SN Computer Science manuscript No.
(will be inserted by the editor)

BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework

Laavanya Rachakonda · Anand K. Bapatla · Saraju P. Mohanty⋆ · Elias Kougianos

the date of receipt and acceptance should be inserted later

Received: 12 Feb 2022 / Accepted: 09 Apr 2022

Abstract Statistics indicate that 40% of road accidents are due to driving while intoxicated or due to driving under influence. With the improvements in science and technology, secure solutions with improvised, practicable, feasible mechanisms should be proposed to eliminate the occurrences of accidents. Keeping this in mind, BACTmobile a fully automated, smart and secured Blood Alcohol Concentration (BAC) Tracking System for vehicles is proposed. BACTmobile collects physiological data, psychological behavior data and physical behavior data to analyze the BAC levels of a person. BAC levels are classified into five categories. With the vehicle's infotainment along with smart connectivity, the driver is allowed to communicate with the vehicle. The collected and analyzed data are sent to cloud servers for storage purposes whilst maintaining security and privacy. A robust, high efficient BAC detection and prediction model is demonstrated with an accuracy of 99%.

Keywords Internet-of-Medical-Things (IoMT) · Healthcare Cyber-Physical System (H-CPS) · Blockchain · Data Privacy · Driving Under Influence (DUI) · Blood Alcohol Concentration · Psychological Behvaior · Smart Vehicles · Cognitive Thinking · Consensus Algorithm · Cybersecurity in Healthcare.

Laavanya Rachakonda
Dept. of Computer Sci. , University of North Carolina Wilmington
E-mail: Rachakondal@uncw.edu

Anand K. Bapatla
Dept. of Computer Sci. and Eng., University of North Texas
E-mail: AnandKumarBapatla@unt.edu

Saraju P. Mohanty (Corresponding Author)
Dept. of Computer Sci. and Eng., University of North Texas
E-mail: saraju.mohanty@unt.edu

Elias Kougianos
Dept. of Electrical Engineering, University of North Texas
E-mail: elias.kougianos@unt.edu.

1 Introduction

Road safety is one of the primary concerns in order to protect people from accidents. Every year, the rate of occurrences of road accidents is significantly growing. 37,461 people lost their lives in road accidents in 2016 in the United States alone. Out of these, 40% are due to driving under influence, 30% are due to speeding and 33% are due to driving with lowered concentration [66].

Fig. 1 Device Prototype of BACTmobile as a H-CPS.

With the impact of growth in technology, it is clear that the time has come to upgrade traditional methodologies for detecting DUI cases. With this as our key motivation, BACTmobile: A Smart Blood Alcohol Concentration (BAC) Tracking system is proposed using the Internet of Medical Things (IoMT). The IoMT is branch of The Internet of Things (IoT) which is a network of devices capable of transferring, sending and exchanging information upon need and design. These devices have their own IP addresses to maintain authenticity [45]. This communication and information exchange is performed without the need of human-to-human interactions. When such networks are primarily focused towards healthcare applications, then such networks can be considered part of the IoMT [55]. The device prototype of BACTmobile system is represented in Figure 1 along with both multi-modal data units. In order to better understand the concept, first the impact of intoxication will be examined.

1.1 What is Intoxication or Influence?

The condition of having physical or mental ability degradation by external factors is called intoxication. This causes changes in perception, mood, thinking processes and motor skills that result from an effect on the central nervous system [49].

1.2 What causes Intoxication?

The percentage of alcohol in the bloodstream of a human being is known as Blood Alcohol Concentration (BAC). If for 1000 parts of blood, there is 1 part of alcohol, then the BAC is defined as 0.10%. The level of intoxication increases linearly with the increase in BAC. Almost all states in the USA have a legal limit of BAC at 0.08%. BAC calculation and the levels of intoxication depend on various factors like age, weight, gender, health conditions, etc. [39].

1.3 What happens when Intoxicated?

Frequent and continuous consumption of alcohol has short-term and long-term effects. Numbness, lack of concentration, slurred speech, and dehydration are few among the short-term effects while infertility, liver and heart problems, and lung infections are some long-term effects. Due to these, performing activities which require mental stability and cognitive thinking like driving can be difficult [59]. Thus, driving while drunk or intoxicated is considered a serious offense.

1.4 BACTmobile at a Glance

In an attempt to reduce accidents, the BACTmobile Healthcare Cyber-Physical System (H-CPS), an intelligent system to monitor and control accidents in vehicles is proposed (see Figure 1). The BACTmobile system has the ability to monitor the vitals, physiological and facial features of the driver to determine BAC levels. BACTmobile H-CPS can not only track the BAC levels, but it can also analyze the mental health of the driver by accepting and analyzing the psychological data using the infotainment center in the vehicle. The psychological data is used to eliminate the possibilities of false positive cases. BACTmobile H-CPS locks the ignition of the car depending on multi-modal data analyses. As the BACTmobile system encourages data transfer and exchange, a secure way to perform these operations has also been included thereby providing secure data storage and access to the system.

The organization of the rest of the paper is as follows: Section 2 addresses the research questions, proposed solutions and objectives of BACTmobile. Section 3.1 provides the state-of-the-art literature and marketable products for BAC monitoring followed by issues in these. Section 4 provides the novel contributions that are proposed through BACTmobile and how it provides an excellent solution to the missing aspects. Section 5 explains the impact of alcohol on various abilities of the human body. Section 6 determines the relationship between the considered features to various classes of BAC. Section 5 explains the flow of processing the considered parameters. Section 8 explains the Machine Learning (ML) models that are deployed in BACTmobile. Section 9 describes the secure storage and access mechanisms used in BACTmobile. Section 10 comprises of the implementation and validation of the proposed methodologies. Section 11 concludes BACTmobile followed by future directions of the research.

2 Research Questions and Objectives addressed in BACTmobile

2.1 Research Questions

The motivation to propose a fully automated edge level system for vital signal and BAC monitoring is to enhance the concept of "Smart-Life". Through BACTmobile, the addressed questions are:

- Can a fully automated, no human input system, monitor BAC without the need of a second person?
- Is technology smart enough to monitor the vitals of the driver?
- Is the proposed system smart enough to eliminate false positives?
- Can this system be a part of the Smart-Vehicular domain?
- Can there be a system that monitors BAC without depending solely on the breath of the driver?

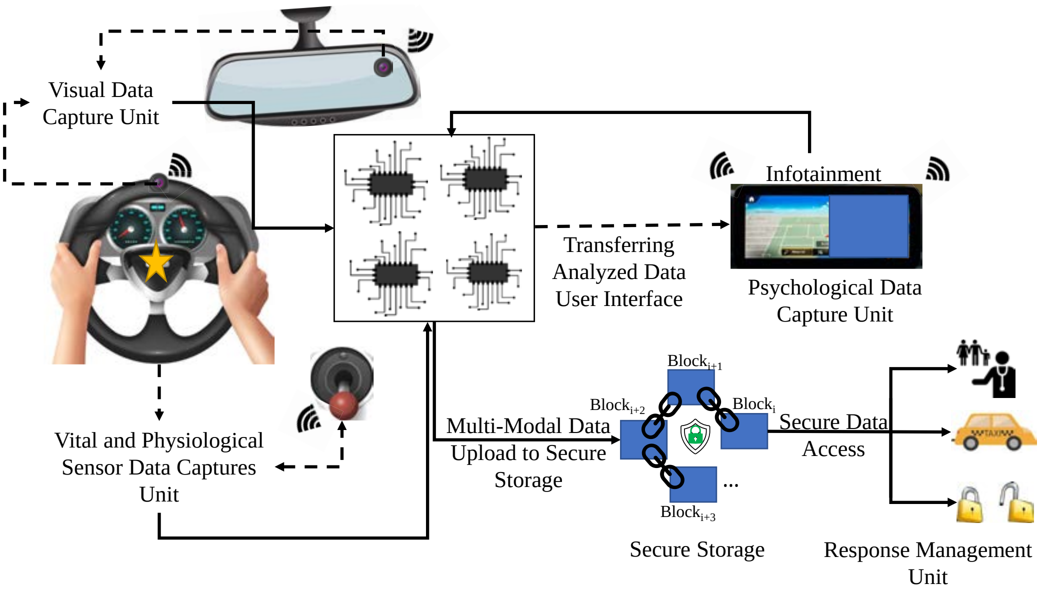


Fig. 2 Proposed BACTmobile as a H-CPS.

– Can stress impact the driving capability of a person?
– Can this system monitor the exact level of intoxication the driver is under?
– Can this system run oat the edge?
– Can the multi-modal data gathered from the driver be private and secured?

2.2 Proposed Solution

With the idea to propose a potential solution which not only monitors BAC levels but also the vital signals of the driver, BACTmobile as a Healthcare Cyber-Physical system is proposed as shown in Figure 2. Multiple areas like steering, gear rod and rear mirror are used as the input multi-modal data capture units. This collected data is processed, analyzed and is displayed on the infotainment for the user. The same infotainment is also considered as the psychological data capture unit when the user needs to have a behavioral analysis.The data from the infotainment is also securely transferred to the nearest hospital, primary care provider and family, when needed.

