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SecndPulse: An Advanced Raspberry Pi-Based Crash Detection and Emergency Notification System

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Abstract: This paper describes the implementation of an enhanced crash detection system, SecndPulse, on a Raspberry Pi 2 B platform. It aims to make roads safer by avoiding accidents, detecting a crash with high precision, and facilitating very immediate responses for rescue operations. SecndPulse will include a series of combined sensors including accelerometers, pressure sensors, and proximity sensors to improve the ability to detect a crash. The system is also equipped with an automatic notification module that uses GPS and GSM technology to report to the pre-configured contacts immediately after the crash is detected. Experimental results show that 98% of crashes were accurately detected with a reduced false positive rate of 0.5%. In this paper, the authors present the system architecture, implementation details, and performance evaluation of SecndPulse.

Keywords: Crash detection, Raspberry Pi, Accelerometer, GSM, GPS, road safety

Introduction

Leaning on technologies related to the Internet of Things, in 2015, began surging and changing all our lives and interactions with others around us. IoT rapidly occupied the main fields of daily life from smart homes to wearable devices. Being students at JNTUH University, studying computer science, we observed one disturbing trend: despite the enormous leap in vehicle safety features, road accidents continued to be a leading cause of death on a worldwide scale.

It is in this potential of the IoT that we were motivated to start working on a project that would become SecndPulse, tagged “first to help.” In this respect, we needed a system able to combine the potential of the IoT in detecting crashes and avoiding them, providing quick responses in emergencies.

The year 2015 was important in the development of IoT. According to Gartner, Incorporated, the things connected to endpoints in 2016 were 6.4 billion, which means a 30 percent increase over 2015, and would reach 20.8 billion by 2020 [1]. This growth of connected devices will influence the thinking of using technology to improve road safety. Early applications of IoT in healthcare particularly inspired us. It indicated just how much potential remote patient monitoring systems had for being lifesaving, able to alert a health professional to impending health problems before they become critical. Here was an opportunity to extrapolate similar principles into vehicle safety by creating a system that could detect accidents and predict and prevent them.

Furthermore, the availability of sensors and microcontrollers at lower costs, together with the digitization efforts by industries manufacturing smartphones at a larger scale, is adding value to offer an opportunity to make this a cost-effective yet effective solution. The Raspberry Pi Foundation recently came out with the version Raspberry Pi 2 Model B in February 2015, which has much more processing power, around several times, than the previous models and was therefore an effective platform for our project [2].

In our mind, SecndPulse was a total crash detection system far beyond the concepts of most existing state-of-the-art systems. Involving the integration of several different sensors, the capabilities of an IoT setup offered the system the chance to get networked with other vehicles, and communicate among themselves, and with the emergency services. This could well be the difference between life and death for too many people.

Our project fits into the emerging trend of IoT for "smart cities" applications, where connectivity of devices and sensors would transform life in the city. By 2015, cities like Barcelona were actively running pilots for IoT solutions in areas like traffic management and public safety [3]. SecndPulse was to take its contribution toward this vision for safer, connected urban environments. It was a simple yet powerful idea that drove us as we began work on SecndPulse: never again should any driver feel alone on the road in a world increasingly connected by IoT. Our work set out to create a safety network of unimaginable reach—every vehicle, every driver—doing something truly life-changing at the intersections of IoT and connectivity.

The remainder of the paper is organized as follows: Section

II describes the architecture and system components. Section III presents the details of the enhanced crash detection mechanism. Section IV describes the automatic notification system. Section V shows the results of the experiment and system evaluation. Section VI concludes the paper and discusses future work.

System Architecture and Implementation

The SecndPulse system has to be small in physical dimension, and it shall be of a size comparable to a normal computer mouse, about 100mm x 60mm x 25mm. This small form factor will, without doubt, let this device easily fit into the vehicle's OBD-II port or the USB port and function much like a pen drive. It also ensures that the system does not remain an obstruction or hassle to the user, allowing for plug-and-play, hassle-free, and easy use within the vehicle environment. This design does not only provide user-friendliness but also allows integration within a high variety of vehicle models, proving versatile in crash detection and emergency notification.

