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An Enhanced Wireless Sensor-Based Security Ensemble for Child Safety Tracking, Monitoring and Alert Using the Mobile Smartphones

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ABSTRACT

The number of missing children and kidnapping is on the rise in recent years. Every parent wills definitely going through an agonizing experience to have their children missing. Therefore there are many safety measurements to prevent this incident from happening. The help of modern technologies is one of the ways to reduce children missing and kidnapping. A child can be tracked by using the GPS (Global Positioning System) and GSM (Global System for Mobile communication) technology. Study models a fuzzy system that fuses sensors and ESP8285 controller to determine fire probability output. It sends an alert to users via a send algorithm having monitored environment conditions as they quickly change. Previous systems used were often found to have provided false alarms owing to their configuration logic. The experimental design that yielded the proposed ensemble however notifies both the residents and the nearest fire department of fire outbreak, source and location using a shortest distance algorithm. The proposed ensemble is efficient, reliable and can handle dynamic changes as in the send algorithm.

1. INTRODUCTION

With the increased insurgence and volent attacks, the rapid spree of terrorism from the Northern part, and fast spreading all across the entire country of Nigeria has called for questions as to their funding (Atuduhor et al., 2024; Osegboun & Oladipo, 2023). Sequel to this is the incessant facts that children are now often found to be missing. Such missing children are classified into 2-groups namely disappearances, and kidnapping/abduction (Aghware et al., 2023b, 2023a; Kareem et al., 2015). Statistics that has been compiled since 2004, more than 6,270 teenagers are reported missing, and over 4,620 of missing children are teenage girls (M. I. Akazue, Okofu, et al., 2024; Saminu & Mohammed, 2022). This shows that the rate of missing children has in recent years, been on the rise as many factors are responsible for the incident to occur. One of such factor is that of parent's inability to supervise their children always (Ojugo & Otakore, 2020b, 2020a; Ojugo & Yoro, 2021; Suleiman, 2022).

Kidnapping and abduction violence cum crimes can take place or happen anywhere, anytime and in any order. It can happen in a playground, supermarket, and

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even in our very own homes (Aleyomi & Olajubu, 2024; Ihama et al., 2023; Ojugo & Yoro, 2020b). Thus, a child embedded tracker with wireless sensor-based Internet of Things (IoT-based) system can enhance their safety and help their parents by constantly emitting the location of their children via the use of short messaging (SMS). This system can help their family to monitor the children anywhere and anytime (Ejeh et al., 2024; Ifioko et al., 2024). The nature of child monitoring allows the use of technological interface in lieu of a child's welfare – ensuring considerable reliance is on the systems design and operation. IoTs have become critical facet in object monitor with real-time data processing, communication, and tracking features. Its overlay ranges from coverage sensors with controllers, wearables and home monitors. It yields such capability via its geo-fencing, state monitor and alerts to caretakers (Ojugo & Otakore, 2020c; Shoeibi et al., 2022).

1.1 Kidnapping Spree and Missing Children

Missing children can be classified into two categories which are disappearance, and abduction or kidnapping. Statistic compiled since 2004, more than 6,270 teenagers have been reported missing and out of these 4,620 of the missing children are teenage girls – implying that the rate of missing children in recent years have increased. Several factors that lead to this incident to happen. One of it is because of the parents could not supervise their children all the time (Allenotor et al., 2015; Allenotor & Ojugo, 2017; Ojugo et al., 2024). Kidnap or abduction can happen any place, anywhere and anytime; So, whether in a shopping mall, supermarket, playground or even in their own house (Malasowe, Okpako, et al., 2024) – such event can take place. Thus, a child tracker system enhances their safety, and keep parents informed about their children's location only by a SMS away. This system can help their family to monitor the children anywhere and anytime (Malasowe, Aghware, et al., 2024; Malasowe, Ojie, et al., 2024; Nahavandi et al., 2022).

