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INTEGRATED SYSTEM FOR SENSING HOME HAZARDS

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Abstract. Optional home insurance covers material losses due to major events that generate significant, including total, damage to the home. By installing and maintaining the presented system, disasters can be detected immediately and, in some cases, can be automatically mitigated. Homeowners could effectively reduce the hazards effects and massively downsize the recovery costs. The proposed integrated system is designed to be cheap and to have low exploitation costs.

I. INTRODUCTION

Property protection against hazards implies property preparation for and mitigation of the effects of natural hazard events. Property insurance is a collection of policies for protecting homeowners against losses produced by unexpected and unwanted events. The global property insurance market was worth in 2019 more than $225 billion (about $690 per person in the US) [1]. At the European level, from more than 100 billion euros in total value, the top three countries leading the 2019 property insurance market are the UK, Germany, and France [2]. In Romania, since 2008, all homeowners must conclude a mandatory home insurance covering the effects of earthquakes, natural water floods and landslides - PAD (Polita de asigurare impotriva dezastrelor naturale, Insurance Policy against Natural Disasters) [3].

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One method of property preparation for hazard events is to use intelligent systems able to sense, act and signal when such unwanted situations appear. National authorities develop projects for early warning systems. For example, the USA Federal Emergency Management Agency (FEMA) implements ShakeAlert, an Earthquake Early Warning System for the West Coast of the USA [4]. In Romania, RO-ALERT System is used when citizens' lives and health conditions are at stake, such as extreme weather conditions, floods, terrorist attacks, and other dangerous situations.

Homeowners may use individual systems for property protection. Currently, the computing and communication developments offer a broad range of IoT solutions. For example, residential smart water-leak detectors can alert the owner about unusual or unexpected water flow, and when coupled with an automatic shut-off valve, can avoid major repairing costs. In Romania, since 2009, gas detectors have been mandatory in homes having a device connected to the natural gas network, if these spaces have double glazed windows installed.

A similar device is presented in [8]. This work proposes an ultrasonic sensor, which is a good alternative only if there are no pets in the sensor's proximity. Our proposal uses a water sensor, for setting different thresholds for alarm starting. This way, false alarms generated by floor washing are avoided. Moreover, our system is comprehensive, as it is designed for multiple parameter detection (house movement, gas and smoke), and also reactive, as it cuts the gas, water and electricity supplies.

A simple and efficient seismometer is described in [9]. The main difference between the two projects is that the MPU-650 sensor used in our proposal has six axes: three for the accelerometer, and the other three for the gyroscope. We, therefore, use two parameters for earthquake detection: movement and acceleration.

This paper presents an Arduino-based system for home protection, addressing the natural disasters which are compulsory to be insured against in Romania: earthquakes, water floods, and landslides. It is designed:

- to sense the land movements, water, and gas presences,
- to cut the water, gas, and electricity supplies, and
- to alert the homeowner.

The system is modular, able to further integrate other components (for example: for alerts on breaking the windows, for network security protection, or for adding AI features).

This paper is structured as follows: Section 2 presents the hardware components used to devise the architecture proposed in Section 3, and to construct the simplified prototype version described in Section 4. The final

Section is dedicated to conclusions and future developments.

II. COMPONENTS USED

This section describes the hardware modules which form the proposed prototype. Each module is briefly described: typical characteristics and the main reasons for its selection are presented. The general idea pursued by these selections is to devise a prototype based on an Arduino board, easy to install and maintain, with affordable and easy-to-find and replace components.

1.1 MQ-2 GAS AND SMOKE SENSOR

The MQ-2 gas sensor is based on the stannic oxide SnO_2, which has low electrical conductivity when in contact with clean air, but it increases its conductivity when it detects gases. This inorganic oxide is the most used material for commercial gas sensors, as it has high reliability and short adsorption-desorption time.

MQ-2 has a high sensitivity for gases such as liquefied petroleum gas (LPG), Propane, and Hydrogen; this sensor can also detect the smoke resulting from combustion. The device comes equipped with 2 pins designed to read data both analog and digital. The sensor has a low price and a high accuracy; these characteristics make it suited for the presented project.