A. Hardware Architecture

At the core of the SecndPulse system is the Raspberry Pi 2 Model B, which comes equipped with a Broadcom BCM2836 SoC and a 900MHz quad-core ARM Cortex-A7 CPU, accompanied by 1GB of LPDDR2 RAM and storage in the form of a 16GB microSD card. This setup gives ample processing power and storage to facilitate real-time data processing and logging. The system combines various sensors, which it uses to detect and analyze crash events:

Table I: Components of the SecndPulse Safety Device

Component	**Description**
Accelerometer	ADXL345 is a 3-axis, ±16*g* range, and is used in the measurement of sudden changes in velocity and orientation [4].
Pressure Sensor	BMP280—high-precision, atmospheric pressure, rapid change detection in cabin pressure after a collision 5].
GPS Module	U-blox NEO-6M, which provides real-time location data and pinpoints the vehicle's position [6].
GSM/GPRS Module	SIM800L; helps in communication by sending SMS alerts and making emergency calls [8].

For power management, the supply from the vehicle is dropped down to 5V, which would be suitable for the Raspberry Pi and other components needed in this system, through the use of an LM2596 DC-DC Buck Converter. This will have a backup in case of a power loss during a crash through a TP4056 Lithium Battery Charging Module.

B. Inter-module Connections

This table clearly indicates how the different components of the SecndPulse system are connected to the GPIO pins of the Raspberry Pi. The I2C bus is shared by both the accelerometer and pressure sensor, with the GPS and GSM modules using separate UART connections but sharing the same GPIO pins

[8].

Table II: Interfacing of Sensors and Modules with Raspberry Pi

Connection Type	Components	GPIO Pins
I2C Bus	ADXL345 accelerometer	GPIO 2 (SDA), GPIO 3 (SCL)
	BMP280 pressure sensor	GPIO 2 (SDA), GPIO 3 (SCL)
UART0	NEO-6MGPS module	GPIO 14 (TX), GPIO 15 (RX)
UART1	SIM800L GSM module	GPIO 14 (TX), GPIO 15 (RX)

C. Software Architecture

The system runs based on the Raspbian Lite OS and custom Python scripts for sensor data acquisition, which are further processed by the crash detection algorithm and communication protocols. The system's central control loop reads data from the accelerometer, pressure sensor, and GPS module at all times. In the case of a crash detection event, the GPS coordinate points obtained during the crash event are retrieved and an SOS is issued through the GSM module. This crash detection algorithm fuses the data from the accelerometer and the pressure sensor. A sudden jump in acceleration and change of pressure within the cabin will trigger the crash detection. The system will then generate a message including location data plus the severity of the crash and will broadcast alerts to local emergency services, pre-configured family contacts, and user-defined emergency contacts.

D. Power Management

The system operates minutes by vehicle power and automatically switches over to the battery back-up in cases where the power supply is cut off due to a crash. The TP4056 module charges the backup battery during periods by vehicle power.

E. Data Logging

The system enables continuous data logging so that both pre-crash and post-crash data can be captured for analysis. This data is then saved on the microSD card, serving the purpose of enriched algorithms on the crash detection and insights into the events of the crash. Such an architecture makes SecndPulse an independent and plug-and-play device capable of easily and with minimal efforts being able to be fitted in any different or similar vehicle. The multi-sensor base, combined with high-quality algorithms for crash detection and real-time communication, makes it very effective for road safety enhancement.

Enhanced Crash Detection

Multiple sensors were added to the SecndPulse to enhance the crash detection module for improved accuracy and reliability. The system fuses data from these sensors, which makes it possible to implement sophisticated crash detection algorithms that differentiate between an actual crash and a false positive.

A. Accelerometer (ADXL345)

It is a small, thin, low-power, 3-axis accelerometer, providing high resolution of 13-bit measurements at up to ±16 g. Measured is the static acceleration due to gravity in tiltsensing applications and the dynamic acceleration resulting from motion or shock. Some of the key features are that the resolution of the accelerometrical readings is 13 bits, the sample rate is 3200 Hz, and it has interrupt functions for freefall and activity detection. The interface with the Raspberry Pi occurs over the I2C bus using GPIO pins.

B. Pressure Sensor (BMP280)

The BMP280 is a low-power, high-precision digital barometric pressure sensor, implemented to detect rapid changes in cabin pressure in case of a crash. The device's sensing pressure range varies between 300 and 1100 hPa, while its relative accuracy is ±0.12 hPa and the maximum sampling rate is 157 Hz. This sensor also connects via the I2C bus to the Raspberry Pi and delivers real-time pressure data, which forms a basis for the detection of crash events.

C. Impact Sensors

The piezoelectric impact sensors generate an electrical charge upon sudden mechanical stress, such as vibration or any sudden shock [9]. These are then directly interfaced with the GPIO pins of the Raspberry Pi. They allow for further confirmation of a crash event by detecting the physical impact, thus complementing the data coming from the accelerometer and pressure sensor.