1.2. IoT-Enabled Track and Monitor

GPS has since emerged as a cornerstone in child monitoring solutions, facilitating accurate and real-time tracking of children's whereabouts. Studies such as those by Jacob et al. (2022) highlight the integration of GPS tracking capabilities with IoT-based systems, enhancing the effectiveness of child safety measures by providing seamless location monitoring and SOS functionalities. The use of IoTs with monitor capabilities offers new opportunities for enhanced safety. Okperigho et al. (2023) used IoT to yield a child-tracker systems with sensor data and connectivity that enabled comprehensive management of children's activities in diverse settings (Kakhi et al., 2022; Okperigho et al., 2024).

Ukadike et al. (2023) explored IoTs as a wearable device and an integral component to tracking systems designed to enhance the safety security of individuals. They noted that this represents a versatile, low-cost solution for child tracking and monitoring with real-time communication capabilities. Its adaption also granted children navigation capabilities to upscale their safety and confidence. Radio Frequency Identification (RFID) emerged as veritable solution to ease object tracking due to ability to provide accurate, real-time data. It uses tags as a robust and versatile mean to explore GSM/GPS techs. Its demerit is with signal interference, and its cost-effectiveness (Malasowe et al., 2023; Malasowe, Edim, et al., 2024). At the core of GSM is RFID tags for object monitoring, Onyan et al. (2024) developed a pervasive tracker for physically challenged persons to cater to their diverse user needs (Akpoyibo et al., 2022; Onyan et al., 2024). Obruche et al. (2023) proposed use of IoT to monitor kids pick-up and drop-off at school, to showcase RFIDs feats in safer transportation (Binitie et al., 2021; Obruche et al., 2024; Ojugo & Nwankwo, 2021).

Integrating RFID with Global System for Mobile Comms (GSM) and Global Position System (GPS) enhances their reliability and extends their functionality that enables a full comprehensive monitoring of child tracking systems capabilities (Joloudari et al., 2022). Ometov et al. (2021) integrated GSM/GPS with RFID tags to yield SMS alerts and real-time location tracking that notified parents and authorities with timely data of their kids whereabouts. It has become innate that the short message service (SMS) plays a pivotal role in child monitor and safety as it proffers a more means and channel with real-time alerts for parents (Og & Ying, 2021; Okobah & Ojugo, 2018; Okonta et al., 2013, 2014). Upadhyay and Sampali (2020) demonstrated a vehicle tracker via smartphones and SMS services to emphasize its use in provision of location-based functionalities (Upadhyay & Sampalli, 2020). Suleiman (2019) proposed an IoT anti-child trafficking Smart Patch, that exploits mobile app to monitor and report all suspicious activities, and uses SMS services to combat child exploit with real-time alerts to parents that prompt emergency actions on need (Hasan et al., 2023; Ojugo, Odiakaose, Emordi, Ejeh, et al., 2023; Ojugo & Eboka, 2021b; Sutikno et al., 2023).

Voke et al. (2023) used a smart asset-tracker with IoT for women and child safety applications. Model uses RF communication and IoT technology to monitor the location of a person in a building – enhancing safety. Its issue was that of scalability with its real-time tracking accuracy due to the validation of the tracking system. Despite its strengths to yield precise location tracking, further studies were tasked to improve its robustness and privacy issues. Akazue et al. (2023) propose an IoT-based lifesaver for kids and object tracking to address the increasing issue in child security. This system uses IoT with real-time tracking of children's locations and objects to enhance safety. Its demerits was with data reliability and privacy (M. Akazue et al., 2023). Also, Manickam et al. (2022) proposed a smart-device for chronic illness monitor with a focus on safety monitor of children with health conditions. It uses GPS and RFID to monitor child's movements and yields real-time notifications to parents. Its challenge was with its integration and data accuracy (Manickam et al., 2022; Ojugo & Otakore, 2018b, 2018a).