1.2 MQ-135 GAS SENSOR

The MQ-135 device is designed for sensing ammonia, CO_2, benzene, alcohol, and hydrogen at a concentration between 10 and 10,000 ppm. This second tool is used for harmful gases, as a counterpart for the MQ-2 sensor previously described. The MQ-135 sensor has low conductivity in clean air; when the targeted gases are present, the conductivity of the sensor increases, directly proportional to the increase in gas concentration. Besides its high sensitivity to the specified gases steam, it also senses smoke and several other harmful gases, so it helps us keep track of dangerous gases usually released in case of inside house fire.

1.3 MPU-6050 ACCELEROMETER AND GYROSCOPIC SENSOR

The MPU-6050 appliance is a motion tracking device that uses 6 axes, coupling a 3-axis accelerometer and a 3-axis gyroscope. It also includes a built-in temperature sensor.

MEMS (Micro Electromechanical Systems) accelerometer consists of a micro-machined structure built on top of a silicon wafer. While accelerometers measure linear acceleration, MEMS gyroscopes measure angular rotation. In order to do this, they measure the strength generated by what is known as the Coriolis force (a force acting on objects in motion within a frame of reference that rotates with respect to an inertial frame).

The MEMS sensor is composed of a proof mass (containing 4 parts M1, M2, M3 and M4) which is kept in a continuously oscillating motion so that it reacts to the Coriolis Effect (the object deflection due to Coriolis force). They move inwards and outwards simultaneously in the horizontal plane.

The MPU 6050 module needs calibration before use. This involves excluding the "zero-error" error. This refers to the detection of false values when the module is on a perfectly flat surface. In this case, the module must be calibrated until the gyroscope readings are equal to 0.

1.4 WATER SENSOR ADAFRUIT

On the Adafruit water sensor, there is a series of 10 copper lines, of which 5 deliver low-intensity electric current, and the other lines are only sensory traces. The water level detection system is based on bridges between contacts made by water.

The series of exposed parallel conductors together act as a variable resistor whose resistance varies depending on the water level. Normally, the value indicated by the sensor is 0 when it is not in contact with water. Any water value higher than 100 ppm (with a margin of error) will activate the solenoid valve.

1.5 RELAY MODULE

A solenoid valve is an electrically controlled valve. The valve has a solenoid, which is an electric coil with a movable ferromagnetic core (piston) in the center. In the rest position, the piston closes a small hole. An electric current through the coil creates a magnetic field. The magnetic field exerts an upward force on the piston that opens the hole. The solenoid valve is operated using a relay and has the task of closing the water supply.

1.6 PST-MCB-4P-16 Smart Mcb Switch Circuit Breaker

Automatic switches are devices that provide protection against fires, which could arise from a faulty electrical circuit (short circuit, overload, insulation defect), protecting people against electric shocks in case of direct contact.

Unlike fuses where, in the event of a short circuit, its fuse consumable must be replaced (electric fuse cartridge), automatic fuses do not require the replacement of any component, they only require to be tripped manually after identifying and removing the shutter reason.

The use of automatic differential fuses ensures a high level of security in the operation of household electrical installations, because incidents can occur, that could lead to electrocution by using household appliances, such as washing machines/dishwashers, air conditioners, electric boilers, etc.

The intelligent component of these fuses facilitates their remote control through the Tuya Smart application, but in order to integrate with the prevention system presented in this project, it is necessary to use the *TuyaWifi.h* library.

The module is configured in the initial phase through the Tuya application and must be paired with the ESP 8266 module of the Arduino microcontroller. As of March 31, 2022, Tuya IoT Development Platform has more than 582,000 registered developers from over 200 countries and regions serving more than 8,400 customers all over the world. [10].

1.7 ARDUINO UNO R3 BOARD

The Arduino Uno R3 development board is based on an ATmega328 microcontroller. The set of Arduino boards offers many options in choosing and using microprocessors and controllers. The boards from the Arduino set can be used in connection to a broad range of expansion boards and other development components, with the help of digital and analog input/output (I/O) pins. Applications designed and developed on personal computers can be uploaded using Universal Serial Bus (USB). Specific C and C++-based programming languages are predominantly used for programming the designed applications. A specific integrated development environment (IDE) is offered by the Arduino comprehensive project, as an alternate option to traditional compiling tools.