2.3 Research Objectives

The idea behind the proposed BACTmobile H-CPS is motivated by considering the health and lifestyle of drivers, and its indirect impacts on society. The main objectives that BACTmobile addresses are:

1. Driver's Health
   As accidents can occur due to various reasons, continuous health monitoring of the driver is very important. With that in mind, BACTmobile proposes vital signal monitoring which can allow the driver to take a break or reach out to the nearest hospital upon need, thereby eliminating any indirect causes for accidents.
2. External Person Avoidance
   As traditional BAC monitoring involves an external person, the objective is to propose a system which is smart enough to analyze the various data of the driver and to analyze his/her mental state, thereby reducing the occurrences of accidents.
3. Driver Education and Safety
   Along with the complete analysis of BAC monitoring, the vital signal information and their corresponding performance is also presented to the driver using the user interface. This will allow the driver to understand the overall health picture and the importance of focused driving.
4. Technological Advancement
   As a breath analyzer is the most used method to monitor the BAC of a driver, the idea of mixing various other physiological, facial and behavioral data to analyze the BAC will be a significant advancement in technology, thereby promoting "Smart-Life".

3 Related Prior Works and Research Gap

3.1 Related Prior Research

With the growth in importance and need to limit the number of fatal road accidents, there have been significant advancements proposed in the literature. A breath analyzer is most used to detect BAC by many of the researchers [1, 13, 63]. Alcohol detection helmets using a breath analyzer are proposed in [52] and [60].

Temperature and humidity sensor data along with the alcohol sensor data are taken into consideration to detect the BAC levels in [41]. A combination of heart rate, respiration rate, accelerometer, gyroscope and alcohol sensor data are considered to detect BAC levels in [24]. Along with an alcohol sensor, heart rate and biometric fingerprint scanners are considered in detecting BAC levels in [7]. An iontophoretic bio-sensing system which uses sweat to detect the sobriety of the person is proposed in [35]. The PPG (photoplethysmogram) signal data from individuals is considered and is analyzed to detect BAC levels in [23]. Though the proposed research contributions consider few physiological sensor data, many other physiological along with psychological and feature data can result in an accurate and efficient system, as proposed in BACTmobile.

In terms of technological advancements, a machine learning algorithm is proposed in [36] to analyze the breath analyzer data. A biometric scan to detect BAC levels is proposed in [54]. Only physiological signal data is considered in [56] to analyze the BAC levels. However, the accuracy, performance and efficiency of the system can be improved if a variety of multi-modal data is considered, as proposed in BACTmobile. The state-of-the-art literature and their limitations are summarized in Table 1.

3.2 Related Consumer Products

With the development and enhancements in Smart Vehicles, there has been an attempt of incorporating alcohol level detection systems to automatically determine the BAC levels of the driver. However, the proposed solutions have mostly used breath analyzers and touch sensor systems without considering additional data, which may improve the efficiency of the system. There are chances of having false negative cases as continuous monitoring is not allowed.

There are wearables which are completely dependent on the driver's wish to test for BAC levels before driving. Such wearables do not help to eliminate the occurrences of accidents [9, 30, 34, 68]. Similarly, there are mobile applications which try to monitor BAC but they are also not useful in reducing the number of accidents [8, 15, 28, 40]. Along with the inability to control the number of accidents, the existing wearables and non-wearables have limitations, as summarized in Table 2.

3.3 Issues with the Existing Solutions

It is evident that not many contributions with technological and feature advancements have been made towards the monitoring of BAC levels in vehicles to prevent the occurrences of accidents. The major issues that are not addressed in most of the existing solutions are:

- Most of the solutions use only breath analyzer data along with very few other physiological signal data.
- A variety of multi-modal data like facial, and behavioral data is not considered.
- The importance of stress and various factors that affect the mental health of the driver are not addressed.
- Continuous monitoring through out the driving period is not provided and therefore the cases of distracted driving or fatal issues while driving cannot be observed.
- Automatic BAC level monitors are not provided.
- Interactive solutions for the users are not provided in the case of false positives.
- None of these solutions store personal data in a privacy assured manner.
- Most of the solutions directly use an alcohol sensor, thereby limiting vital data monitoring.
- Classification of BAC levels is not provided.
- In most of the research, accident relief or preventing measures are not provided.
- A convenient BAC monitoring detection system has not proposed.

4 Novel Contributions

4.1 Our Vision of BACTmobile

BACTmobile H-CPS is a system that is proposed not only to monitor the BAC levels of the person but also to monitor vital signals in order to track and control the occurrences of accidents. The analysis of BAC levels is done by considering various multi-modal data like physiological, feature or facial data and behavioral data to analyze the mental health of the driver. The processed and analyzed data is securely transferred to the cloud for storage purposes only. To maintain the credibility of the driver, privacy assured data is transferred to the response management unit upon need. The private and secure data transfer and the working of the BACTmobile H-CPS in IoT Framework is represented in Figure 3.

Table 1 State-of-the-art Literature to Monitor BAC Levels.

Research Work	Feature Data Used	Drawback
Li, et al. [41]	Only Physiological - Temperature and Humidity sensors	System is semi automatic. This requires human input and mobile phone for the user to know the BAC levels. Does not avoid driving under influence and occurrence of accidents.
Jayoung, et al. [35]	Only Physiological - Excessive sweating is considered	System is semi automatic. Requires mobile phone for the user to know the BAC levels. Does not avoid driving under influence and occurrence of accidents.
Chen, et al. [24]	Only Physiological - Heart rate and respiration rate	No system is proposed. Does not avoid driving under influence and occurrence of accidents.
Azizan, et al. [7]	Heart rate, biometric fingerprint	System is not automatic. Requires external person for the user to know the BAC levels. Does not avoid driving under influence and occurrence of accidents.

Table 2 Overview of Alcohol Level Trackers.

Product	Type	Technology used	Drawback
WrisTAS [30]	Wearable	Uses transdermal alcohol sensor	Does not account mulpile features. Does not help in eliminating accidents.
BACtrack SKYN [9]	Wearable	Touch sensor	It is not applicable for road accident eliminations.
Proof [34]	Wearable	Skin sensor	It may be an inconvenience to users and it does not work to reduce accidents.
Vive [68]	Wearable	Skin Sensor	User may still drive even if he is above BAC level.
BAC track [8]	Non-wearable	Breathe analyzer	Does not account multiple sensors and features.
Floome [28]	Non-wearable	Breathe analyzer	User can still decide to drive.
Breeze [15]	Non-Wearable	Breathe analyzer	Requires third person's assistance and does not eliminate the occurrences of accidents.
Lapka [40]	Non-wearable	Breathe analyzer	Does not avoid driving and occurrence of accidents.

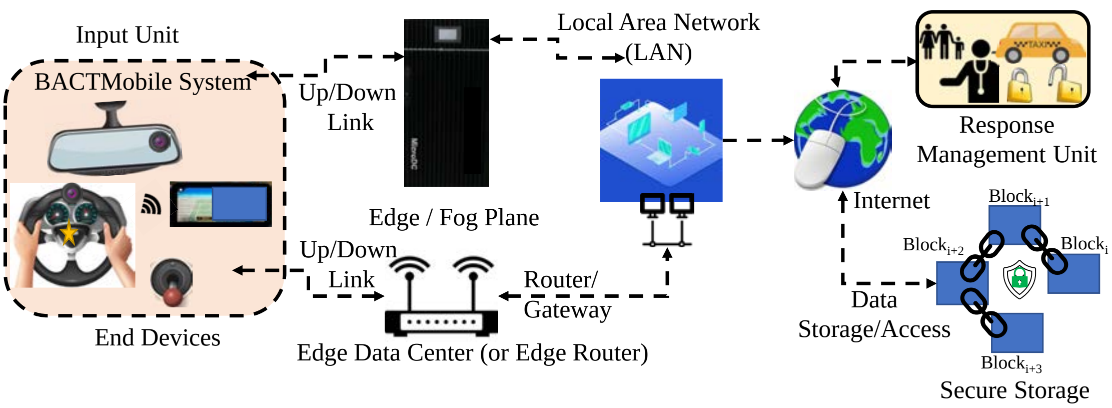


Fig. 3 BACTmobile System in Internet-of-Things (IoT) based Healthcare Cyber-Physical System (H-CPS) Framework.

4.2 Broad Perspective of the Proposed Solution through BACTmobile

As the BACTmobile is mainly targeted to be deployed in compact spaces like cars, the form factor of the proposed system is important. To maintain a good form factor, there is a need for a wireless system model which can ensure decoupling of the sensing layer and edge layer physically. Hence, both wired and wireless models are designed for BACTmobile H-CPS to monitor BAC levels.

In the proposed wired model for BACTmobile, all the required sensing elements or the input data centers (as shown in Figure 2) are assumed to have a direct physical connection to the multi-modal data processing unit where the gathered data is processed, analyzed to check for BAC levels and possible fluctuations in vital signals.

In the proposed wireless model for the BACTmobile, as the connections form the input data centers to the multi-modal data processing units are assumed to have a non-physical connection, secondary data processing units with wireless data sharing capabilities are required to gather or process the data for a specific type. This gathered and processed data is sent to a primary data processing unit where the analysis of BAC is performed. Secure data transfers from the input data units to the processing units are performed.