Sreejith et al. (2019) investigated a child-tracker using Arduino-based GPS module to address safety issues. System integrated wearable-activity tracker wrist bands with sensors to monitor children's behaviours, and send emergency data to parents' smartphones, on need basis. Its challenge was in ensuring continued connectivity and optimizing sensor accuracy. Joshi et al. (2020) investigated a child tracker with activity scheduling system that sought to address parental issues with face-to-face monitoring and child safety. System integrates units such as wearable devices and GPS trackers, with a cloud-based application to yield real-time location tracker and activity scheduling functionalities. System offered the potentials to enhance parental oversight for child safety (Joshi et al., 2020). Lu and Rakovski (2022) used a neural network tracker to handle toddlers' curiosity to explore potentially dangerous situations. It used face recognition and tracker algorithms to monitor their movements and alert parents of hazardous objects. Its challenges were in optimizing algorithm accuracy and minimize false alarm (M. I. Akazue et al., 2023; Ibor et al., 2023; Lu & Rakovski, 2022).

Kizilkaya et al. (2023) propose a smart child tracking system, aiming to address the challenges parents face in monitoring their children's movements and ensuring their safety. System used Arduino board and GSM to yield real-time location of children, and enabled parents to receive tracking data via SMS. System offers enhanced child safety; But, challenges exist in optimizing sensor-network performance and ensuring reliable communication, which can be resolved via refined design to address potential limitations to improve user experience and adoption (Kizilkaya et al., 2022). Krishna et al. (2023) advanced works of Lu and Rakovski (2022) using a deep neural network with long-short term memory learning in vision tracking to monitor and ensure toddlers' safety indoors. They explore multi-factor authentication with vision-based models to monitor toddlers and alert parents of imminent emergencies, potential dangers (M. I. Akazue et al., 2022; Krishna et al., 2023; Sreejith et al., 2019).

With a comprehensive review of related literatures, it has been documented that many currently available child monitor and alert systems lacks the comprehensive integration with existing technologies to result in limited functionality and reliability. This will hamper their effectiveness and often yield degraded performance. The study is motivated (Ifeka & Akinbobola, 2015; Igwenagu, 2015; Ojugo & Yoro, 2020a) as thus:

1. Limited functionality: This lack thereof, will yields limited functionality in basic tracking without advanced features like real-time monitor and alert. This will in turn, generate reliability challenges.
2. Reliability: Existing systems seem to be compromised due to insufficient use of IoTs to yield inaccurate data processing and communication failures, which can undermine the effectiveness of the system in ensuring child safety (Ojugo, Allenotor, Oyemade, et al., 2015).
3. Adoption Barriers: Less integration will create barriers to adoption among users, including parents and caregivers, who may be reluctant to trust and rely on systems that do not fully harness the tech capabilities, and potentially hinder its widespread adoption and use.
4. Optimal connectivity and battery life: Many such proposed systems often face the challenge of continued connectivity and optimizing battery life for prolonged tracking periods. We must adapt power efficient communication protocols like LoRaWAN or Bluetooth Low Energy with advanced battery management techniques to extend device longevity without sacrificing tracking reliability.
5. Sensor Network Performance: Sumathi et al. (2023) noted challenges in optimizing sensor network performance to ensure reliable comms with tracking systems. To address these requires the integration of sensor fused algorithms that incorporates data from multiple sensors (e.g., GPS, accelerometer, gyroscope) to enhance its tracking accuracy. Use of redundancy and error correction like signal amplifiers and packet retransmission will help mitigate data loss and further ensure uninterrupted devices communication (Brizimor et al., 2024; Estes & Streicher, 2022; Obasuyi et al., 2024).
6. Scalability: Hennink et al. (2022) noted the importance to ensure tracking system scalability, especially in monitor of kids. To overcome these, we use fault-tolerant paradigms can enhance system reliability by mitigating single points of failure and enabling seamless scalability that seeks to accommodate a growing number of user devices. Also, via cloud-based API – it yields elastic data storage, scalability and maintains ensemble responsiveness and availability (Hennink & Kaiser, 2022).
7. Optimized Accuracy with Reduced False Alarms: Yoro et al. (2022) identified the need to optimize accuracy and minimize false alarm in toddler tracking. To address these requires continuous refinement of deep learning algorithms, including data augmentation techniques and model fine-tuning, to improve recognition accuracy and reduce false alarms (Yoro, Aghware, Akazue, et al., 2023; Yoro, Aghware, Malasowe, et al., 2023).