III. PROPOSED SYSTEM ARCHITECTURE

This project aims to prevent and detect disasters that may occur in the home, by implementing sensors that measure the main elements that can lead to disasters such as water, fire, hazardous gases, and earthquakes. These calamities are detected using specific sensors and the homeowner is notified on the mobile application; also, there is an active siren in the home to warn about the presence of the disaster.

The data is read from the sensors using analog pins; after evaluating this data using thresholds previously set by the user, if the values are higher, then the microcontroller initiates different processes as needed, such as turning off the water supply, starting the alarm and notifying the owner on the phone.

The Blynk mobile application was used to send notifications, which can be configured to display in real time the data read by the sensors. This implementation can be used by the authorities or even by home insurance providers to prevent and to mitigate disasters.

Figure 1 shows how the data is taken over and transmitted to the microcontroller and then to the Blynk Server. The user is alerted when the sensed values exit the set intervals and trigger the needed actions.

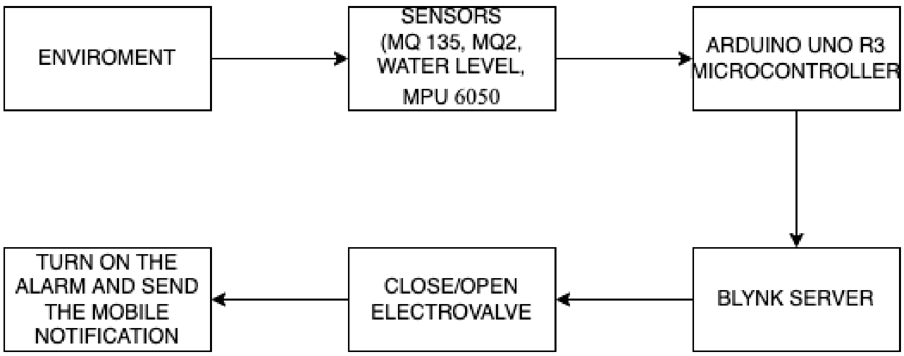

Figure 1 Proposed system architecture

IV. PROTOTYPE

To test the idea presented, we designed a prototype that has the role of detecting water, smoke, toxic gases, and earthquakes. For this prototype we used the components presented above and we used the Blynk library to facilitate the reading of the sensors and to send notifications on the phone when the thresholds have been exceeded. The earthquake detection module was the most difficult to use as it involved sending data continuously to the Blynk server and this canceled the data reading for the other sensors. This problem was solved by eliminating the data reading from the *loop* function and new functions were created to read each sensor, and later the *setInterval* function was used to read the data at specific time intervals. This approach significantly increased the accuracy of the values read by the sensors.

One thing to mention is that the solenoid valve that controls the water when it starts sends an electric shock to the relay, and it locks, to solve this problem a diode 1n4007 was used which was soldered on the pins of the solenoid valve and allows electric current to flow in one direction, so the relay can operate the solenoid valve without interference.

