Research Article

Journal of Applied Engineering Education

Architecture of A Smart System for Combating Human Kidnapping

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Submitted: 2024, Jul 31; **Accepted**: 2024, Sep 05; **Published**: 2024, Oct 01

Citation: Akinyokun, O. C., Omoruyi, O. K. (2024). Architecture of A Smart System for Combating Human Kidnapping. *Journal of Applied Engineering Education, 1*(1), 01-10.

Abstract
The paper presents the architecture of hybrid system for combating human kidnapping. The system is made up of smart objects, Internet of things, Real Time Location System (RTLS), Radio Frequency Identification (RFID), Global Processing System (GPS), Global Mobile Communication (GSM), Objects Identification and Recognition System, Video cameras, IP cameras and Microcontroller. The conceptual diagram of GPS analyzer, video analyzer, RFID analyzer and electric circuit diagram of the components of the architecture are presented. RFID tag reading algorithm which incorporates the database of the kidnapped victims, landmarks, RFID readers and mounted cameras are presented. The global location and positioning data generation which incorporates GPS positioning estimation, GPS NMEA format and GPS accuracy are addressed. RFID positioning estimation which incorporates objects identification and recognition are presented. The GPS signal denied areas, microcontroller and hybrid location engine are presented.

1. Introduction

The comprehensive literature review and development of a smart system for combating human kidnapping has been presented in Akinyokun and Omoruyi (2022) and Omoruyi et al., (2023). The conceptual diagram of the architecture of the smart system is presented in Figure 1.1. The system has two phases namely: hardware operational requirements phase and software analytic framework phase. The hardware operational environment of the integrated sensor framework has four stations namely: Sensor Processing Station (SPS), Media Server Station (MSS), Smart Engine Server (SES) and Security Management Station (SMS).

The SPS has hardware and software for signal sensing and comprises of workstations equipped with video camera, RFID tags, GPS receivers and body worn sensors. Video camera sensors are required for capturing the video data of the area being monitored. A nano-digital camera is embedded into a broach-type model attached to buttons or human hair for taking and forwarding real time pictures to a Digital Server Room (DSR). The device worn by the kidnapped victim, consisting of a mini-digital camera and sensors captures the picture of the kidnapper alongside the GPS coordinates of the location and transmit to a remote server. GPS provides global monitoring of persons while RFID tags are required for monitoring places where GPS signal are absent. RFID tag readers are placed at strategic locations so that the reader can capture the position of each wearable device by detecting the identification signal from the tag. The SPS requires identification cards carrying chip embedded tools for the effective checkpoint identification of carriers. The chips could be embedded, injected beneath the skin, placed into wristbands, buttons or hair of an individual for monitoring and safety. The captured data from the sensor processing unit are stored on the cloud-based MSS. The SES is responsible for logical reasoning of the system. Internet Protocol version 6 (IPv6) was selected as the communication protocol for the provision of addressing schemes for data transfer on the web. The hardware components of the Non-Visual Module (NVM) comprises of smart objects, Internet of things (IoT), RFID sensors and GPS that are responsible for signals and location. GPS is used to calculate the location of the kidnapped victim. A rudimentary view of the GPS systems is that the device determines the position by solving a system of equations based on the Pythagoras theorem in three dimensions and a time offset from the GPS reference time. This facilitates the requirement that at least four satellites must be visible to compute the user position.

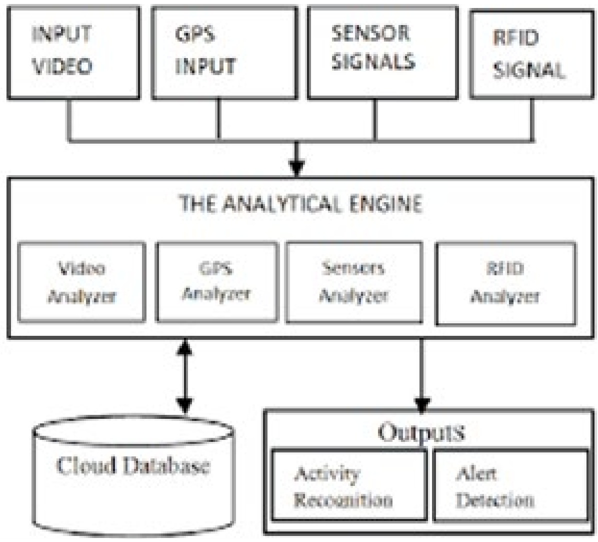

Figure 1.1: Architecture of the system

2. Architecture of The Smart System

The architecture has GPS analyzer, Video analyzer, RFID analyzer, RFID readers, IP camera, video camera, localization, positioning, data generation, GPS signal denied areas, microcontroller and hybrid location engine.