To overcome these, we implement the smart child-tracking system as thus: (a) develop comprehensive understanding of existing child monitoring and tracking techs with regards to their capabilities, limitations, and ethics, (b) adopt latest trends in IoTs relevant to child track/monitor, (c) identify design requirements to implement our smart child tracking in lieu of accuracy, reliability, and user-friendliness, (d) implement a prototype tracking system with integrating embedded systems such as controllers, sensors, and communication modules, and (e) evaluate its effectiveness and usability via real-world test scenarios and user feedback (Ojugo, Akazue, Ejeh, Ashioba, et al., 2023; Ojugo, Ejeh, Odiakaose, Eboka, et al., 2023; Wemembu et al., 2014). It promises revolutionary change in the track/monitor of children with improved user-trust, greater functionalities, assured user acceptance and better reliability.

2. Materials and Methods

2.1. The Existing Framework

Existing tracker system is based on by Anant et al. (2018). It sought to address the critical feat with child safety, and give parents realtime coordinates of their wards at school and the requisite attendance. The innovation had several gaps like (Ako et al., 2024; Ojugo & Eboka, 2014, 2018b, 2018a, 2019, 2020, 2021a; Okpor et al., 2024):

1. First, tracking coverage area is restricted to the route between the child's home and school, which is insufficient today. The children's extracurricular activities, and visit to friends – makes it essential to have a more comprehensive tracker that covers a wider geographical area (Ojugo, Ugboh, Onochie, et al., 2013; Ojugo et al., 2021a, 2021b).
2. Its reliance on SMS alerts as the primary comms mode with parents may not be the most efficient or reliable approach. SMS delivery can be delayed/disrupted due to network jitters and latency – potentially, causing delays in critical data to reach the parents. SMS lacks interactive capability in channels for parents to respond or take immediate action (Ojugo & Ekurume, 2021; Oyemade et al., 2016; Oyemade & Ojugo, 2020; Setiadi et al., 2024).
3. Battery life as the continuous operation of GPS and GSM modules can quickly drain the battery, requiring frequent recharging or replacement. This, often poses both a logistical challenge as well as creates risk of a non-functioning unit, that eventually compromises child's safety. Furthermore, the system's functionality may be affected by interference in certain areas such as underground or poor coverage sites. And result thus, in inaccurate location tracking or missed notifications (Ojugo, Yoro, Oyemade, et al., 2013; Ojugo, Yoro, Yerokun, et al., 2013; Yoro & Ojugo, 2019a, 2019b).
4. Robust emergency response capabilities. In critical situations, such as a child going missing or encountering danger, system does not provide direct communication channels between parents and children or immediate escalation arising from such emergency services. This limitation could prove crucial in timely response and resolution of high-risk scenarios .

While the existing system presents a commendable effort to enhance child safety, addressing these weaknesses is crucial to ensure a more comprehensive, reliable, and effective solution that meets the evolving needs of modern families and communities.

2.2. The Experimental Framework

Our framework yields the Figure 1 with both hardware and software components. To detect coordinates, alert parents, and notify emergency contact via twilio – the ensemble consists of the sensors and microcontrollers, each of which is designed to monitor/track object coordinates, and via SMS notification to alert emergency contact(s). It then uses the WiFi to send the received data for analysis to the nodeMCU, which is fused with the GPS for seamless operation (Sarwar et al., 2019; Sendra et al., 2020; Sungheetha & Sharma R, 2020). With the data acquired as input and sent to the nodeMCU, the ensemble retrieves and analyse the received data – by comparing the coordinates against the received inputs from sensors in real-time. It yields accurate data and alerts to emergency contacts where there is difference between received data and the stored data coordinate location. Divided into 2 segments based on it is function to both provide a real time data cum alert parents, and a cloud-app that interacts directly with the guardians and other emergency contact (Ojugo, Aghware, Yoro, et al., 2015a; Ojugo, Eboka, Yoro, et al., 2015; Ojugo, Akazue, Ejeh, Odiakaose, et al., 2023; Sathyakala et al., 2018; Shahraki et al., 2018; Sharma et al., 2020).