The potential applications of the proposed BACTmobile H-CPS are as follows:

- Automatic continuous monitoring of various physiological, and facial parameter variations during the complete driving period with no user activation.
- A method which educates the users to fully attain and understand the importance of road safety.
- A system capable of detecting BAC levels along with the mental state of the driver without the need of an external officer or person.
- Automatic accident preventing mechanisms while driving.
- Monitoring vitals throughout the long distant driving period to monitor any abnormalities.
- A system capable of contacting for help without the need for the driver to ask for it upon need.
- An approach which has the capability to establish a relationship between the various physiological, facial and behavioral parameters to BAC levels.
- A system that provides a tamper proof single truth data source to share or exchange information when needed
- An interface capable of communicating with the driver to analyze the mental behavior.
- Processing the information or data on an edge device while secure data storage is done in the cloud.
- Allowing the driver to understand the underlining factors of distracted driving which also include stress.
- A system with single and compact solution which has the potential to connect or be in any network.
- A system with real-time data sharing with resource constrained edge devices.

4.3 Novel Contributions of BACTmobile

The novel contributions proposed through BACTmobile are:

- A system which performs automated multi-modal, multi-data, continuous monitoring of the physiological, facial, and psychological parameters throughout the driving period of the driver to accurately analyze the mental state and the driving ability.
- A non-invasive, automatic real-time monitoring system which is activated when the ignition starts.
- A response system using psychological parameter analysis to eradicate false positive cases.
- A device which enables two-way communication when needed.
- A system that proposes a battery-operated wearable device which recharges while the engine is working.
- A novel method to propose a system that monitors the vital signals and can analyze the stress levels and other emotions associated with stress of older adult drivers, which may lead to accidents.
- A system which gives an option for the driver to contact for help or family or other means of transport through the IoT, using the infotainment as the interface.
- A system that not only does continuous location detection and tracking but also shares that to the nearest emergency in case of an accident.
- An advanced method which doesn't require 2nd or 3rd person's involvement.
- A system that detects the exact BAC with 5 intervals in order to provide a detailed understanding to the driver.
- A system that promises both in-network and out-of-network privacy assured secure data transfer throughout the driving period.
- A system using a novel algorithm which is focused in obtaining high throughput, reliability and low power usage to establish a secure connection among entities.

5 Impact of Alcohol and its Analysis for BACTmobile

While chronic alcohol consumption can lead to anemia, cancer, cardiovascular diseases, dementia, depression, seizures, gout, nerve damage, liver damage, pancreatitis, etc., [61], the impacts of alcohol on specific physiological, physical and behavioral aspects of the human body are discussed in the following section.

5.1 Impact of Alcohol on Physiological Parameters

Along with the impact of alcohol on the human body organs, alcohol consumption also induces changes to physiological parameters. Some of the physiological parameters that are most affected are:

1. Heart Rate Variability: Increased and regular consumption of alcohol causes weakened heart muscle and irregular heartbeats [51]. Heavy drinking also causes episodes of tachycardia, which is also known as increased heart rate. Complications of such frequent episodes may lead to blood clots which can cause heart strokes [17].
2. Blood Pressure: Alcohol consumption on a single occasion can cause increased blood pressure and regular consumption of alcohol leads to hypertension [37]. High blood pressure can cause thickening and hardening arteries which may cause heart strokes [33].
3. Blood Sugar Levels: Alcohol consumption on a single occasion may cause blood sugar to rise but excess alcohol consumption decreases the blood sugar levels. This drastic and sudden drop in sugar levels can cause severe effects which may also lead to unconsciousness [25].
4. Blood Oxygen Saturation content: Severe alcohol consumption can disrupt the absorption of oxygen by hemoglobin which may lead to low blood oxygen levels which leads to unconsciousness [14].
5. Temperature: Alcohol consumption on a single occasion increases the temperature making the face and body warm. Regular and excessive consumption of alcohol causes the body temperature to drop, which may lead to severe health conditions [47].
6. Respiration Rate: Excessive consumption of alcohol leads to discomfort in breathing. This may increase the rate of breathing and also makes it heavy [38].
7. Electrodermal Activity: Excessive consumption of alcohol can increase the sweat excretion also known as hyperhidrosis, which causes dehydration [10].

5.2 Impact of Alcohol on Physical Behavior

Alcohol can have both short-term and long-term negative effects on the eyes. There is a significant change in the eyes, and the parameters related to eyes like eye redness, pupil diameter, eye movement, etc. Mathematical approaches have been implemented in [4] and [16] in order to establish the relationship among the blood alcohol concentration and eye parameters. Some of the parameters which help in determining sobriety are:

1. Pupil Diameter (PD): Alcohol consumption relaxes all muscles in the body including the iris muscles, thereby dilating the pupils. This dilation increases the diameter of the pupils [20].
2. Eye Redness (ER): Due to the pupil dilation and vessel expansion in the eyes, eye redness is experienced when alcohol is consumed [46].
3. Facial Sweat (SE): Alcohol consumption brings the heart rate up and widens the blood vessels. This causes the skin to feel warm and flushed which releases sweat [10].
4. Facial Bloating (FB): Alcohol causes water retention in the face. This makes the face look puffy and bloated [31].
5. Eye Movement (EM): Alcohol consumption causes a loss of coordination between the eyes and the brain. This compromised functionality of receiving and sending messages from brain to eyes, leads to involuntary eye movement or a jerking motion by the eyes [58].

5.3 Impact of Alcohol on Cognitive Thinking for Psychological Behavior

Due to the impact on brain chemicals, alcohol affects mental health, overall mood and daily functioning of a human being. Excessive consumption can lead to stress disorders, anxiety and depression [57]. Some of the parameters that are most affected are:

1. Critical Thinking (CT): Excessive and regular consumption of alcohol causes memory fog and affects the critical thinking of human beings. Studies show that students who do not consume alcohol have better grade point averages when compared to students who do [12].
2. Concentration and Focus (CF): Alcohol consumption causes disorganization and confusion which make it hard to focus on any particular activity. Due to preoccupation, the person loses the ability to concentrate and thus can be distracted from the task at hand [59].

3. Memory Power (MP): Alcohol affects shot-term memory as it slows down the communication between nerves. Excessive consumption of alcohol causes long-term memory loses as it affects the brain structure itself [43].
4. Body Coordination (BC): Over consumption of alcohol affects the brain's chemicals and causes it to lose coordination with other body organs [59].

6 Proposed IoMT-Based Feature Extraction for Automated Blood Alcohol Concentration Monitoring in BACTmobile

Most of the parameters from Section 5 have been used in BACTmobile to establish a relationship between BAC and bodily parameters. The BAC classification in BACTmobile is divided to five levels - sober to non-sober. This relationship between the physiological, physical and cognitive behaviors to BAC are discussed in this section.

6.1 Proposed Blood Alcohol Concentration Levels for BACTmobile

BAC is defined as the percentage of alcohol present in a human being's blood stream. The number of drinks, amount of time in which they are consumed, body weight, age, and sex are among the various factors that are considered in calculating BAC. In most of the states in the USA, it is considered illegal if a person is under influence or intoxicated with an alcohol concentration of 0.08% or higher. For commercial motor vehicles, the limit is 0.04% [39]. Considering these factors, a five level classification of BAC is proposed in BACTmobile. The levels start from sober, i.e., 0% to non-sober, i.e., 0.08%.

6.2 Relationship between Physiological Signals and Blood Alcohol Concentration

The physiological features which are considered in BACTmobile are Heart Rate (HR), Body Temperature (BT), Respiration Rate (RR), Blood Pressure (BP), Blood Oxygen Saturation (SpO2) and Sweat Excretion (SE). The resting heart-rate of the human body is 60-90 bpm [5]. For an intoxicated person, the resting heart rate is observed over 100-105bpm leading to an episode of tachycardia [17]. The normal body temperature of a human being is considered as 97-99°F [29]. When a person is intoxicated, the body temperature can drop below 95°F [47]. Resting respiration rate for adults is from 12 to 20 breaths per minute. For a drunk person, resting respiration ranges of <8 and >20 is considered abnormal [38]. Blood pressure is considered normal when systolic pressure is less than 120 and a diastolic pressure is less than 80. For a frequent drinking person, the systolic pressure between 120 and 140 with a diastolic pressure lf greater than 80 to 90 is considered elevated [67]. The normal blood oxygen concentration in a human body is considered in the range of 95 to 100%. For a drunk person, the observed blood oxygen levels are less than 93% and if the levels are less than 88%, then they are considered to be dangerously low [62]. Facial and palm sweat are two features that are considered in BACTmobile. These parameters vary and there is a observed excretion when a person is drunk [10].