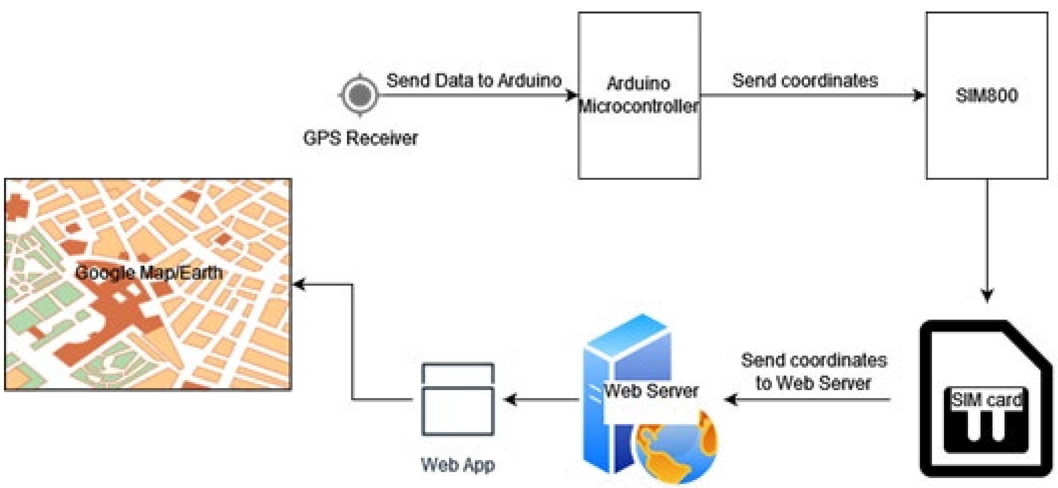

Figure 2.1: Conceptual Diagram for the GPS Analyzer

The GPS analyzer presented in Figure 2.1 has its sole input as coordinates coming from a GPS receiver. The longitude and latitude values received from the GPS receiver is transferred to a microcontroller (Arduino Uno) which has been programmed to transfer the received coordinates to the Web server at internals of five minutes. The microcontroller sends these values to the web server using an TCP/IP protocol by utilizing SIM800 Dual Module carrying the SIM card of a network. The entire log of the received coordinates can be viewed on the web application developed. Google Map integrated into the web application can also be used to monitor in real time the position of the person carrying the device.

2.2. Video Analyzer

The Video Analyzer presented in Figure 2.2. The primary input source is the IP cameras stationed at landmarks. The camera constantly compares the faces captured in its scene with sets of images of persons of interest, either a kidnapped victim or a kidnapper. The object detector of the trained model developed detects the object from the scene. Thereafter, the feature extraction layer extracts key features from the object like eyes, noses, lips, eyebrow and others, features which differentiates a person from another. An object recognizer compared the features to existing feature values on the object database. If a matching object with similar feature value is found. A person of interest is recognized or another object from the scene is analyzed.