Ensemble detects instantaneously via the ESP8285 and it is sensors to ensure parents are alerted in real-time, and guardians are notified of the emergency (Kakarlapudi & Mahmoud, 2021; Singh & Sharma, 2017). To ensure faster system response, all sensors and components are connected via the node-MCU to detect coordinates within 30.3metres (i.e. 100feets). This ensures that indoor and outdoor data generated via wireless sensors, are sent as fastest time possible as in Figure 1 and Figure 2 respectively (Ojugo, Aghware, Yoro, et al., 2015b; Ojugo, Eboka, Okonta, et al., 2015).

In addition, node-MCU analyses all data, and compares output with set threshold to determine the point of origin and send such coordinates as set parameters that if exceeds predetermined threshold value(s), it indicates the existence of change in coordinates. Thus, ensemble will alert all contacts via the cloud-app (API), it computes the nearest emergency contact via algorithm in listing 1. This occurs in real-time to yield a reliable, efficient monitor and tracking of object coordinate. It is use of the sensors and controller, will promptly alert parents in the event of a change in coordinate (Eboka & Ojugo, 2020; Oyemade & Ojugo, 2021; Zhang et al., 2019).

Algorithm 1: Listing

Input: Number of nodes, N; **Output**: print distance, alert emergency contacts, previous
create vertex set D
for each (vertex v = = G) **Do**
  Distance[v] ← infinity
  compute previous[v] ← undefined
  Add v to D: **new distance[source]** ← 0;
  return **true**: **else endif**
End
function fine_tune (D)
where D is not empty Do: **u** ← in D with min_distance[v]
function alert_emergency_contact(phone_numbers, parent_gaurdian_list)
For each neighbour v of u **Do**
  return output → (result == final output): **else**
end if: END