6.3 Relationship between Physical Behavior (Body Language) and Blood Alcohol Concentration

For BAC analyses, along with the features mentioned in Section 5.2, Forehead Frown (FF) and Excessive Smile (ES) are also considered. The normal pupil diameter in adults varies from 2-4 mm in bright daylight to 4-8 mm in the dark [44]. When drunk, the ability of the pupils to react to light is reduced and so the adapting capability to changing light conditions deteriorates [32]. In addition, a dilation in the size of pupil is noted when drunk [16]. When intoxicated, alcohol dilates the blood vessels in the eyes and so there is a noted change in eye redness [21]. Excessive alcohol consumption leads to facial and palm sweat along with night sweat [10]. As alcohol consumption dehydrates the human body, facial and stomach bloating are commonly observed [31]. Normal eye movement ranges were $44.9 \pm 7.2°$ in addiction, $27.9 \pm 7.6°$ in elevation and $47.1 \pm 8.0°$ in depression [42]. It is noted that a regular person moves eyes three times a second, over 100,000 times each day [50]. When a person is drunk, an involuntary rapid eye movement is detected [58]. Frequent consumption of alcohol changes the person's mood and stress levels. These emotions are also observed on the face of the person. Frequent frowning of forehead and excessive smiling are two of the features that are used in BACTmobile for BAC analyses [19].

6.4 Relationship between Cognitive Thinking and Blood Alcohol Concentration

In BACTmobile, a new approach of detecting BAC and sobriety of the driver is developed. This new approach uses cognitive thinking parameters such as memory, brain-body coordination, critical thinking, concentration and focus. Alcohol induced blackouts are caused due to over consumption of alcohol which may lead to loss of memory, losing the capability to make rational decisions and sometimes unconsciousness [69]. Studies indicate that when a driver is drunk, he/she tends to focus on a single, often central point, for longer periods of time, neglecting other important peripheral zones thus limiting the visual activity and concentration capabilities [27, 59]. Motor skills such as eye, hand and foot coordination are affected when a person is heavily drunk. Such crucial body noncompliance can lead to severe accidents [26, 64].

7 Proposed Multi-Modal Data Modeling for Automatic Parameter Processing for Blood Alcohol Concentration Level Tracking in BACTmobile

7.1 Detailed Block Level Representation of the Proposed Multi-Modal Data Flow in BACTmobile

The various multi-modal data, i.e., the physiological, physical behavior or facial analysis data, vital data, and cognitive thinking analysis data are collected and are fed to a Tiny Deep Neural Network (DNN) model. The vision analysis is taken from continuous monitoring of the driver using images and videos. This vision data is automatically processed in the DNN model by following object classification, detection and tracking mechanisms, as explained later in Section 7.3. All the data are analyzed for BAC levels and mental health stability. Depending upon the need, help is provided to the driver as, shown in Figure 4.

7.2 Modeling Physiological and Vital Data for Edge Platform

From the end devices, all the physiological, physical behavior and psychological or cognitive data is collected through the assigned data centers, as shown in Figure 2. All the raw physiological and vital data are obtained. This obtained data is pre-processed by boundary conditioning it. This pre-processed data is fed to the DNN model which also has visual data for physical behavior analysis. Here, the considered parameters are compared with the baseline, which is assumed to be taken during the vehicle's initial orientation. Any changes or sudden fluctuations to the baseline are detected and monitored through out the driving process. If there is a change detected, BAC levels are analyzed and depending upon the level of BAC, psychological data is required from the driver. Finally, the mental health, physical health and sobriety of the driver are analyzed and are sent to the help units upon need, as represented in Figure 5.

7.3 Modeling Physical Behavior Data for Edge Platform

Physical behavior analyses in BACTmobile consider visual data either of images or videos. The facial parameters as mentioned in Section 6.3 are considered as features here. After the collection of all the required data, the data is processed using graphical annotation tools. This processed data allows the model to select the detected human as target for continuous movement and behavior tracking throughout the driving process. The selected features are analyzed in the DNN models that are deployed and the BAC levels are detected, as explained in Section 8. For this detection, the physiological and vital data are also considered to obtain an accurate detection. If the levels are abnormal, then the cognitive thinking analyses is performed and the sobriety of the driver along with the mental health of the driver are determined, as shown in Figure 6.

7.4 Modeling Cognitive Thinking Data for Edge Platform

Once the processed physiological, visual, and vital data are analyzed to detect the BAC levels, if the detected BAC levels are abnormal or not sober, then to eliminate the false positive conditions, a simple cognitive thinking capability test is conducted to the driver. The driver is asked with a simple questionnaire which comprises of image and non-image related questions. These questions vary from choosing the car that the person owns from a list of images, asking the user's name, simple mathematical questions and these solutions are compared with the previously gathered solutions which are assumed to be taken during the vehicle's initial orientation. If these solutions match, then the user is considered sober. In addition, the driver has options to call a cab or help or emergency services through the infotainment, as needed in required situations, as shown in Figure 7.

8 Proposed Training Methodology for Automatic Data Processing in Wired and Wireless Approaches designed for BACTmobile

A model is a relationship between the parameters or features to the labels or classes. Here, the physiological, physical behavior are the features and classes of

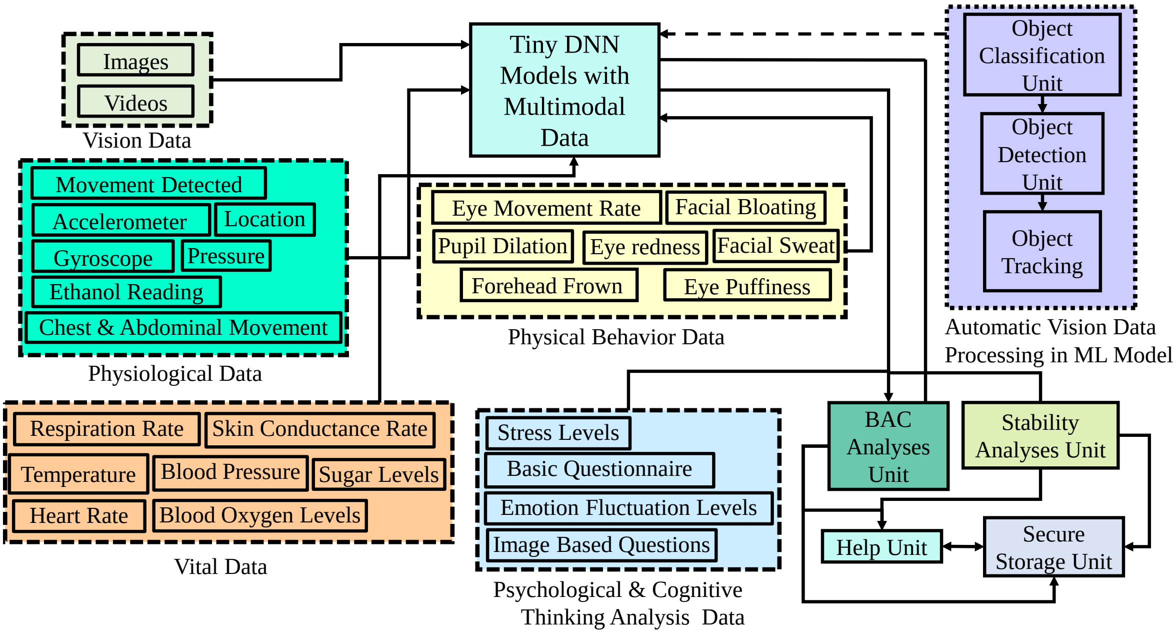


Fig. 4 Block Level Representation of the Proposed Multi-Modal Data in BACTmobile H-CPS.

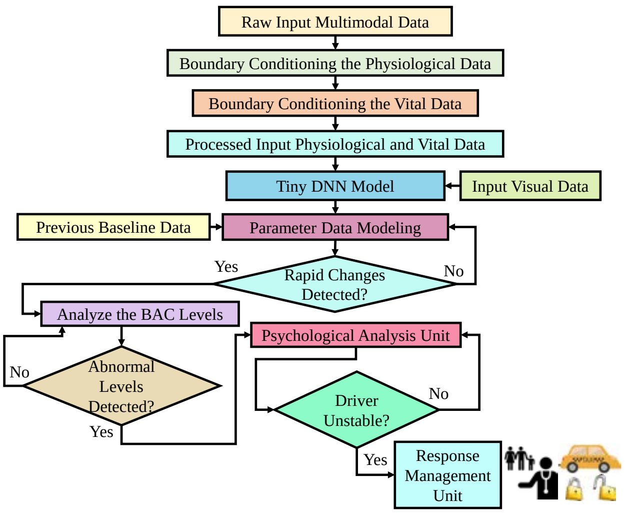


Fig. 5 Proposed Automatic Flow of Physiological and Vital Data in BACTmobile H-CPS System.

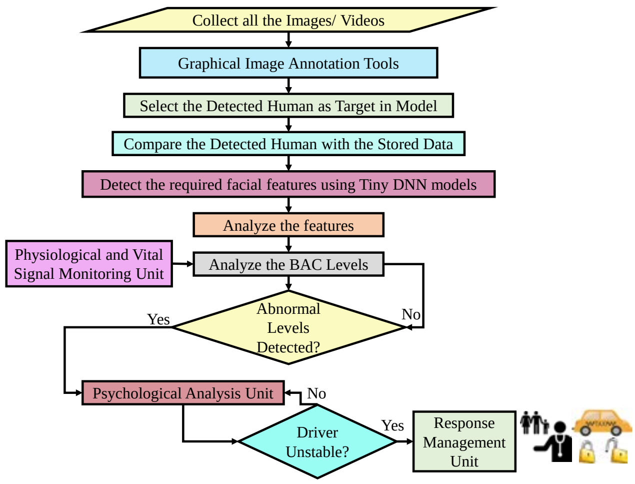


Fig. 6 Process of Vision Data Analysis Proposed in BACTmobile H-CP System.