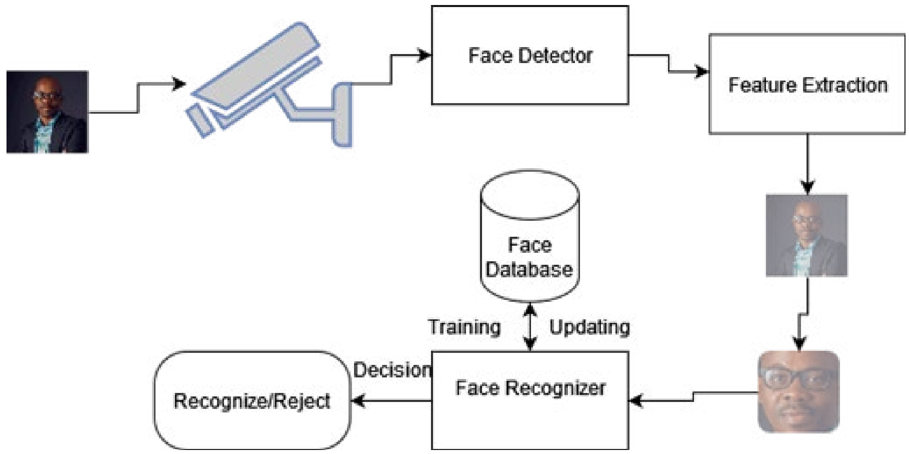

Figure 2.2: Conceptual Diagram for Video Analyzer

• Algorithm 2.1: Object Recognition Algorithm
I - The input image (a matrix representing pixel values).
DD - The database of known objects, each represented by a set of features.
F(I) F(I) - The feature extraction function, which extracts relevant object features from the input image I.
S(F1,F2) S(F1,F2) - The similarity function, which measures the similarity between two sets of features F1F1 and F2F2.
TT - The similarity threshold, which determines whether a match is found.
The algorithm can then be expressed as follows:

Step 1:
• Object Detection: Detect objects in the input image I using a object detection algorithm:
Fobjects = ObjectDetection(I)
Here, Fobjects represent a set of detected object in the image II.

Step 2:
• Feature Extraction: Extract features from the detected objects using the feature extraction function F(I): Ffeatures=F(I) Ffeatures represents a set of features extracted from the detected object.

Step 3:
• Recognition: Compare the extracted features Ffeatures of the detected object with the features of known objects in the database DD. This involves calculating the similarity between the features: Ssimilarity = S(Ffeatures,D) Ssimilarity represents a similarity score or distance metric between the detected object's features and the features of known object in the database.

Step 4:
• Recognition Decision: Determine whether a match is found based on the similarity score Ssimilarity and the similarity threshold TT: if Ssimilarity≥T: Match foundif Ssimilarity≥T: Match found else: No matchelse: No match

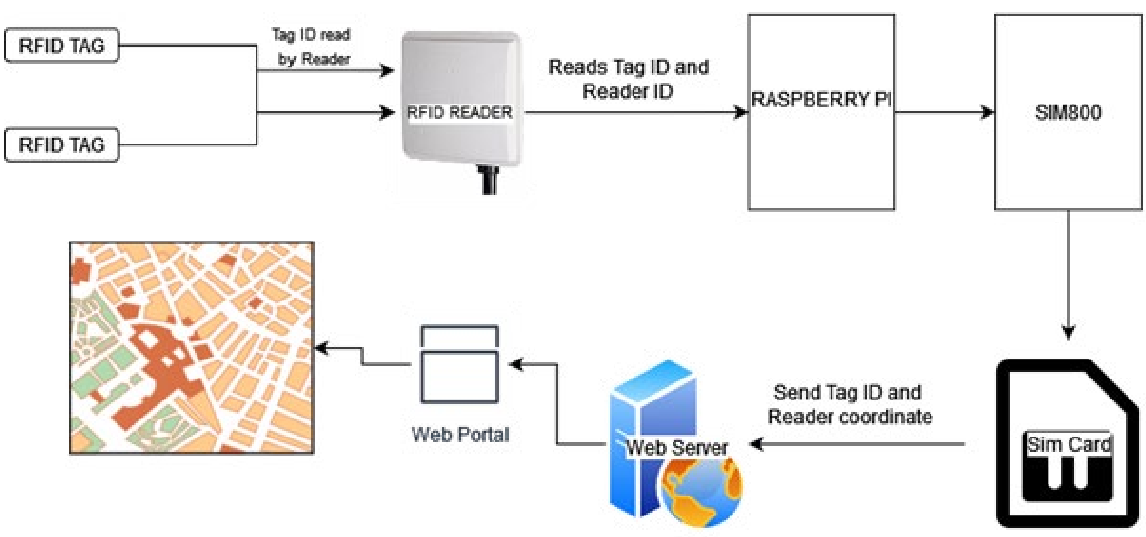

Figure 2.3: Conceptual Diagram for RFID Analyzer

2.3. Rfid Analyzer

The conceptual diagram for RFID analyzer is presented in Figure 2.3. The long-range RFID readers stationed at strategic locations like landmarks, toll gates and key inter-state roads, continuously scans its coverage area to read the unique IDs of wearable tags that passes through its coverage perimeter. The RFID readers which are connected to a microcomputer like raspberry pi, are static and geolocated. The raspberry pi receives the unique IDs from the tags it reads and sends it to the web server, alongside the geolocation or location of the particular RFID reader that read the tag. Any tag ID earlier assigned to a victim can be tracked via the web portal integrated with Google Maps.