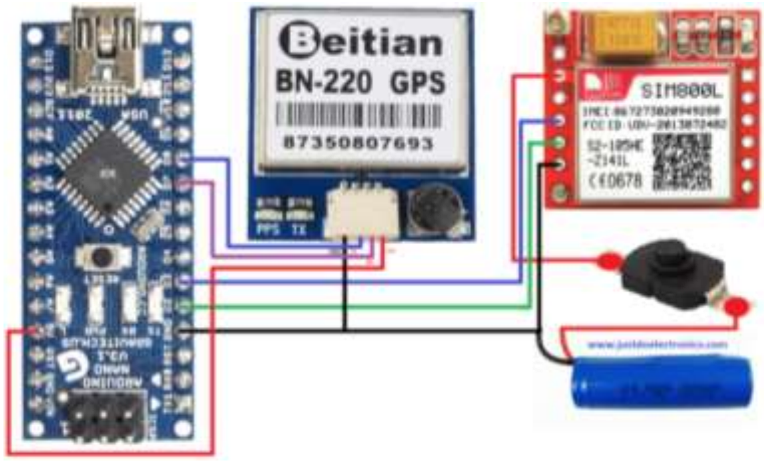

Figure 1. The Hardware Assembly of the Child Tracker System

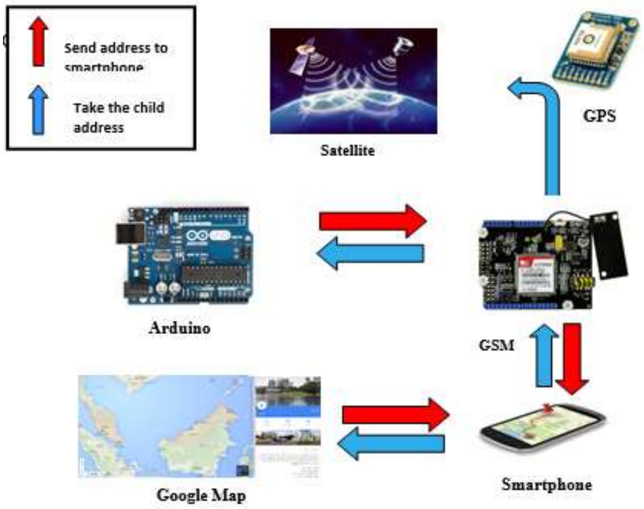

Figure 2. Overall System Block Diagram for Child Tracking System

3. Result Findings & Discussion

3.1. Model Performance and Benchmark

Shortest path heuristic includes a single-path between a source to all other vertices and all-pair path which evaluates the shortest path between all vertices in a graph. To determine the chosen route for a child as we extend the coverage, we consider a single-source yields fastest responses – comparing Dijkstra versus Bellman's Ford to identify the shortest, most efficient path between any 2 nodes (Allen et al., 2024; Sinha, 2024). Dijkstra out-does the Bellman Ford in both (un)directed nodes with positive weights, and on a comparative time analysis. Dijkstra's algorithm yields a time complexity of O(|E|+|V| Log|) , which agrees with (Abernathy, 2021; Shoeibi et al., 2022; Tomar & Manjhvar, 2015). While, Bellman-Ford, the time required is O (|V|×|E|) and agrees with (M. I. Akazue, Edje, et al., 2024).

The comparison shows Dijkstra is faster than Bellman-ford. For the longest amount of nodes (Muslikh et al., 2023; Ojugo, Ejeh, Akazue, Ashioba, et al., 2023; Safriandono et al., 2024), Djikstra yielded a 2.072secs response time; while the Bellman-Ford yielded a response time of 9,577secs. And it is supported by the works of (Ojugo, Abere, Orhionkpaiyo, et al., 2013).

3.2. Findings and Discussion

Our unit consists of GPS/GSM module, which is responsible for tracking the location of the children by the user and the signal will be sent out by GSM network. The simulation of the Arduino software was done severally to ensure the functionality. The GPS/GSM module is connected via serial port that helps it interface with the

Proteus. Data is obtained from the RX pin of Arduino and sent to the Serial Terminal via TX pin. Virtual Terminal shows the longitude and latitude coordinates as retrieved from the GPS. With the codes uploaded on the Arduino board, it retrieves the GPS coordinates such that when the GPS is set to HIGH – it turns ON the GPS, it was able to receive the signal from satellite.

The GSM module was tested by sending an AT-command with results as in Figure 3. The GSM sends feedback response "OK" to note it is ready to receive text message. With AT commands sent to GPS to check whether notifications were obtained when SMS was sent to the GPS. If a message was sent to the GSM shield, notification was obtained as in Figure 3 (Oladele et al., 2024; Omoruwou et al., 2024). Thus, both GSM and GPS module functioned well in Proteus simulation. The GPS obtained the latitude/longitude while the GSM received and stored the message in a string data which had been extracted. A test was done to test the GPS module whether it can obtain the latitude and longitude of the location. The device was connected to the PC through a serial port. Then, the GPS/GSM module was turned ON (Ojugo, Odiakaose, Emordi, Ako, et al., 2023). GPS module need some time to warm up and became stable. The password to enable system was sent via smartphone. After some minutes, SMS was received by smartphone as shown in Figure 3 (Aghware, Adigwe, et al., 2024; Aghware, Ojugo, et al., 2024; Emordi et al., 2024; Odiakaose et al., 2024; Otorokpo et al., 2024).

Figure 3. SMS sent/received as GPS is both ON/OFF (Malasowe, Aghware, et al., 2024)

Conclusion

Study models a fuzzy system that fuses sensors and ESP8285 controller to determine fire probability output. It sends an alert to users via a send algorithm having monitored environment conditions as they quickly change. Previous systems used were often found to have provided false alarms owing to their configuration logic. The experimental design that yielded the proposed ensemble however notifies both the residents and the nearest fire department of fire outbreak, source and location using a shortest distance algorithm. The proposed ensemble is efficient, reliable and can handle dynamic changes as in the send algorithm. Our goal was to integrate this ensemble onto existing infrastructure so as to effectively reduce loss of life and properties. The increased use and adoption of machine learning approaches and a variety of other automated processes with industrial IoT technologies both on the home frontiers and industrial applications has continued to drive up the demand for adaptation of advanced flame detection solutions.

Conflict of Interest

The authors declare that there is no conflict of interest.

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