was found that the detection success rate during daytime was 94.74%. Also, the detection of rainwater-filled potholes had a success rate of 71.43% while detection during night time (illuminated by headlamp and streetlight) had a success rate of 43.75%. With the ability to detect potholes, it may help the road users especially motorcyclists to avoid bumping into potholes and prevent life-threatening road accidents. Furthermore, the data for pothole locations can be used for further developments in different industries such as the automotive industry.

Keywords: pothole, object detection, computer vision, pothole detection, Internet of Things, vehicle's safety feature, road safety

1. Introduction

Potholes are the main factor of road accidents in Malaysia. In fact, accidents caused by potholes from 2018 till the end of 2020 in Selangor recorded a huge number of 233 cases, causing 148 deaths and 34 serious injuries as shown in Selangor Journal [1]. It is undeniable that potholes pose a serious threat to road safety. The majority of potholes are produced by water seeping into tiny cracks in the surface of the road caused by vehicular wear and tear and deterioration over time.

According to the 2018 police statistics, casualties involving riders and pillions of the motorcycles in Malaysia made up a shockingly high 67.1% of all traffic-related casualties. The number of motorcycle casualties in 2018 was 3.7 times more than the passenger cars casualties as stated by Zainal Abidin et al. [2]. This shows the necessity of a new safety technology on the motorcycles or even cars. Khalid, M. S. A. et al. states that the quality and quantity of safety technologies on the motorcycle is still insufficient as compared to the passenger car [3]. This is because the motorcycle models are produced based only on the regulations by JPJ (The Road Transport Department Malaysia) without introducing and implementing more new safety technologies on the motorcycles, especially the smaller engine motorcycles.

In this work, the Pothole Detection System (PoDS) is proposed. This system detects potholes on the road and alerts the motorcyclist if there is any pothole. Firstly, the image of the road captured by a camera will be sent to an AI computer vision program to determine if there is any pothole. When pothole is detected, the LED will light up and the buzzer will buzz to alert the riders. At the same time, the location data of potholes will be uploaded to the cloud database through IoT system. The main purpose of this database is to inform officials responsible for road maintenance on where the major potholes are which could potentially be dangerous for motorcyclists and other road users. The data collected can also be used for other purposes in such industries such as the automotive industry.

This PoDS project is based on existing 2D image processing method, and the researchers of this project tried to add in the pothole images under different conditions such as potholes filled with rainwater and potholes in dark, rather than just using the typical pothole images during daylight to do the AI training and field test. Besides, the pothole image processing is integrated with the ThingsSpeak cloud to form an Internet of Things (IoT) system where the prototype is not only about detecting pothole in real time for the drivers, but also has the ability to collect the location data of the pothole to more usages according to the data collected. This project's researcher's also hope to make this prototype functionable on a motorcycle, in which a brief field test on motorcycle was done and it will be discussed in the discussion section of this paper.

2. Methodology

In Pothole Detection System (PoDS), there is a combination of pothole detector and IoT system to enhance the overall performance. With this combination, PoDS is able to provide two main features, where the first feature is to detect pothole and alert the road users at the same time. Its second feature is to send and

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store the data in cloud database which can be retrieved by road users anytime.

In order to integrate pothole detection and IoT system, the microcontroller, NodeMCU is selected to perform the task as it includes firmware for running ESP8266 Wi-Fi module which fits perfectly for IoT part. Other than that, NodeMCU will be programmed using Arduino IDE software where C++ programming language is applied. The program for IoT system and integration of both pothole detection and IoT system will be written in NodeMCU. The flowchart for the entire system (PoDS) is shown in Figure 1.