• Algorithm 2.2: RFID Tag Reading Algorithm

Some mathematical symbols are defined in the following:

- TT - The set of RFID tags.
- RR - The RFID reader.
- DD - The database of known RFID tag information.
- E(T) - The function to extract data from an RFID tag TT.
- C(D,E(T)) - The function to compare the extracted data E(T) with the database DD to determine if it is a match.
- MM - A match result (1 for a match, 0 for no match).

The algorithm can then be expressed as follows:

Step 1

RFID Data Reading: Read data from the RFID tag using the RFID reader RR:

E(T)=Read Data(R,T) E(T) represents the data extracted from the RFID tag TT.

Step 2

Identification: Compare the extracted data E(T) with the database DD to identify if it's a known RFID tag: M=C(D,E(T)) MM is a binary value (1 for a match, 0 for no match), indicating whether the RFID tag TT is known and recognized based on the database DD.

Step 3

Recognition Decision: Determine whether the RFID tag TT is recognized or not:

if M=1: RFID tag recognized if M=1: RFID tag recognized else: RFID tag not recognized else: RFID tag not recognized

The key mathematical components in this algorithm are the functions E(T) for data extraction and C(D,E(T)) for data comparison against the database. The decision is made based on the match result MM.

2.4. Circuit Diagram of Architecture

The component circuit connection presented in Figure 2.4 comprises of the RFID Analyzer, Video Analyzer and GPS Analyzer. The three analyzers all route their sensor readings and image captures to the database server. A solar enabled uninterrupted power supply ensures that the stationed RFID readers and IP cameras are always on. A single raspberry pi can process inputs from both the RFID reader and IP camera, which goes a long way to reduce infrastructural cost.

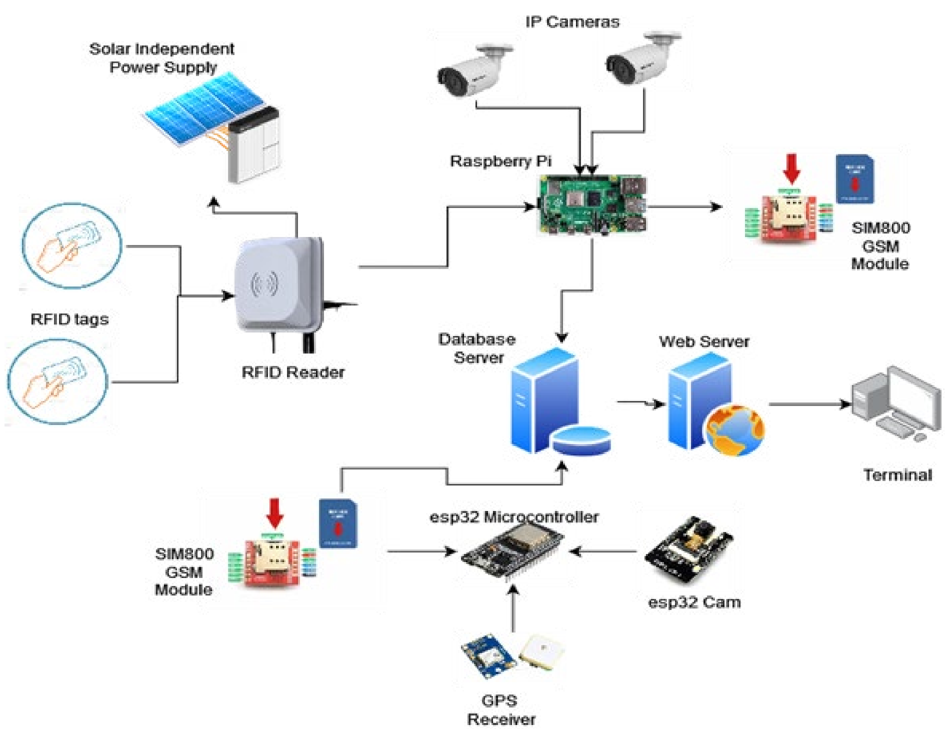

Figure 2.4: Circuit Connection of all Components of the Architecture

3. Database of Victims, Devices and Landmarks

The first step in the design of the system is the development of the database infrastructure. The database includes tables of the biodata of individuals, wearable devices, electronic devices and landmarks. The entities and the schema of the database are presented as follows:

• Personal details {per-id, per-first-name, per-other-name, per-gender, per-marital-status, per-dob, per-photo-location, per-email-add, per-phone-number, per-passport-number, per-wearable-id, per-photo-location, per-wd}

• Fixed Device details {dev-id, dev-name, dev-location, dev-mac-add, dev-longitude, dev-latitude, dev-sim-number}

• Wearable Device details {wd-id, wd-mac-id, wd-sim-number}

3.1. RFID Readers, Mounted Cameras and Related Devices Location

The listing of all the physical landmarks where the fixed devices like RFID readers and cameras are mounted and the database of all necessary parameters are created. The following are required:

- Landmark name
- GPS location coordinates
- Landmark sensor/device ID
- Device name
- Device type
- Physical location of electronic devices
- Media Access Control (MAC) address
- Serial number
- Deployment information
- Assigned identification code

4. Localization and Positioning Data Generation

The localization and positioning data generation sub-system handles the detection of signals by the individual readers, carries out the position calculation and a final estimation of position. Due to the nature of human kidnapping, search and rescue efforts are basically done outdoors. Hence, Outdoor and signal-denied areas are crucial factors to be considered in this research.

4.1. GPS Positioning Estimation

Since World War II, location and tracking has been of great relevance especially when the military recognized their advantages for targeting, positioning, fleet management and navigation. In recent times, GPS has found a wider range application in wildlife tracking, package delivery, stolen vehicle recovery, resource management and so on (Bajaj *et al.,* 2002). GPS comprises a network of twenty four satellites which are in six different twelve hour orbital paths that are strategically spaced out so that at least there are five in view from every point on the globe, as depicted in Figure 6.1. These satellites continuously transmit military as well as civilian navigation data on two Low band frequencies. There are five monitor stations and four ground antennas as at the time of this research, located in various places around the world that gather range data on each satellite's exact position. This information is relayed to a master control station whose responsibility is to provide overall coordination of the network and transmit correction data to the satellites (Bajaj *et al.,* 2002). By measuring the distance from a group of satellites in space, an object's position on earth is calculated. This calculation is carried out by measuring the time it takes for a radio signal from a particular satellite to reach the object of interest. The radio signal travels at 186,000 miles per second, which is the speed of light. The distance can be calculated using the formula:

$$\text{Distance} = \text{Velocity} \times \text{Time} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

GPS satellite ranging allows a receiver to determine its 3-dimensional position: latitude, longitude and height. A GPS receiver measures range to four satellites in order to determine its latitude, longitude and height. In a GPS system, the user whose position is to be determined must have access to at least four satellites in orbit at the same time (Adewole, 2019). The subsequent calculation of the position of the user is obtained by solving a set of equations based on Pythagoras theorem in three dimensions and a time offset from the GPS reference time as shown in Equations 3.2, 3.3, 3.4 and 3.5 (Richard, 1998). The centre of the Earth is taken as the origin in the coordinate system. Working in three dimensions, information is needed from four satellites. Call these S_1, S_2, S_3, and S_4; and suppose that S_i is located at (X_i, Y_i, Z_i) when it transmits a signal at time T_i. Suppose the signals are received at times T_i^*, according to the clock in the receiver. Let $t_i = T_i^* - T_i$ and let ε represent any error in the clock time. The receiver allows for the mean effects of passage through the Earth atmosphere and computes distances $d(t_i, \varepsilon)$ that indicate how far the object is from each of the satellites.

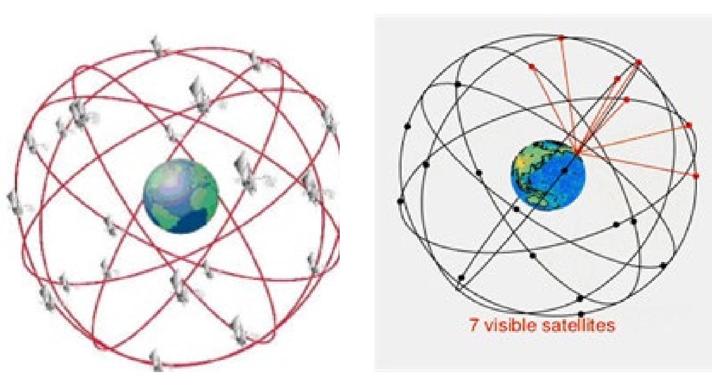

Figure 3.1: GPS Satellites Orbital paths

$$d(t_i, \varepsilon) = (x_o - X_1)^2 + (y_o - Y_1)^2 + (z_o - Z_1)^2 \quad \ldots\ldots\ldots\ldots\ldots 3.2$$