BAC levels are labels. As there are various data types as parameters, in BACTmobile Deep Neural Networks (DNN) are used. Any neural network consists of neurons, otherwise called as processors in its hidden layers. The neurons from the inner layers are activated by the weighted connections from the previously activated neurons as, represented in Equation 1.

$$z(X) = \sum_{i=1}^{N}(\omega_i x_i + \omega_o), \tag{1}$$

where $X = x_1, x_2, \cdots, x_n$ is the n-dimensional input, z is the response of the neuron, ω_i are the weights for each input and ω_o is a constant bias. If a neural network has more than three hidden layers, then it is considered as a deep neural network. There are various types of neural networks like Fully Connected NN (FCNN), Convolution NN (CNN), Single Shot Detector (SSD), etc., with different types of activation functions such as logistic, Rectified Linear (re-Lu), soft-max, etc. In the output layer that produces the predictions, the neurons and hidden layers can be chosen at random [18].

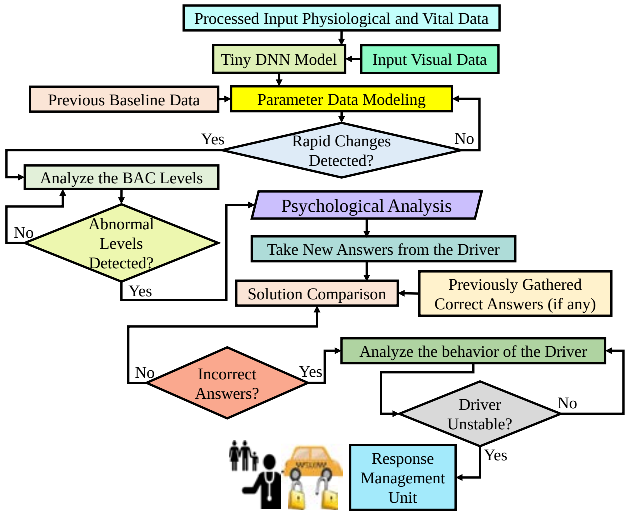


Fig. 7 Proposed Automatic Flow of Cognitive Thinking Data in BACTmobile H-CP System.

8.1 Proposed Machine Learning Model for Physiological Data Processing

A Fully Connected Neural Network (FCNN) or a dense network has been deployed in BACTmobile. Here, all the neurons in each layer are connected to every neuron from the previous layer. A supervised Learning methodology with Logistic Regression is used as a classifier in the deployed DNN model. The designed model has one input layer with 6 neurons which comprise of the sensor output, followed by five hidden layers with 20 neurons each and one output layer to determine the BAC class prediction with 5 neurons, as BACTmobile classifies BAC levels to five as represented in Figure 8.

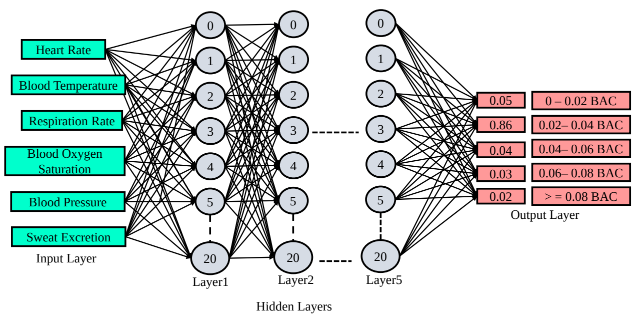


Fig. 8 Tiny DNN for Physiological Data Modeling.

From Equation 1, a net weight is calculated which is given as an input to the activation functions as shown in Equation 2. These functions are used to determine the output shape of each node in the layers. The hidden layers are activated using Rectified Linear function as shown in Equation 3. Given a layer i and its values $(x)_i$, the next layer j with values $(h)_j$ can be derived by:

$$h_j = f((W)_{j,i} \cdot (x)_i + (b)_{j,i}), \tag{2}$$

where $(W)_{j,i}$ is the weight matrix, and $(b)_{j,i}$ the bias. f is the Rectified Linear Unit (ReLU) activation function:

$$f(x) = \begin{cases} 1 & x > 1 \\ x & x = 1 \quad \text{and} \quad 0 \\ 0 & x < 0 \end{cases} \tag{3}$$

The output layer which provides inference or predictions, uses the soft-max function as its activation function as shown in Equation 4:

$$p = \text{softmax}(\omega \cdot x + b), \tag{4}$$

where ω, p, and b denote weight, predictor function and bias, respectively.

The physiological DNN model is a classification problem and the training is performed using the supervised learning mechanism where the model is trained from examples that contain labels. The training loop for the physiological data modeling is represented in Algorithm 1.

Algorithm 1: Process of Supervised Learning Training for Physiological Data in BACTmobile

---

1: Define number of iterations.
2: Iterate each iteration or epoch.
3: Within every epoch, iterate over each example from the training dataset by grabbing the features which are the physiological data and labels which are the BAC level classes.
4: From the above step, a prediction is made. Calculate the inaccuracy of the prediction.
5: Calculate the model's loss and accuracy.
6: Update the model's variables using gradient descent algorithm.
7: Update the loss and accuracy accumulators.
8: *Repeat the above steps for all the examples in the dataset.*

8.2 Proposed Machine Learning Model for Physical Data Processing

For the image and video data processing, also known as physical behavior processing in BACTmobile, an SSD-MobileNet-V2 model is deployed. A Single-Shot Multibox Detection (SSD) framework captures only one shot to detect multiple objects present in an image using the multibox algorithm. SSD predicts the boundary boxes from the images and establishes a relationship between the physical behavior parameters and the BAC classes.

This uses MobileNet-v2 which is a Convolutional Neural Network with 53 layers deep to make predictions [3]. The architecture of the SSD framework with respect to BACTmobile is represented in Figure 9.

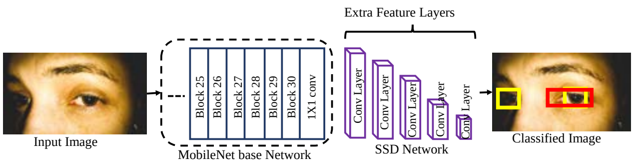


Fig. 9 Tiny DNN for Physical Data Modeling.

The process of training and obtaining the classification along with detection of objects from the images is explained in Algorithm 2.

Algorithm 2: Process of Object Detection and Classification

1: Collect all the images which are used for training the model and to test the learning capabilities of the model.
2: With the usage of graphical annotation tools, create bounding boxes over the specific objects for all the images from the collected dataset.
3: Using the same, the format for the images from JPEG is converted to XML.
4: Priors, which are also known as multiple bounding boxes for the specific features are created using the annotation tool.
5: All the dimensions of priors are made equal using box-coder.
6: A mandatory step to make sure all the matched and unmatched thresholds for matching the ground truth boxes for priors is set using the concept of Intersection Over Union (IOU) as represented in Figure 10.
7: Using resize or reshape functions, the XML format images are made equal in size.
8: Every image which is sent to the model is assigned to a feature map by using convolutional and rectified linear functions.
9: The objects of the images which are sent to regression or convolution are detected through bounding boxes in the images based on the feature map created from the step above.
10: *For every and all the images in the dataset, the above steps are repeated.*

As mentioned above, SSD uses Intersection Over Union (IOU) (also known as Jaccard overlap) to identify the matches of the images from the feature map. Any predicted bounding box which has an IOU overlap of 0.5 or greater with the ground truth bounding boxes, as shown in Equation 5, is considered to be a match for making a prediction, as shown in Figure 10 [3]:

$$IOU = \text{Area of Overlap}/\text{Area of Union} \tag{5}$$

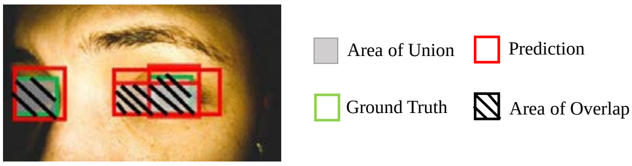


Fig. 10 IOU Illustration considered in BACTmobile.

8.3 Metrics for the Proposed Machine Learning Models in BACTmobile

In order to analyze the performance of the model, metrics are evaluated. The basic metrics to understand the model's evaluation, TP, TN, FP, and FN are taken [53] and defined as:

– True Positive (TP): A correct detection. This occurs when the IOU is greater than or equal to the set threshold value (0.5).
– False Positive (FP): A wrong detection. This occurs when the IOU is less than the set threshold value.
– False Negative (FN): This occurs when a ground truth is not detected.
– True Negative (TN): This is the possible outcome where the model correctly predicts the ground false. This is not considered in object detection classifiers because there are many possible bounding boxes that should not be detected within an image.