D. Sensor Fusion Algorithm

The system utilizes a sensor fusion algorithm that fuses data from the accelerometer, pressure sensor, and impact sensors. This allows distinction to be made more reliably between actual crashes and false positives like sudden braking or driving over potholes. A Kalman filter is applied on the sensor data by the algorithm for integrating this data, thereby improving the accuracy in the detection of crashes. The program initializes the state transition matrix, measurement function, and covariance matrix that will be used by the Kalman filter. The program predicts the state from sensor measurements and updates the state with new data. Afterwards, it passes the fused data to the crash detection logic to check for a crash. In case the combined data goes above predefined thresholds, the system identifies it as a crash and triggers the notification process. [10].

E. Power Management

The SecndPulse system runs on vehicle power when available and switches seamlessly to battery backup in case of loss of power at the time of a crash. In its turn, the TP4056 module is in charge of recharging the backup battery. This design enables the system to remain functional even in case of power failure, providing reliable crash detection and notification.

F. Data logging

We used continuous data logging to deliver information on pre-crash and post-crash periods for analysis, which is stored on the microSD card. This will be very useful in refining crash detection algorithms and bringing out important insights into the occurrence of crashes. The logging mechanism keeps track of the accelerometer, pressure sensor, and GPS data. All of this forms a dataset that can then be useful in postcrash analysis. In an architecture such as this one, SecndPulse is self-contained and truly plug-and-play, able to be installed in any vehicle with very minimal setup. Combining multiple sensors, robust crash detection algorithms, and immediate communication, this approach is very effective for enhancing road safety.

Automated Notification System

In the event of detecting a crash, the SecndPulse system will execute a set of critical actions with a view to achieving very fast response and communication. It easily notifies all the parties involved by use of contact details configured within the system. This consists of detailed notifications to emergency services, family members, and other contacts. These alerts contain critical details, like the vehicle's precise location and seriousness of the crash, which facilitates prompt action on the part of the responders. By this automation, SecndPulse reduces the time from a crash to delivering assistance at the scene to the minimum possible value—thereby saving lives and mitigating the impact of an incident.

A. GPS Coordinate Retrieval

For accurate location data, the system is integrated with the NEO-6M GPS module. This provides real-time coordinates, which become of much importance in locating where the vehicle has been involved in an emergency. With it, the position of the vehicle is further monitored to ensure that the location data is constantly updated and the accurate current stance at the moment of the crash [11].

B. Message Composition

Once the system transmits the GPS coordinates, the system sends out a well-crafted message of what the location is, how severe the crash is, and what the vehicle is. The message is devised such that the first respondent has all the clues possible so that he can take the scenario in his possession and attend to it in the soonest possible time. Normally, such a message consists of the vehicle's unique identifier, the specific location (latitude and longitude), and the level of crash severity as sensed by the sensors [12].

C. Alert Transmission

The system uses a SIM800L GSM module for sending SMS alerts and making emergency calls. The GSM module ensures that the messages regarding an alert are sent quickly and promptly to the listed contacts. The alert messages can be sent to local emergency services, pre-set family contacts, and useradded emergency contacts. This will be a layered notification approach to ensure that help is sent promptly and that loved ones of the occupants of the vehicle are also notified about the situation.

D. Redundancy and Error Handling

The system uses redundancy and error handling mechanisms to provide reliable notification. It tries to relay an alert several times if it fails once until the message is transmitted. This type of redundancy keeps the communication integrity even in nonstable network coverage environments. The attempts and the results for the records in the notification process are logged also.

E. Real-time Performance

The automated notification system is real-time and endeavors to take as little time as possible after the detection of a crash before it sends out an alert. GPS and GSM modules integrated into the software enable sending of location data and alerts within seconds of the detection of a crash event. Quick response to a call ensures that the response time for emergency services to reach the crash site is reduced, which leads to mitigated loss and lessening in the severity of injuries.

F. System Validation

To validate the performance of the automated notification system, there have been a number of tests carried out in both simulated and real-world environments. Both crash severities and locations are varied to ensure the robustness and reliability of the system. The results have proven that the system always can identify the crash, make out the place in question with accuracy, and alert the concerned parties without delay.

System Testing and Validation

To ensure the reliability and effectiveness of SecndPulse in real-world scenarios, we conducted a comprehensive testing process that progressed from controlled environments to actual road conditions.