$$d(t_i, \varepsilon) = (x_o - X_2)^2 + (y_o - Y_2)^2 + (z_o - Z_2)^2 \quad \ldots\ldots\ldots\ldots\ldots 3.3$$

$$d(t_i, \varepsilon) = (x_o - X_3)^2 + (y_o - Y_3)^2 + (z_o - Z_3)^2 \quad \ldots\ldots\ldots\ldots\ldots 3.4$$

$$d(t_i, \varepsilon) = (x_o - X_4)^2 + (y_o - Y4)^2 + (z_o - Z_4)^2 \quad \ldots\ldots\ldots\ldots\ldots 3.5$$

The position is located on each of four huge spheres. In most situations, there will be only one sensible value of ε that allows the spheres to have a point in common. The location is determined by solving the system of equations. When a numerical solution is found, the rectangular coordinates are converted into essentially spherical coordinates of latitude, longitude, and altitude above sea level.

4.2. GPS NMEA Format

The format in which the GPS readings from the receivers are expressed is known as the National Marine Electronics Association (NMEA) format. NEMA is a standard data format supported by all GPS manufacturers (Adewole, 2019). NMEA format gives equipment users the ability to mix and match hardware and software. NMEA-format GPS aids software developers in developing software for a wide variety of GPS receivers instead of having to write a custom interface for each GPS receiver. All NMEA messages start with the $ character and each data field is separated by a comma.

4.3 GPS Accuracy

In the GPS measurement system, Line of Sight (LOS) access to at least four satellites are required as shown in Figure 3.2, $[S_{xi}\ S_{yi}\ S_{zi}]$ refers to the i^{th} satellite (1,2,3,4) coordinates, $[G_x\ G_y\ G_z]$ indicates the GPS receiver coordinates and Ri represents satellite range as $[S_x\text{-}G_x,\ S_y\text{-}G_y,\ S_z\text{-}G_z]$.

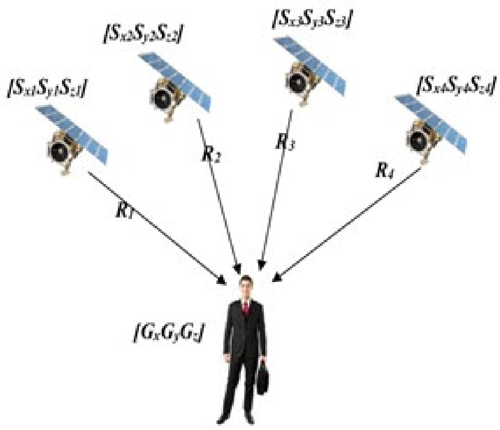

Figure 3.2: GPS measurement system

Kalman filter is used to reduce GPS errors and thus increases the accuracy of the localization system. It is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each time frame.

The states of the system are defined to model the system dynamics. Also, a measurement model is defined to characterize the relationship between the state vector and any measurement. The Kalman filter procedure shown in Figure 3.3 is initiated by the assumption of the initial estimate of states, x^-_o and its error covariance, P^-_o.

The optimal Kalman gain K_k is utilized to achieve the update estimate of the pseudorange measurements x_k and its error covariance P_k is then calculated. The next state x_{k+1} and error covariance $P\text{-}_{k+1}$ is then calculated based on the current state estimate. The GPS accuracy is measured using the Twice Distance Root Mean Squared, ρ, as shown in equation 3.5:

$$P = 2((\sigma^2_x + \sigma^2_y)^{1/2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

where σ_x and σ_y are the standard deviations of latitude and longitude respectively for the estimated coordinates by Kalman filter.