8.3.1 Precision

The ability of a model to classify only the relevant examples from the considered dataset is known as its precision (P):

$$P = \left(\frac{TP}{TP + FP} \times 100\%\right). \tag{6}$$

8.3.2 Recall

The ability of a model to classify all the relevant examples from the predicted relevant examples is called recall (R):

$$R = \left(\frac{TP}{TP + FN} \times 100\%\right). \tag{7}$$

8.3.3 Classification Accuracy

The accuracy of a model can be defined as the ratio of correct predictions made by the model to all the predictions made by the model:

$$\alpha = \left(\frac{TP + TN}{TP + TN + FN + FP}\right) \times 100\%. \tag{8}$$

8.3.4 Confusion Matrix

A summary of prediction results on a classification problem as deployed in BACTmobile can be considered as a confusion matrix. The number of correct and incorrect predictions are summarized with count values and are assigned to each class in this matrix. As the name suggests, this matrix will show if the deployed model is confused in the process of making predictions, as shown in Section 10.2.1.

8.3.5 Confidence Interval

The metric that defines the confidence of the proposed model while making predictions is known as the Confidence Interval and is defined in Equation 9:

$$CI = error \pm z\sqrt{\left(\frac{(error \cdot (1 - error))}{n}\right)}, \tag{9}$$

where n is the sample size, $error$ is the confidence error and z is a critical value from the normal distribution.

9 Proposed Secure Data Storage and Access in BACTmobile System

In BACTmobile, as data is shared and exchanged through a network, blockchain technology is used. The blockchain can be simply defined as data structure which has hash connected blocks of data and provides certain characteristics like immutability, security and distributed data architecture. From the advent of the blockchain application Bitcoin [48] as financial solution to remove centralized authorities, it has shown many potential applications in various fields like healthcare [6, 53], agriculture [11, 65], and finance [22].

Any data tampering during the information exchange can cause serious problems in misdiagnosis of the situation which can lead to adverse problems. Hence, a secure data storage and access model is presented in the current BACTmobile implementation. To maintain the data integrity and prevent data tampering, the blockchain can be the solution. As adopting a full blockchain in such a resource constrained IoT environment is difficult, Proof-of-Authentication (PoAh) lightweight consensus based blockchain is adopted instead of the computationally intensive Proof-of-Work (PoW). The microprocessor which determines the BAC levels is considered to be a part of the network and is assumed to act like a client node in the proposed blockchain. A client program running in the edge node will help the client node to generate data transactions and send it to the network. Proposed data upload and access mechanisms to and from the blockchain is given in the following three algorithms.

At the beginning, every new node which wants to participate in the BACTmobile network has to register. During the registration process, the edge node which is responsible for performing the multi-modal analysis will use the cryptography library of python to generate RSA public and private keys for ensuring access of information only to the intended parties. Once the public key PvK_N and private key $P\gamma K_N$ are generated, these are persisted in the file system of the edge node for using while transactions. The registering node method is called with the node's MAC address, a randomly generated source id (SID), the port number on which the client application is running along with the public key generated in the previous step, as parameters. This function will iterate through each existing node and update the node list of existing nodes with the newly added node N. Once all existing nodes are updated with the new node information, a copy of this node list from the existing node will also be copied to the newly added node to allow the discovery of other existing nodes by the new node. Along with that the chain information is also copied to the new node N during the initialization/registration phase. The registration process of a new node is shown in Algorithm 3.

Once the edge node performs multi-modal analyses, the processed information along with all the physiological data is grouped into a transaction which is then encrypted using the public key of the destination node to prevent exposure of data to entire network. This encrypted transaction data is then hashed and a digital signature is generated using the private key of the edge node. This acts as a primary authentication mechanism that allows to check the integrity and non-repudiation of the generated transaction. The digital signature generated will be appended to the transaction hash, MACID and destination node ID before publishing to the network. The published transaction is then added to the pool of unconfirmed transactions at each node until a trusted node based on the trust value threshold is chosen to perform the consensus mechanism. This chosen trusted node will then pick the transaction from the unconfirmed pool and generate a hash of the encrypted transaction data to get computed hash. As the public key of every node is available to the network during the registration phase, the trusted node will be aware of the public key of the source's edge node. The trusted node makes use of this edge node public key to decrypt the digital signature to find the hash generated by the edge node. The trusted node then compares both the computed and decrypted hash

Algorithm 3: Proposed Node Registration Algorithm for BACTmobile.

Require: Every Edge node will have their MACID and assigned Source ID which acts as an identification for that device and their own generated Private ($P\gamma K$) and Public keys(PvK).Port number (Port$_{num}$) at which the client node is running.

for Every New Node N **do**
  Generate Unique Source ID (SID) randomly which is unique to this node
  RSA Public key (PvK_N) and Private Keys ($P\gamma K_N$) are generated for Node N using cryptography library of Python
  Private Key for Node N $P\gamma K_N \leftarrow$ rsa.generateNewKey(public exponent, key size)
  Public Key for Node N $PvK_N \leftarrow$ $P\gamma K_N$.getPublicKey()
  RSA keys are persisted in file system of the edge node
  Public key file $\leftarrow$ writePublicKey(PvK_N, fileName)
  Private key file $\leftarrow$ writePrivateKey($P\gamma K_N$, fileName)
  Register new node and broadcast it to all existing nodes
  registerAndBroadcastNode(Port$_{num}$,MACID,SID,PvK_N)
  for Each Existing Node N$_i$ **do**
    Update Node list with new node
    Node List NodeList$_i$ $\leftarrow$ NodeList$_i$.append(Node$_N$(Port$_{num}$,MACID,SID,PvK_N))
  end for
  NodeList$_N$ $\leftarrow$ getNodeListOfExistingNodes()
  Run Consensus and copy the longest acceptable chain to new node N
  Chain for Node N Chain$_N$ $\leftarrow$ getLongestAcceptedChain()
  Return SID
end for

to check the integrity of the message and make sure the edge node is the real owner of the transaction. Once the hash matches, the MACID is checked for secondary authentication. In a final step after MACID matches, a proof-of-authentication random nonce is generated and appended to the transaction metadata and a new block is added to the chain before sending it to the rest of the network. This data upload mechanism is explained in Algorithm 4.

Finally, data access for the proposed BACTmobile secure storage solution is presented in Algorithm 5. In this step the published block is checked for the destination ID. The node whose source ID matches with the destination ID will read its own private key from the file system. This private key is used to decrypt the transaction information present in the block. The decrypted transaction information is used to get the parameters and BAC classes information to the destination.

Algorithm 4: Proposed Data Upload Algorithm for BACTmobile.

Require: Results and Metadata from Edge node after performing multi-modal analysis on sensory physiological data. Every edge node has their own Private ($P\gamma K_e$) and Public keys(PvK_e).

for Every time interval t$_i$ **do**
  A data transaction Trx is created by an edge node client (e) with processed information I_e and Blood Alcohol Concentration β_e value from analysis.
  $Trx \leftarrow createTransaction(I_e, \beta_e)$
  Metadata with car identification number along with driver details is appended to the Transaction Block
  $Trx \leftarrow Trx.append(Metadata)$
  Trx is encrypted with public key of the destination node (PvK_d) for providing data privacy.
  $Trx^+ \leftarrow Trx.encrypt(PvK_d)$
  Each Transaction Block is signed by the private key of the edge node e
  $D_{sign} \leftarrow P\gamma K_e(SHA-256(Trx^+))$
  MAC address of the source edge node e is added for secondary authentication.
  Block $B_e \leftarrow Trx^+.appendHeader(D_{sign}, MAC)$
  Generated Block B_e is broadcast to the network of nodes
  Transaction is added to unconfirmed transaction pool and waits for trusted node to perform consensus steps
  A trusted node (V) is selected from the list of nodes $< List > nodes$ with trust value greater than threshold (θ)
  Trusted node V verify digital signature using public key of the source node
  $DecryptedMessageHash(MD_{dec}) \leftarrow$ Decrypt(D_{sign},PvK_e)
  $ComputedMessageHash(MD_{com}) \leftarrow$ $SHA-256(receivedtransaction(Trx^+))$
  if $MD_{dec} == MD_{com}$ **then**
    Check MACID with MACID from node list of the verifying node for secondary authentication
    if B_e.MACID == NodeListOfVerifyingNode.getMACID(B_e.SID) **then**
      Generate Proof-of-Authentication random nonce and append to block before publishing to network
      Remove transaction from unconfirmed transaction pool
    else
      Discard the block
      Remove transaction from unconfirmed transaction pool
    end if
  else
    Discard the block
    Remove transaction from unconfirmed transaction pool
  end if
end for

10 Implementation and Validation of BACTmobile

10.1 Implementation of BACTmobile Data Processing using Off-The-Shelf Components

For the physiological data processing in BACTmobile, the TensorFlow Keras API has been used. A linear stack