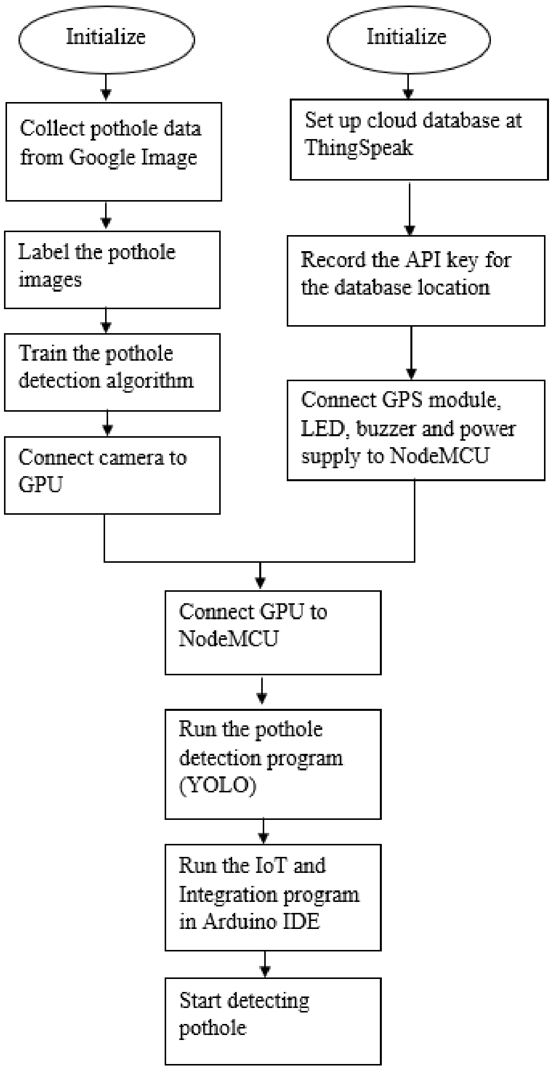


Figure 1. Flowchart for overall production of PoDS

In Figure 1 above, after training pothole data, pothole detection system will be set up completely with camera and NVIDIA Jetson Nano. Then, NodeMCU will be connected to NVIDIA Jetson Nano to perform the remaining tasks, for instance, the pothole detection data will be sent to NodeMCU to further process and send the data to the output devices such as LED and buzzer. Furthermore, GPS module that is connected to NodeMCU as one of the IoT components will be providing the location data which will be processed by NodeMCU before sending the data to cloud database (ThingSpeak).

2.1 Pothole Detection

The Pothole Detection System (PoDS) is built to perform the real-time object detection for potholes and alert users with alarm and red LED if a pothole is detected on road. Real-time object detection for pothole is achieved by implementing YOLOv4-tiny algorithm where multiple pothole images are labelled and applied to train the YOLOv4-tiny detector. In this system, approximately 1200 potholes images are collected from Google Image and labelled in YOLOv4-tiny algorithm. The images in the dataset can be classified into 4 categories which are photos of pothole under daylight, pothole without daylight, pothole filled with rain water and road without pothole as shown in Table 1 below.

Table 1. Potholes data classification

Road categories	**Scenarios**
Category A	Potholes under daylight
Category B	Potholes without daylight (at night)
Category C	Potholes filled with rain water
Category D	Road without potholes

YOLOv4-tiny model will then be initialized and trained with all those labelled pothole images on Google Colab. The hyperparameters used in the training for the YOLOv4-tiny model are shown in Table 2. Other hyperparameters not mentioned below are set as their default values.

Table 2. Hyperparameters used to train pothole YOLOv4-tiny pothole detection model.

Hyperparameter	Value
Classes	1
Maximum Batches	6000
Batch	32
Subdivisions	16
Width (pixels)	608
Height (pixels)	608
Step	4800, 5400
Filter	18
Iteration	3200

Next, the mean average precision (mAP) of the model will be obtained by predicting other pothole images that is not used in the training dataset. mAP is a common metric used in object detection algorithms such as YOLO to rate the object detection model's performance based on simulation. In PoDS, after training of labelled data, the best weight of the pothole detection has mAP of 54%. This data is shown in Figure 2. The pothole detection model's weight with the best mAP is applied to PoDS. The flowchart for building pothole detection AI model is shown in Figure 3.