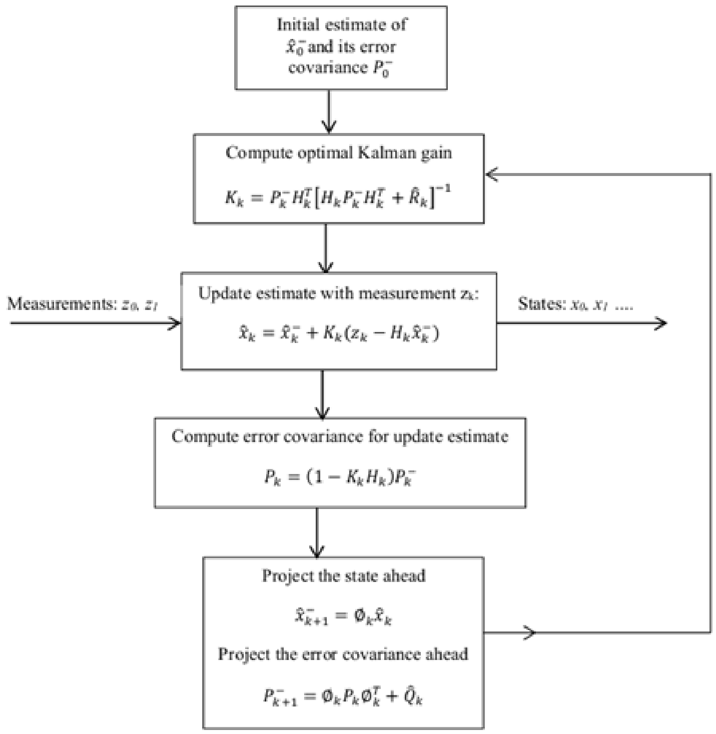

Figure 3.3: Kalman Filter procedure

4.4. RFID Positioning Estimation

RFID stands for Radio Frequency Identification and it is a term that describes a system of identification. This technology is based on storing and remotely retrieving information or data as it consists of RFID tag, RFID reader and backend database. RFID is not a new technology. It has passed through many decades of use in various domains like military, healthcare, library, sports, security, animal tracking and so on. The progressive advancement in RFID technology has brought about advantages related to optimization of resources, increase in efficiency with business processes, enhanced customer care and so on (Ahsan *et al.,* 2010). RFID tags store unique identification information of objects and communicate with the tags in order to allow remote retrieval of their unique ID. RFID technology depends on the communication between the RFID tags and RFID readers. The read range of the reader is dependent on its operational frequency.

4.5. Object Identification and Recognition

Many times a kidnapping event would have occurred hours before it is known to friends and family of the victim, simply because there is an absence of a real-time mechanism to identify the pointers or common objects of a kidnapping scene. Some of these common objects are facemasks, guns, cutlasses and so on. Traditional Closed-Circuit TV (CCTV) can record the scene but will need a replay or an continuous human monitoring of the scene which is a very unreliable as he human is prone to fatigue, expensive and delayed solution. Our proposed solution will also include a Scene Monitoring Module that will harness the features of Computer Vision technology to automatically in real-time identify a predefined list of notable objects at a crime scene to further trigger a possible notification of Human kidnapping event to a remote server, also including the geographical location of the said scene. Furthermore, there have been instances of kidnapped victims seen in a different state of abduction and not recognized by occupants of the new location. The proposed solution will feature a facial recognition module that upon identification of a face of a previously enlisted missing victim, it will send a snapshot of the victim and the geolocation coordinates to a remote server so an instant search and recovery effort can be carried out by the nearest authorities.

4.6. GPS Signal Denied Areas

One of the major challenges with GPS technology are areas where there is no reliable link to the satellites in orbit. Examples of such areas are tunnels, inside buildings, basements, heavy forest areas and so on. Our proposed alternative to address this is the use of RFID tags to identify these places as landmarks and to carry out a location estimation calculation based on the closest GPS reliable zone.