Algorithm 5: Proposed Data Access Algorithm for BACTmobile

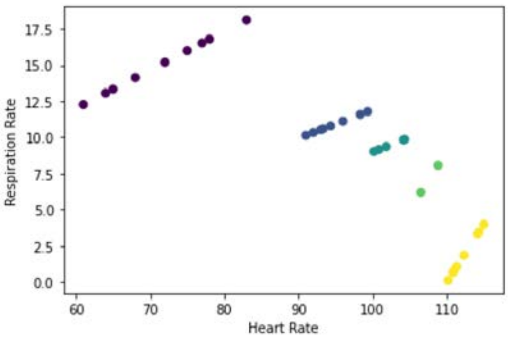
```
Require: Destination node has its own public key PvK_d)
    and private key PγK_d
while Every new block added to chain do
    Checks if destination id in block is same as the source
    id of the node
    if B_e.DID == currentNode.SID then
        Decrypt the transaction data in block to get the
        physiological and Blood Alcohol concentration data
        Trx+ ← B_e.Trx+
        Read private key from the key file
        PγK_d ← readPrivateKey(fileName)
        Trx ← cryptography.decrypt(Trx+, PγK_d)
        Processed information I_e and Blood Alcohol
        Concentration β_e are extracted from transaction
        information
        (I_e, β_e) ← Trx.getInformation
    end if
end while
```

model with t.keras.Sequential is used to create a dense model with tf.keras.layers.Dense with 5 hidden layers with 20 neurons each, 1 input layer with 6 neurons and 1 output layer with 5 neurons for BAC level classification. A total of 25,000 sample data out of which 20,000 samples were used for training the model and 5000 were used to test the model based on the baseline information available from Section 7.2.

The parameter scattering plot with Respiration Rate and Heart Rate is represented along with the initial predictions before training the model with a larger number of epochs, as shown in Figure 11.

```
Prediction: [4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4]
Labels: [0. 3. 4. 1. 1. 2. 0. 3. 3. 3. 0. 2. 1. 4. 4. 0. 0. 1. 0. 3. 0. 1. 2.
4.1. 1. 3. 0. 4. 1. 3. 0.]
```

(a) Prediction and Labels before Training



(b) Scattered Plot of Heart Rate and Respiration Rate

Fig. 11 Data Visualization before Training BACTmobile Model.

tf.keras.losses.SparseCategoricalCrossentropy determines the accumulated loss throughout the training process. With this, the initial loss of the model before the training was 13.075. With stochastic gradient descent algorithm called as the optimizer and by using the function, tf.keras.optimizers.SGD and learning rate of 0.01, this model has been optimized. With the number of epochs or iterations set to 401 and the batch size of 32, the observed loss and accuracy for a difference of 50 in epoch, along with the loss and accuracy plots for 400 epochs is shown in Figure 12.

When the trained model is tested with 5,000 data samples, the test set accuracy obtained was 100%.

For the physical behavior data analyses, the TensorFlow Object Detection API has been used. As BACTmobile is deployed in the edge, TensorFlow Lite is also deployed on a Single Board Computer (SBC). This complete setup along with the node (for physiological data processing) is represented in Figure 13.

As TF Lite does not support RCNN models, SSD-MobileNet is used. For the execution to be deployed on SBC, first the model has been trained with the API, as explained with the steps from Algorithm 2. The frozen inference graph obtained here is then exported to TensorFlow Lite which is compatible with mobile and edge devices. The model has been trained with 1,500 images and the classification of BAC levels is done based on the literature from Section 7.3. [2] is considered for the initial implementation in [54] which is also taken into consideration in BACTmobile, with eye bags as one of the additional features. Out of these, 1,200 images are used for training while 300 are used for testing.

The object classification for TensorFlow and TensorFlow Lite implementation on the SBC is represented in Figure 14.

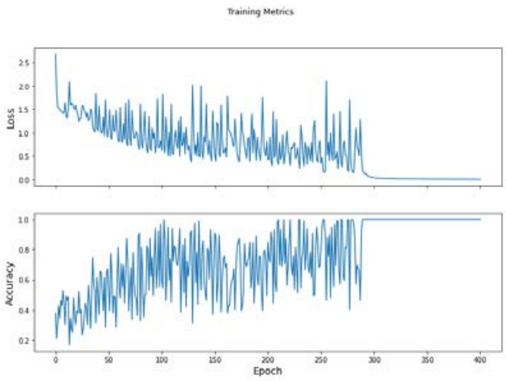
For the Cognitive Thinking Data analyses, the user is requested to enter some information to check the mental state of the driver and to eliminate any minute chances of having a false positive case. For this, the infotainment in the car is used as an input source. A Graphical User Interface (GUI) with App Analyzer in MATLAB is used to prototype BACTmobile's vision. This GUI has a basic questionnaire to be answered by the user, along with a display of the current location and a capability to call for help as represented in Figure 15.

10.2 Implementation of BACTmobile Data Privacy and Storage using Off-The-Shelf Components

The proposed Proof-of-Authentication based blockchain is implemented using an SBC with the Broadcom BCM2711B0 as System-on-Chip (SoC) which has a powerful processing core of quad-core A72 operating at 1.5GHz clock

Epoch 000: Loss: 2.682, Accuracy: 37.815%
Epoch 050: Loss: 1.087, Accuracy: 53.782%
Epoch 100: Loss: 0.615, Accuracy: 59.664%
Epoch 150: Loss: 0.513, Accuracy: 90.756%
Epoch 200: Loss: 0.426, Accuracy: 84.874%
Epoch 250: Loss: 0.349, Accuracy: 80.672%
Epoch 300: Loss: 0.036, Accuracy: 100.000%
Epoch 350: Loss: 0.006, Accuracy: 100.000%
Epoch 400: Loss: 0.003, Accuracy: 100.000%

(a) Epochs and its Loss and Accuracy



(b) Accumulated Loss and Accuracy Plot

Fig. 12 Data Visualization after Training BACTmobile Model.

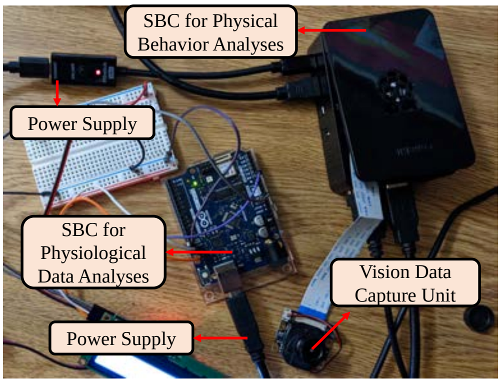
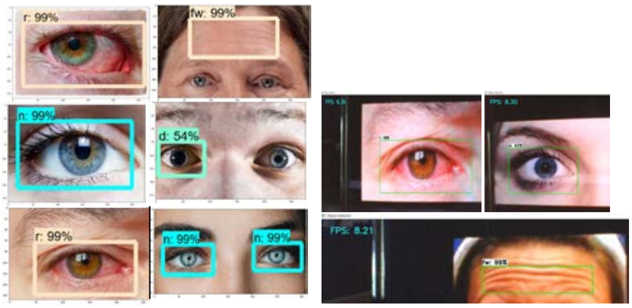
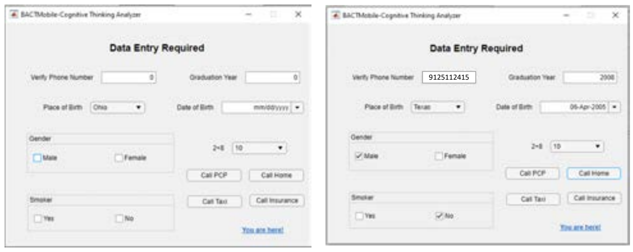


Fig. 13 Physiological and Physical Behavior Analyses on SBC in BACTmobile.



(a) TensorFlow Result (b) TensorFlow Lite Results on SBC

Fig. 14 Object Detection in BACTmobile Model.