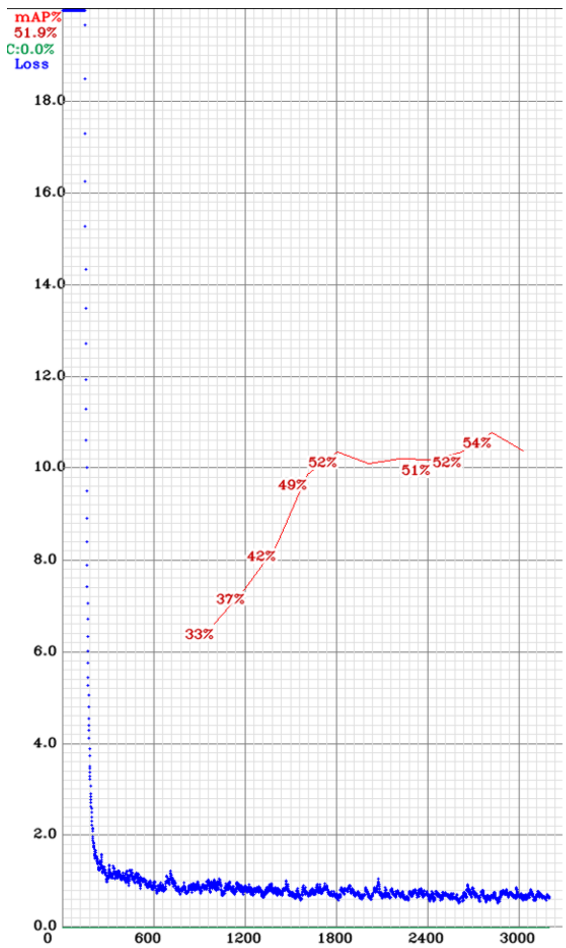


Figure 2. Graph of mean average precision (mAP) against iteration throughout the training of the pothole detection AI model

The mAP stated here is not to be confused with the field test's success rate. Although the mAP is 54% in simulation, but the field test's success rate in the field tests results section shows a higher success rate in a typical daytime scenario. Thus, there is a certain reliability on this prototype in real application which performs better than the simulated mAP results.

For the setup of PoDS prototype, it consists of power inverter, monitor, small computer, web camera, microcontroller, GPS module and output devices such as red LED, and buzzer. The keyboard and mouse are only used at the initialization stage of the PoDS. Thus, after initialization of PoDS, PoDS will be working without keyboard and mouse. The small monitor is used for the researchers to observe the pothole detection results visually during the field tests. The specific models for each equipment used are shown in Table 3.

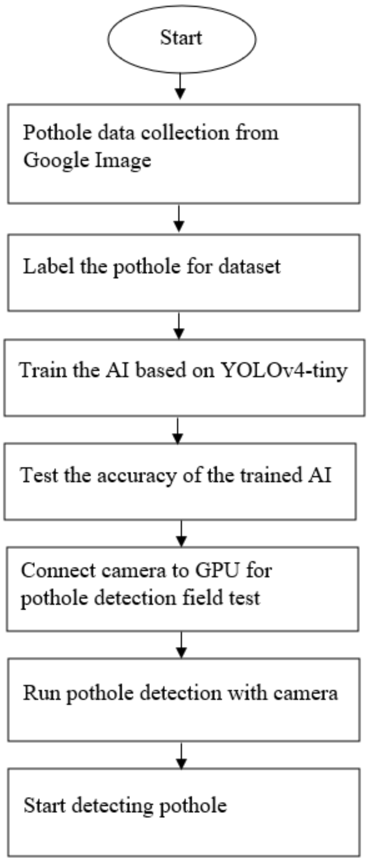
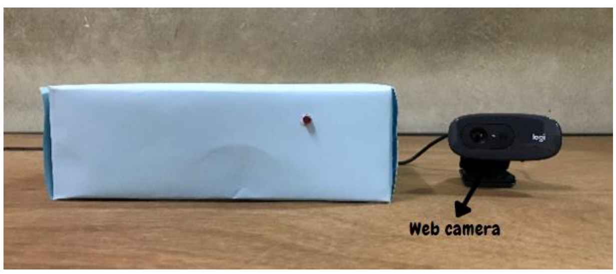