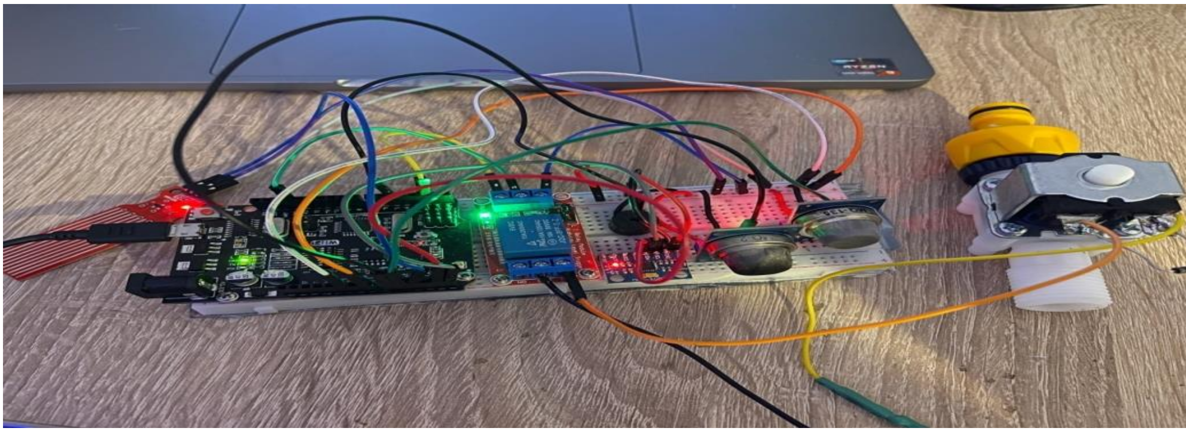

Figure 2 Prototype

Id	Name	Alias	Color	Pin	Data Type	Units	Is Raw	Min	Max
1	MQ135	MQ135		V7	Integer		false	0	1000
2	Water_PIN	Water PIN		2	Integer		false	0	1
3	Water_level	Water level		V2	Integer		false	0	10000
4	FUM	FUM		V8	Integer		false	0	1000

Figure 3 Declaration of the Datastreams in the Web Dashboard

In order to collect the data from the sensors and to send notifications to the phone, it is necessary to use some virtual pins. Virtual pins have the role of data exchange between the hardware and The Blynk App. Their declaration is done using the Web Application, thus being able to set different parameters such as minimum and maximum values of the sensors. In short, virtual pins are channels for sending data.

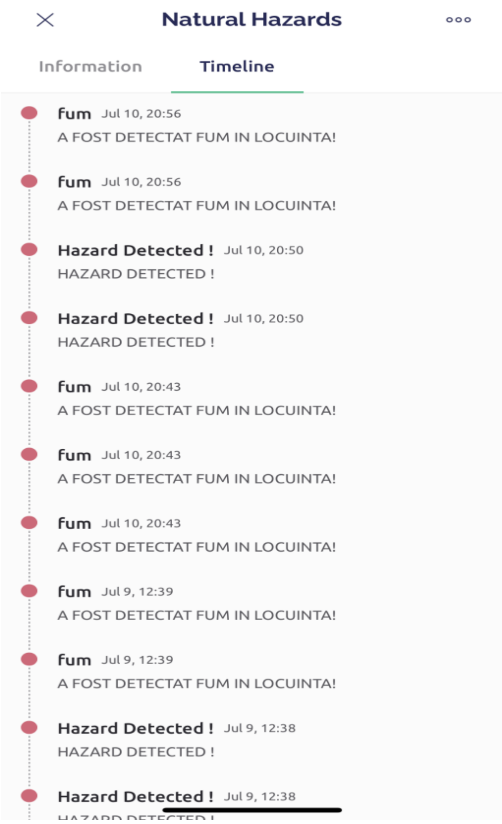

Figure 4 Phone notifications- events detected

The Blynk Mobile Application and the Web Dashboard allow keeping track of messages and alerts so the user can have a record of events, but this can also be useful for authorities. The Blynk application allows the creation of several types of messages such as Info, Warning, Critical and Content.

In order to improve the way the sensors are adjusted, a mobile interface was set up; it also displays the current values read by the sensors, and can control the valve which cuts the water supply (Figure 5).

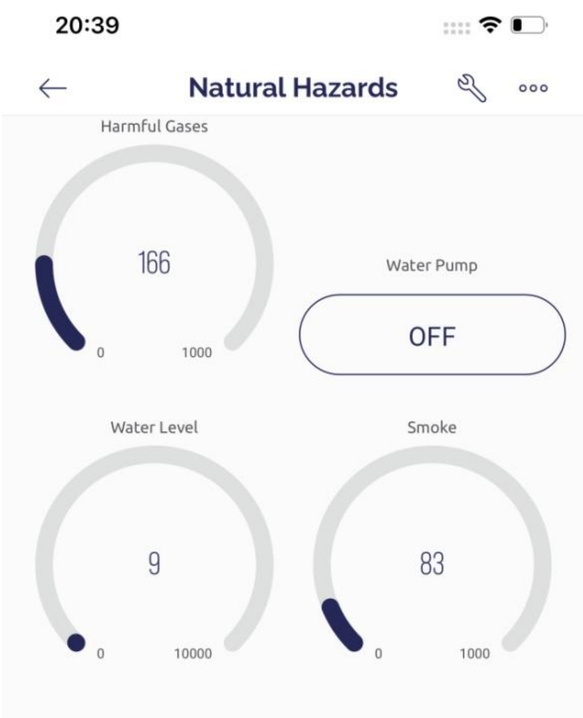

Figure 5 Mobile Interface used for sensors calibration

All the devices are connected as presented in Figure 6. The image was created using a paid version of Frizing, a software tool able to provide a broad range of electrical components images and easy and clear connection features.