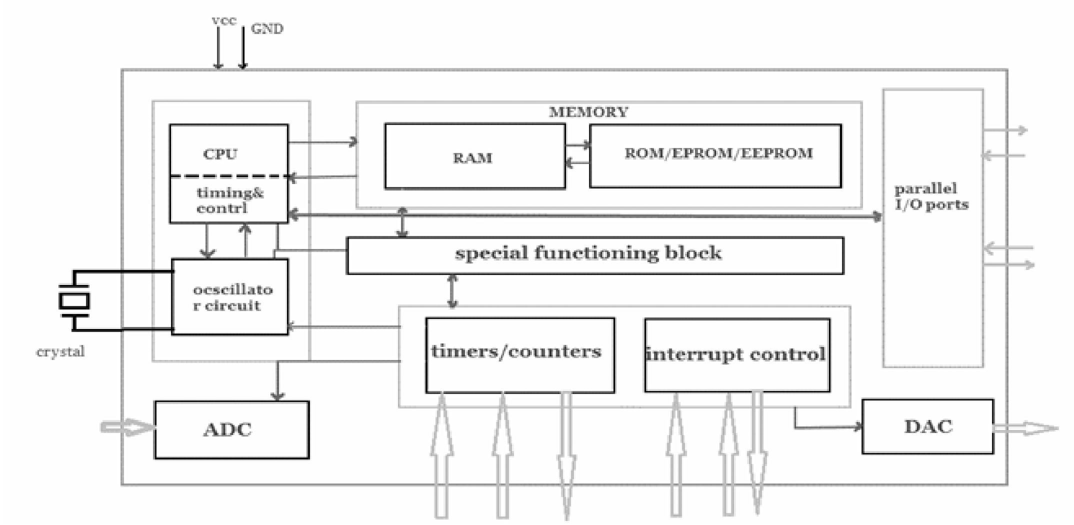

Figure 3.4: Typical Block Diagram of a Microcontroller

4.7. Microcontroller

Majority of the devices in this research are meant to be autonomous and wearable. One important characteristic of the wearable devices for a tracking application is covertness and miniaturisation, that is, it can be made in a very small form factor and secretly worn and hidden out of sight from adopters. Therefore, we will be making use of a microcontroller as it meets these requirements. A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip. Microcontrollers are found in vehicles, robots, office machines, medical devices, mobile radio transceivers, vending machines, home appliances and so on. A typical block diagram of a microcontroller is shown in Figure 3.4. It is made up of the following sub-units:

• Central Processing Unit (CPU): is the brain of a microcontroller, which is responsible for fetching the instruction, decodes it, then finally executes the code. The CPU connects every part of a microcontroller into a single system. The primary function of the CPU is fetching and decoding instructions. The instruction fetched from program memory must be decoded by the CPU.

• Memory: The function of memory in a microcontroller is the same as a microprocessor. It is used to store data and program. A microcontroller usually has a certain amount of RAM and ROM (EEPROM, EPROM and so on) or flash memories for storing program source codes.

• Parallel input/output ports: Parallel input/output ports are mainly used to drive/interface various devices such as LCDs, LEDs, printers, memories and so on to a microcontroller.

• Serial ports: Serial ports provide various serial interfaces between a microcontroller and other peripherals like parallel ports.

• Timers/counters: This is one of the useful functions of a microcontroller. A microcontroller may have more than one timer and counters. The timers and counters provide all timing and counting functions inside the microcontroller. The major operations of this subunit are performed clock functions, modulations, pulse generations, frequency measuring, making oscillations and so on. This also can be used for counting external pulses.

• Analog to Digital Converter (ADC): ADC converters are used for converting the analog signal to digital form. The input signal in this converter should be in analog form and the output from this unit is in digital form. The digital output can be used for various digital applications.

• Digital to Analog Converter (DAC): DAC performs the opposite operation of ADC conversion. DAC converts the digital signal into analog format. It is usually used for controlling analog devices like DC motors, various drives and so on.

• Interrupt control: The interrupt control used for providing interrupt (delay) for a working program. The interrupt may be external (activated by using interrupt pin) or internal (by using interrupt instruction during programming).

• Special functioning block: Some microcontrollers are used only for some special applications. Examples are space systems and robotics. These controllers contain additional ports to perform such special operations. These are considered as special functioning blocks.

4.8. Hybrid Location Engine

The hybrid location engine serves as a centralization unit by bringing together all captured signals by the various heterogeneous sensors on the positioning and tracking system. The algorithm that runs on this engine periodically calculates and estimates the position of the human being tracked. In order to make an inferential conclusion out of all the signals from the various components and modules, the Hybrid Location Engine (HLE) will take these feedbacks as input, carry out necessary computations and analysis to produce a well-informed output that sufficiently gives a reliable position of the tracked individual.

5. Conclusions

The research carried out an extensive and comprehensive review of Smart Objects and Internet of Things (IoT) and their application to solving the menace of kidnapping. Smart Objects and Internet of Things (IoT), RFID, GPS, Microcontrollers, GSM module, Smart cameras were used in the research. A web application portal was developed for easy profiling of devices, victims, landmarks and real-time tracking of object and facial recognition. The research developed an architecture for smarts system for combating human kidnapping with a view to improving the security awareness of a community and providing data for informative investigation and efficient tracking of kidnapped victims.

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