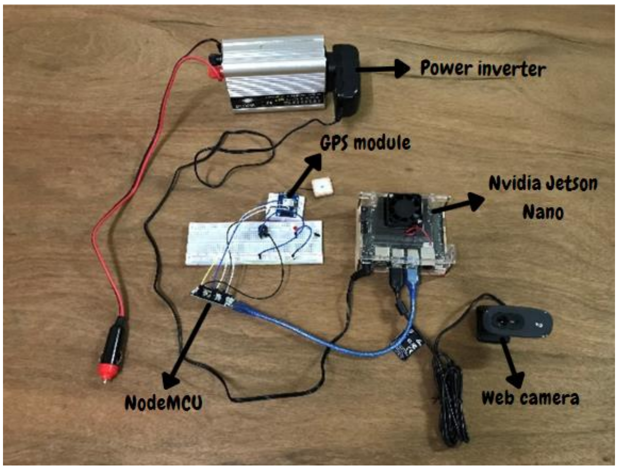
Figure 3. Flowchart of building the pothole detection AI model

Table 3. Model name of PoDS components

Components	**Model Name**
Power Inverter	DC to AC 12V Portable Power Inverter
Monitor	Raspberry Pi IPS HDMI Capacitive Touch Monitor 7 inch
Small computer	Nvidia Jetson Nano
Web Camera	Logitech C270
Microcontroller	NodeMCU V2 Board
GPS module	GY-NEO6MV2 GPS module



(a) Front view of PoDS prototype



(b) Components of PoDS

Figure 4. Pothole Detection System prototype and its components

2.2 Pothole Database via Internet of Things

To improve the system's functionality, the feature of Internet of Things (IoT) is added to PoDS. This feature is built with Arduino, together with the cloud database, ThingSpeak. When the pothole is detected with YOLOv4-tiny detector, the IoT system will receive the pothole location data in form of longitude and latitude, then store and visualize it in ThingSpeak. Furthermore, the users will be able to access to ThingSpeak to retrieve the location data for further use such as analysis of pothole location data at specific area. IoT system is implemented to provide additional feature of PoDS using components such as NodeMCU microcontroller and GPS Arduino-based module with the online cloud database, ThingSpeak. The IoT components and the flowchart of IoT system are shown in Figure 5 and Figure 6 respectively.

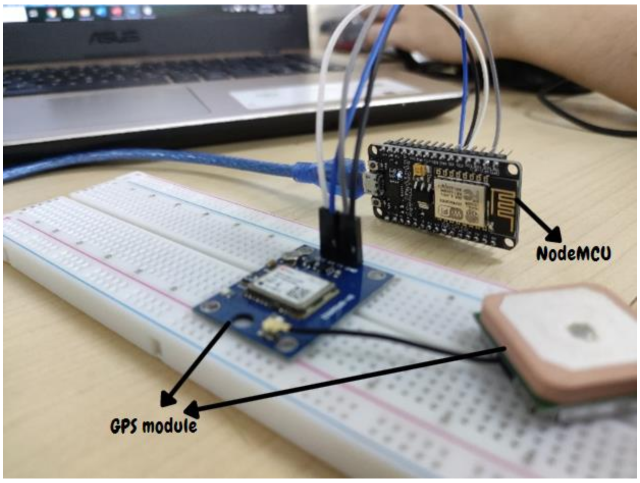


Figure 5. IoT components (NodeMCU, GPS module)