On the development board there are 8 switches whose combinations change the operating mode of the Arduino development board and the ESP 8266 module, as presented in Table 1.

In the prototyping phase, we chose to connect the module to the Internet using a serial connection. We could therefore exclude the need to adjust the buttons which switch the Arduino board in the Flash mode and later in the ESP 8266 mode. For internet connection, we used the script *blynk-ser.sh* from the Blynk library, executed using the following commands:

cd Documents/Arduino/Blynk/libraries
ls
./blynk-ser.sh

After the batch execution of the previous lines, the console returns a set of messages and successfully sets up the connection to the Blynk server, as seen in Figure 7.

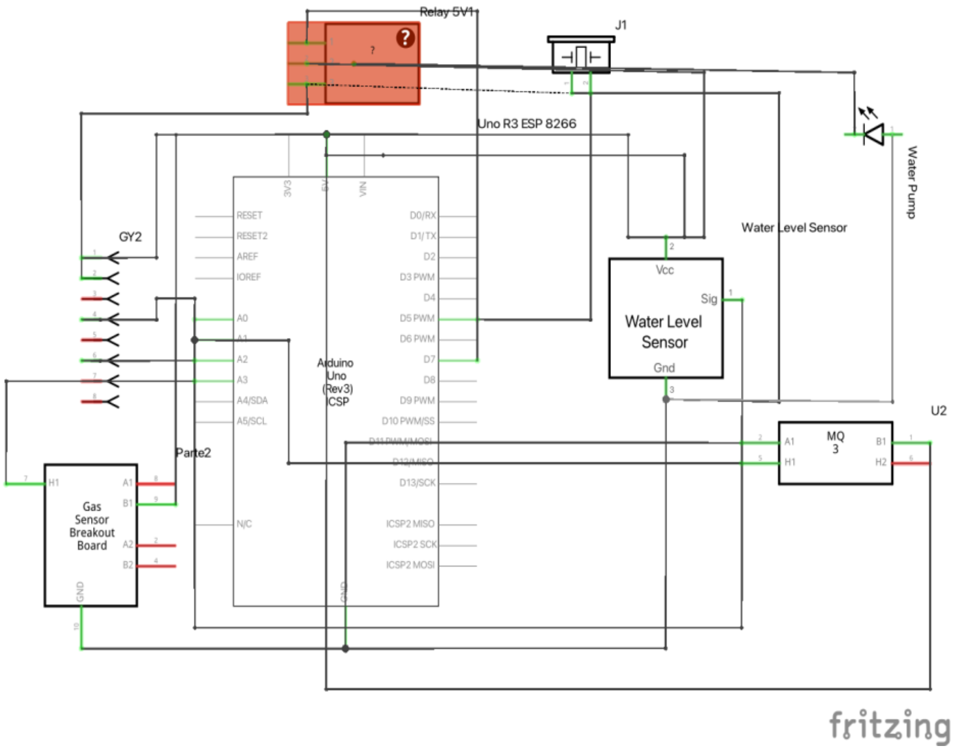

Figure 6 Electrical connections of the project components

Settings	switch 1	switch 2	switch 3	switch 4	switch 5	switch 6	switch 7	switch 8
CH340 connect to ESP8266 (up-load sketch)	OFF	OFF	OFF	OFF	ON	ON	ON	No USE
CH340 connect to ESP8266 (connect)	OFF	OFF	OFF	OFF	ON	ON	OFF	No USE
CH340 connect to ATmega328 (upload sketch)	OFF	OFF	ON	ON	OFF	OFF	OFF	No USE
Mega328+ESP8266	ON	ON	OFF	OFF	OFF	OFF	OFF	No USE