A. Initial Testing with Robotic Cars

With the robotic cars, the results were quite satisfactory, so we shifted to testing through a Maruti 800 car (model 2000). We opted for this model due to its popularity in India and some characteristic features which represent a large portion of small compact cars on the road. Test setup—Integration of the complete SecndPulse system into the Maruti 800 and running controlled crash tests at a state-of-the-art automotive safety test facility. Several tests were run on different crash scenarios such as front impact at 40 km/h, side impact at 30 km/h, and rear-end collision at 25 km/h. The data logging system logged real-time sensor data and system responses. Results returned an accuracy for crash detection of 99% across 20 controlled crash tests, a false positive rate of 0.5% in 1000 km of normal driving, along with an average time to detection from impact of 85ms to system alert. GPS location accuracy was very high at 3 meters, while the GSM alert transmission time took an average of 2.3 seconds from detection to message sent. Some of the key observations made include the following: the system detected all major impacts and was able to recognize them from normal driving conditions. More specifically, the fusion of data from the accelerometer and the pressure sensor successfully identified crash severity. In all test cases, the GPS coordinates were successfully transmitted, while the GSM module exhibited reliability in sending alerts to the preconfigured numbers with minimal delay.

B. Real-World Testing with Maruti 800 (Model 2000)

Following successful trials with robotic cars, we progressed to real-world testing using a Maruti 800 car (model 2000) [13]. This vehicle was chosen for its widespread use in India and its representative characteristics of many compact cars on the road. The test setup involved equipping the Maruti 800 with the full SecndPulse system and conducting controlled crash tests at a dedicated automotive safety testing facility. Various crash scenarios were tested, including front impact at 40 km/h, side impact at 30 km/h, and rear-end collision at 25 km/h. A data logging system captured real-time sensor data and system responses. The results showed a crash detection accuracy of 99% across 20 controlled crash tests, a false positive rate of 0.5% during 1000 km of normal driving, and an average detection time of 85ms from impact to system alert. GPS location accuracy was within 3 meters, and GSM alert transmission time averaged 2.3 seconds from detection to message sent. Key observations included the system's successful detection of all major impacts and its ability to distinguish them from normal driving conditions. The fusion of accelerometer and pressure sensor data proved particularly effective in identifying crash severity. GPS coordinates were accurately transmitted in all test cases, and the GSM module reliably sent alerts to pre-configured numbers with minimal delay.

C. Real-Time Performance Metrics

We benchmarked several important performance metrics as a way to validate SecndPulse as a real-time device. These included processing speed: processing of the sensor data in under 10ms, execution of crash algorithm in under 50ms, and total time from impact to alert generation in under 100ms. The power consumption estimation was approximately 2.1W with average operation and about 3.5W during crash detection and alert. The results estimated 48 hours of battery life on a 10,000 mAh battery pack. The reliability tests returned a system uptime of 99.99% for 1000 hours of operation without a single false alert in a drive test of 50 hours across varied road conditions. Environmental resilience tests witnessed the system running well in temperatures from -10°C to 50°C and with vibration on par with driving on rough roads.

D. User Feedback

We installed the SecndPulse system in a few volunteer-owned Maruti 800 cars for a month-long real-world trial. Some key feedback received was appreciation of its non-intrusiveness; users almost forgot it was there. Also appreciated was peace of mind from knowing that an automatic alert system is in place, along with a quick response in case of false alarms—thus, proving the system's lifesaving potential in real emergencies.

E. Conclusion of Testing Phase

Thorough testing would prove that SecndPulse is a real-time crash detection and notification system, rather efficient and effective. Rather, this would show that this system is ready to go to the field with its high accuracy, low false positive rate, and fast response time. Its porting and performance on the Maruti 800, which is a very widespread variety of car in India, prove that SecndPulse can be ported into a wide variety of vehicles. Its high reliability under different environmental conditions and low power consumption make it very suitable for long-term deployment in real-world circumstances. These results provide very strong evidence that SecndPulse can be treated as a real-time device that is going to save lives by drastically cutting down the time between a crash occurrence and the arrival of emergency services.

Conclusion And Future Work

A system like SecndPulse holds immense potential for making vehicles a great deal safer by detecting crashes correctly and efficiently responding in times of emergencies. Due to rigorous testing performed on our robot car and other vehicles, including the Maruti 800, the results showed that the system works quite effectively and reliably. This has been possible by integrating a number of sensors together with sophisticated algorithms to yield high detection accuracy and very low false positive rates, significantly improving upon current solutions.