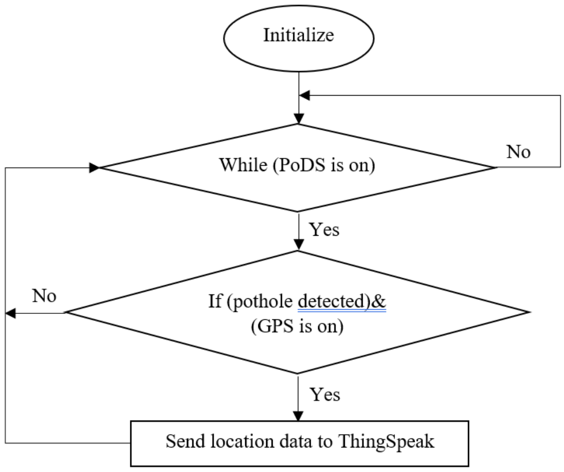


Figure 6. Flowchart of IoT operation

As shown in Figure 5, for initialization, the GPS module will be connected to NodeMCU as well as the PoDS. NodeMCU and GPS module will be implemented using Arduino program. The API key for the specific storage location on ThingSpeak has been added into the Arduino program. When the GPS module is switched on, NodeMCU will start to run the IoT program. If pothole is detected by YOLOv4-tiny, NodeMCU will proceed to send the relevant location data to ThingSpeak.

Other than the basic feature of storing pothole location data, the IoT system in PoDS also allows user to access to the cloud database to retrieve the location data. For future development, the IoT system will be providing software for users to detect potholes in real time without having the full setup of PoDS.

3. Field Tests Results

In order to test the PoDS functionality and accuracy, a total of 4 field tests with different scenarios has been conducted in Tenth College area of Universiti Putra Malaysia. Each of the field tests is expected to detect potholes on the road and produce the alert signals to the riders/ drivers by flashing red LED and producing buzzer sound. Therefore, if pothole is detected successfully, red LED lights up and buzzer buzzes. The vehicles selected in these field tests are a Sedan car and a motorcycle. The camera was installed on the centre top of the windshield, behind the rear-view mirror while for motorcycle, the camera was installed above the headlamp to provide an even view for both sides of the vehicle and to minimize any possible distractions. The lens was angled slightly downwards where the lcd display showing about 80% road and 20% sky to provide balance of exposure and pothole details. For the setting up of the field test, the camera was attached to a car that was moving forward at 40km/hour. The classification of the 4 field tests is displayed in Table 4.

Table 4. Field tests conducted for PoDS

Field Tests	Scenario
A	Daytime
B	Pothole filled with rain water
C	Night (headlamp only)
D	Night (headlamp + streetlight)

For Field Test A, B, C and D, the accuracy of the pothole detection system (PoDS) is tested and calculated in terms of success rate and false positive rate. In the labelling pothole database, 3000 two-dimensional (2D) road images with pothole are initially labelled. However, roughly 2000 pictures are discarded because of their low quality in terms of the angle of image. Only about 1200 high quality images are ultimately chosen to ensure the accuracy of the pothole detection system. Through Google Colab, the pothole detecting model is trained. In layman's term, we are instructing the computer system to recognize the appearance of pothole by showing it with tons of pothole images. The best simulation's test result yields 54% accuracy, thus it will be the accuracy of our algorithm based on the simulation.

The success rate and false positive rate of our system can be calculated by using the formulas below.

Formula (1):

$$Success\ rate = \frac{pothole\ detected}{total\ pothole\ on\ road} \times 100\%$$

Formula (2):

$$False\ positive\ rate = \frac{time\ of\ detected\ false\ positive}{time\ of\ the\ road\ without\ pothole} \times 100\%$$

In Table 5, it is shown that the detailed performance table for experiment by each road condition. Figure 7 shows the result images at each road condition using our pothole detection system (PoDS).

Table 5. Detailed performance of PoDS

Situation	Pothole existed	Pothole detected	Success rate	False positive rate
Daytime	19	18	94.74%	2.08%
Pothole filled with rain water	35	25	71.43%	7.16%
Night (headlamp only)	11	0	0.00%	12.73%
Night (headlamp + streetlight)	16	7	43.75%	7.37%

(a) Daytime

(b) Pothole filled with rainwater

(c) Night (headlamp only)

(d) Night (headlamp and streetlamp)

Figure 7. Result images at each category using PoDS for field test

During IoT system implementation, GPS module is used to identify the pothole locations while NodeMCU serves as microcontroller with Wi-Fi module; thus, when the NodeMCU receives data which indicates the detected pothole from Jetson Nano, it will process the location of pothole and send the location data in latitude and longitude form to our database in ThingSpeak cloud as shown in Figure 8. Even though a LTE module which can always send data to the cloud at real time is better than the

Wi-Fi module which only sends data to the cloud when connected to Wi-Fi, Wi-Fi module is chosen as the budget is limited for our project.