All the components work independently	OFF	OFF	OFF	OFF	OFF	OFF	OFF	No USE

Table 1. The eight switches outcomes for controlling the project components

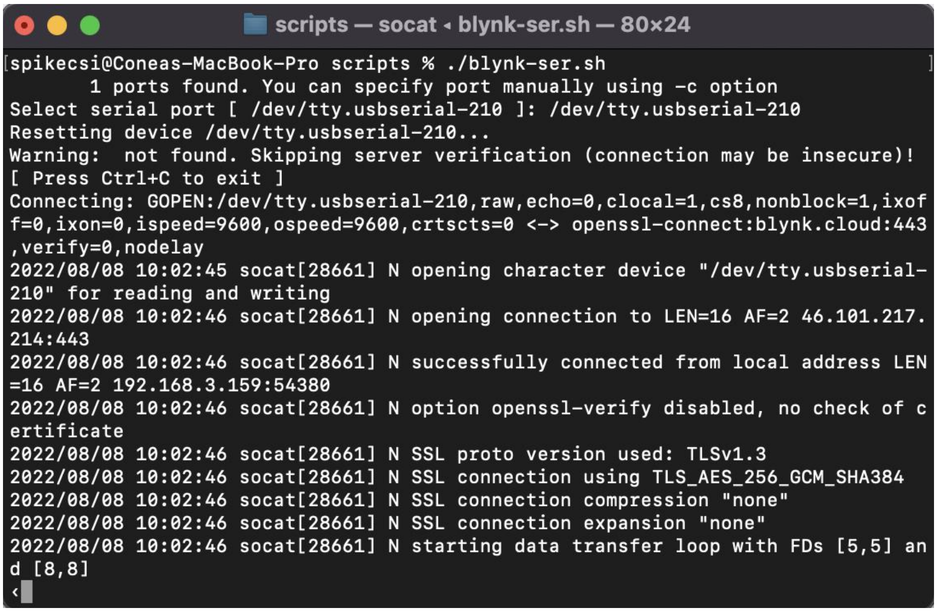

Figure 7 - Console messages showing the successful connection to the Blynk server

V. CONCLUSIONS AND FUTURE WORK

Monitoring and detecting disasters or unpleasant events should play a significant role in the daily life of any person. Thus, these devices can be scaled and integrated with home insurance as they cover the main events provided in most contracts, such as earthquakes, floods, and fires. The insurance companies could include the proposed system in their commercial offer, or can offer it for free, when a comprehensive insurance policy is bought.

The proposed system may be bought and installed in the basement of the apartment blocks, where human supervision is scarce. As the latest EU statistics show, almost half of the European Union citizens live in blocks of flats [6].

In the future, the system can be improved by adding a GSM module that can initiate a call to the emergency services and announce if there is a threat in the house. The earthquake system can notify the authorities depending on its magnitude that there may be victims.

We plan to add sensors for sensing the window integrity, indentifying in real time when the glass is broken, on purpose or as a result of an emergency situation. Such sensor may use either a microphone, or an accelerometer. The microphone captures the sound, and if a user-set threshold is exceeded, then an alarm is triggered. The accelerometer senses the movements and vibrations and starts the alert procedure.

A system similar to the one used for stopping the water supply can be used to start an irrigation system in case a fire breaks out. In the future, a solenoid valve can be added to control the gas supply and in the case the sensors detect harmful gases, to stop the gas and the current.

Similar preoccupations are described for example in [7]: comprehensive systems for simultaneously addressing a set of disasters are proposed in USA. We, therefore, consider that our proposal is in line with current studies and research and that the prototype validates it.

European Union early understood the importance of house protection using intelligent systems, and financed multiple research projects for devising new frameworks, system design proposals and technological advances on this path. Through Horizon 2020, the project *Safe-Guarding Home IoT Environments with Personalised Real-time Risk Control* (*GHOST*) was financed. It is an example of a multi-national proposal, aimed at responding to multiple security threats is smart homes [12]. Moreover, the connection between the IoT and AI domains is currently explored by researchers all over the world. For example, the European project *Intelligent Secure Trustable Things* (*InSecTT*) plans to build trust in AI-based intelligent systems and solutions as a major part of the *Artificial Intelligence of Things* (*AIoT*) [13].

European Commission set up in December 2020 an agenda for addressing the security issues for IoT devices and networks [14]. This program targets assisted living, healthcare, manufacturing, food supply, energy, and transport, by financing eight projects at continental scale, with open-source results, designed for easy transfer to a broader category of applications. In order to address this direction, we plan to include a module able to deal with device and whole system protection against security breaches.

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