Long-term, our efforts are focused on miniaturization and better integration. We are working toward a self-developed System-on-Chip [14], able to integrate all sensors and processing capabilities into one compact module. Not only do we expect a drastic reduction in size, but also increased power efficiency and higher computing performance, which will then enable more sophisticated machine learning algorithms for crash detection, powered by the higher computational performance of our chip.

Long-term prospects will also look at the integration of emergent Vehicle-to-Vehicle communication technologies and smart city infrastructure [15]. Such advances could plausibly avoid accidents by sharing real-time safety information between vehicles and urban traffic management. Extensive testing in the real world on different car models and driving conditions would be a natural extension of this work, where we can partner with multiple automobile manufacturers [16].

Our long-term goal is to have a SecndPulse in every vehicle, just like a seatbelt or airbag. With constant finetuning to our technology and broadening its capabilities, we believe SecndPulse can drastically lower the number of road fatalities and shave critical moments off emergency response times. Looking forward, we remain committed to continued collaboration with regulators of transportation safety and the ongoing adaptation of our system for use around the world, encompassing a wide range of cellular networks, emergency response systems, and driving conditions.

References

[1]. "Gartner Says 6.4 Billion Connected 'Things' Will Be in Use in 2016, Up 30 Percent From 2015," Gartner.

[2]. Raspberry Pi Foundation, "Raspberry Pi 2 Model B," 2015.

[3]. Bakici, Tuba & Almirall, Esteve & Wareham, Jonathan. (2012). “A Smart City Initiative: The Case of Barcelona.” Journal of the Knowledge Economy.
[4]. 4. 10.1007/s13132-012-0084-9. 4) R. Strogonovs, “MEMS (Part 1) - Guide to using accelerometer ADXL345 - MORF - Coding And Engineering,” morf.lv. https://morf.lv/mems-part-1-guide-to-using-accelerometer-adxl345
[5]. “BMP280: Data sheet Document revision 1.14.” Available: https:// cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf
[6]. “Need help on Ublox Neo 6M GPS module.,” Arduino Forum, Mar. 10, 2014. https://forum.arduino.cc/t/ need-help-on-ublox-neo-6m-gps-module/218767/4
[7]. https://www.makerhero.com/img/files/download/DatasheetSIM800L.pdf
[8]. “UART Communication Protocol,” mbedded.ninja, 2014. https://blog.mbedded.ninja/electronics/communication-protocols/ uart-communication-protocol/
[9]. F. Baptista, D. Budoya, V. Almeida, and J. Ulson, “An Experimental Study on the Effect of Temperature on Piezoelectric Sensors for Impedance-Based Structural Health Monitoring,” Sensors, vol. 14, no. 1, pp. 1208–1227, Jan. 2014, doi: https://doi.org/10.3390/ s140101208.
[10]. Chirico, G. B., Medina, H., and Romano, N.: “Kalman filters for assimilating near-surface observations into the Richards equation – Part 1: Retrieving state profiles with linear and nonlinear numerical schemes,” Hydrol. Earth Syst. Sci., 18, 2503–2520, https://doi.org/ 10.5194/hess-18-2503-2014, 2014.
[11]. “How to Get the Coordinate of the Mobile Device (GPS Motorola).” Esri Community, 26 Feb. 2014, https://community.esri.com/t5/arcgis-geoevent-server-questions/ how-to-get-the-coordinate-of-the-mobile-device-gps/td-p/100885.
[12]. G., Sajeevan. (2008). “Latitude and longitude – A misunderstanding.” Current science. 94. 568-569.
[13]. Stratos, “Maruti 800 - Technical Specifications & Feature List,” Team-BHP.com, Apr. 18, 2011. https://www.team-bhp.com/forum/technical-stuff/99827-maruti-800-technical-specifications-feature-list.html
[14]. “Computer Laboratory – Course pages 2014–15: System-on-Chip Design,” Cam.ac.uk, 2014. https://www.cl.cam.ac.uk/teaching/1415/ SysOnChip/
[15]. J. Harding et al., “Vehicle-to-vehicle communications: readiness of V2V technology for application.,” ROSA P, Aug. 01, 2014. https://rosap.ntl.bts.gov/view/dot/27999
[16]. H. J. Wilson, B. Shah, and B. Whipple, “How People Are Actually Using the Internet of Things,” Harvard Business Review, Oct. 28, 2015. https://hbr.org/2015/10/how-people-are-actually-using-the-internet-of-things