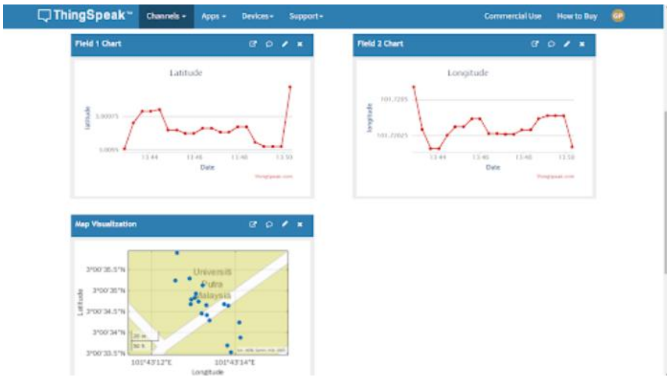


Figure 8. Example database of IoT system implementation

4. Discussions

The field test results showed that the performance and accuracy of PoDS depends greatly on the illumination of the road condition as the system relies on camera to capture the road conditions. The better the illumination of the road condition, the higher the success rate in detecting potholes. PoDS was proven to have the ability to detect pothole filled with rainwater after a rain with an overall success rate of 71.43%.

As for the IoT part, it should work theoretically, but the signal of the pothole location data was not uploaded to the cloud successfully in the field test. One of the possible problems are the insufficient power supplied to the GPS module because GPS module requires consistent power supply. It may also be due to the poor quality of the GPS module or other unknown problems in the experiment.

One of the limitations of PoDS is that its detection performs much poorer under dark conditions than daytime although the system is highly needed in dark conditions due to the limited visibility. The same issue exists for the rainy-day conditions. However, once the pothole location data is uploaded to the cloud, it can be stored and utilized to remind other drivers about the pothole even during dark conditions or rain. This is because now the pothole is no longer detected using computer vision, but it comes from the data stored in the cloud. This would require additional upgrade to PoDS for the pothole location to be sent back to the drivers. Another limitation of this current prototype PoDS is the pothole detection performance in real time. Potholes that are in close proximity with the vehicle is detected with greater accuracy, whereas potholes that are too far from the vehicle are missed. Hence this causes the alert to be triggered very late when the driver is approaching a pothole. Thus, the driver has only a very short reaction time to react towards the pothole. This limitation may be caused by various factors such as the processing speed of the GPU in the small computer, the angle and resolution of the camera and the speed of the moving vehicle.

An attempt was made to install the same prototype on a motorcycle. The field test results for motorcycle were unsatisfactory because this project's researchers decided not to attach a monitor to collect the test data on a moving motorcycle due to safety concerns. Hence, the field test on motorcycle was incomplete. The weaknesses found for this prototype on a motorcycle are the insufficient brightness of the conventional LED indicator.

Further improvements that can be made include using a microprocessor with higher computing power, using a camera with higher resolution, using a more sufficient and more stable power supply to all the equipment especially for the GPS module, and increasing the quality of the dataset to train the pothole detection algorithm. PoDS should also be improved for it to work under rainy and dark conditions.

5. Conclusion

In conclusion, a Pothole Detection System (PoDS) was successfully developed and operated. It is able to help drivers and riders on the road to avoid possible potholes threats. With the help of computer vision by using YOLOv4-tiny algorithm, consisting more than 1000 image dataset trained for configuration and detection of potholes. Thus, it can help to prevent road accidents caused by the potholes. The system is implemented real time in a vehicle using a NVIDIA Jetson Nano Developer Kit with a camera. As the system is connected with GPS, it is able to track the location of the detected potholes. The data of the pothole locations are also determined at the same time when the pothole is detected, and these data are sent to the ThingSpeak cloud system. A map showing the pothole locations can also be viewed and referred from the ThingSpeak website. The cloud data can also be used to solve for bigger scale problem. In future, not only for satellite navigations and car manufacturing development, but these data also allow the government to estimate the annual budget required for fixing the potholes.

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