(a) Infotainment Input (b) Infotainment Output after Selection

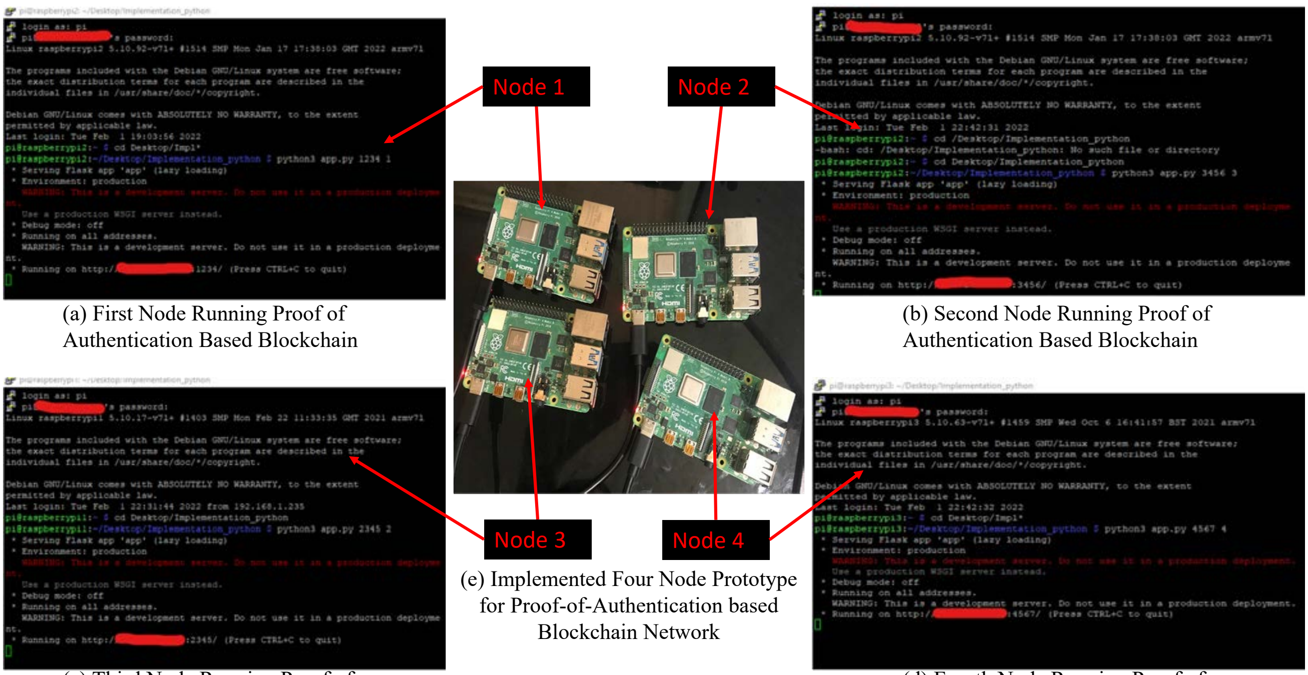
Fig. 15 Infotainment Prototype in BACTmobile Model.

and 4GB of LPDDR4 SDRAM. These nodes are responsible for processing the parameters and perform multi-modal analysis to determine the BAC level and the driver stability classification. This edge node will also act as the client node in the blockchain running client program to interact and perform its operations. Each node in the network is uniquely identified by using a randomly generated ID called source ID and has its own RSA public and private keys with key size of 2048 bits. The implemented 4-node prototype is shown in Figure 16.

A block structure as shown in Figure 17 is adapted in the implemented blockchain solution and consists of a block header and body, where the header consists of source and destination information along with the required information to verify the integrity of the blockchain (hashlink), transaction (digital signature) and nonce generated from the Proof-of-Authentication consensus mechanism. Generating the block for each field which is described in Table 3.

During the registration process Source ID, Node URL and MACID are shared with the network. Once the node registration request is sent, the source node is added to all the nodes in the network and all the network nodes will be added to the peers of the current requested node. As an example, the registration of the fourth node into the network is shown in Figure 18. APIs are provided in the implemented blockchain solution to perform different operations by a peer node in the network.

The generation of a new transaction and mining is explained in Figure 19 which shows the transaction created by the second node and sharing the data to the fourth node in the network. During the transaction



(a) First Node Running Proof of Authentication Based Blockchain

(b) Second Node Running Proof of Authentication Based Blockchain

(e) Implemented Four Node Prototype for Proof-of-Authentication based Blockchain Network

(c) Third Node Running Proof of Authentication Based Blockchain

(d) Fourth Node Running Proof of Authentication Based Blockchain

Fig. 16 Implemented Proof-of-Authentication based Blockchain Network For Secure Data Storage and Access in BACTmobile.

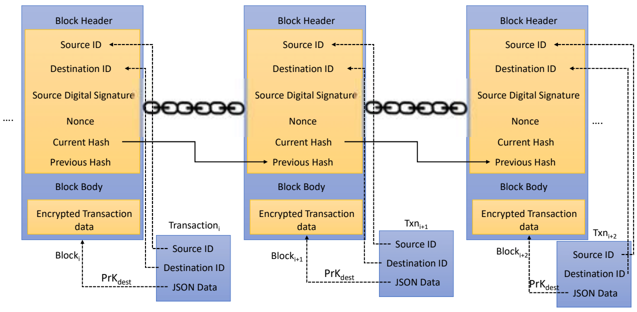


Fig. 17 Block Structure of Implemented Proof-of-Authentication based Blockchain in BACTmobile.

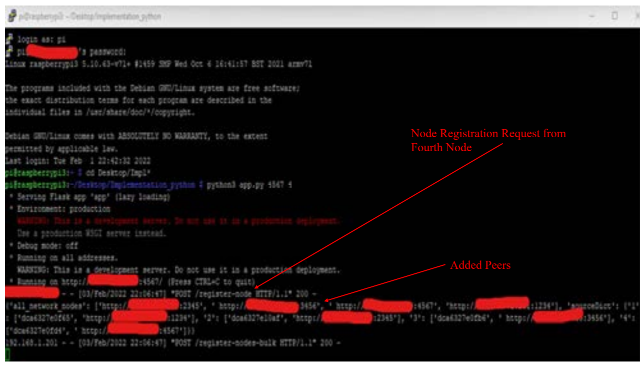
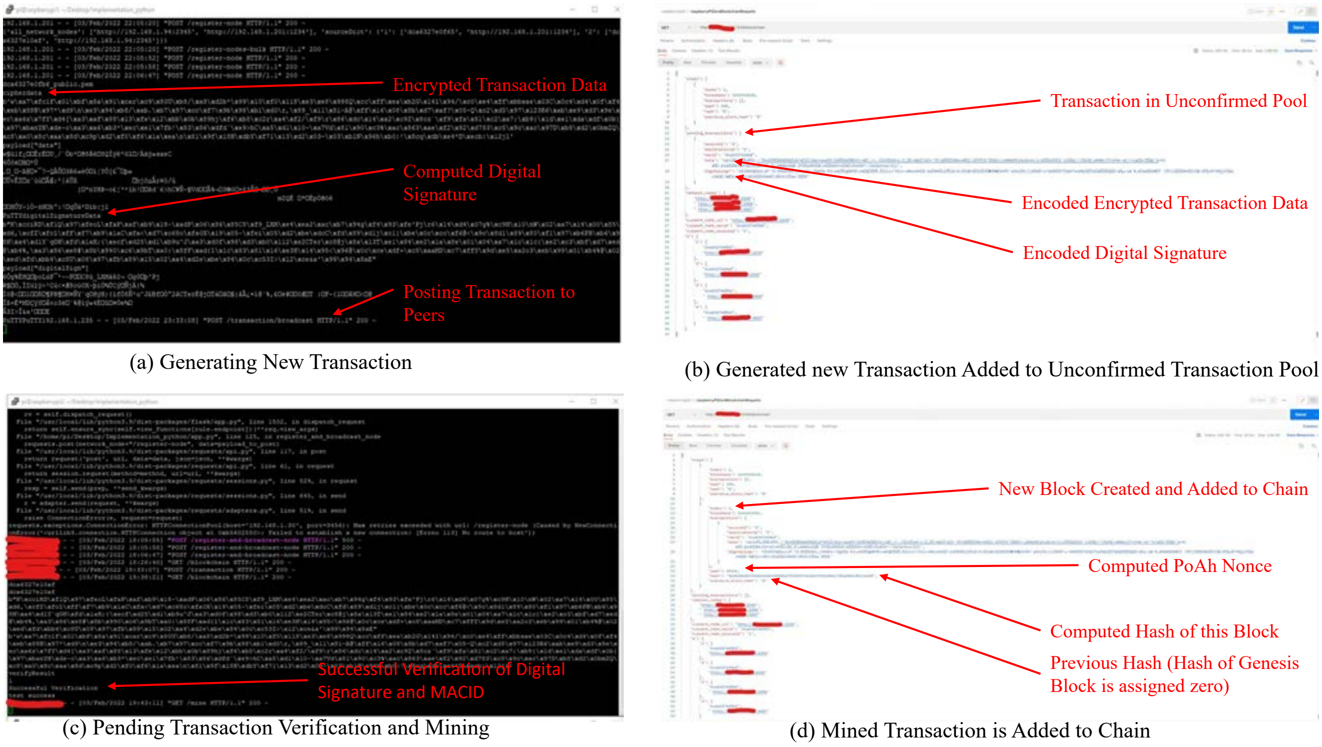


Fig. 18 Node Registration Request from Fourth Node Showing Added Peers

creation the data is encrypted using the public key of the destination so that data cannot be accessed by the other nodes in network. A digital signature is also computed and appended to the transaction which can help in verifying the integrity of the data when transmitted through the network. Once the transaction is created, it will be added to the unconfirmed pool and is available to all the peer nodes in the network. A trusted node is chosen based on trust value and a miner is selected among the peer nodes. The elected mining node will then perform the mining process. In this case the first node was chosen as miner because of the default trust value given and the transaction is mined after successful verification of the digital signature and MACID. Once the mining process is done, a new block is generated and added to the chain.

To access the data securely from the network, the destination node requires a private key. The destination node will traverse through the blocks generated and filter based on the destination ID. Once the transactions are filtered, the transaction data is decrypted using the private key to access the data. As the other peers in the network are unaware of the destination node's private key, they will not be able to access the encrypted data. Secure Data Accessing is represented through Figure 20.



(a) Generating New Transaction

(b) Generated new Transaction Added to Unconfirmed Transaction Pool

(c) Pending Transaction Verification and Mining

(d) Mined Transaction is Added to Chain

Fig. 19 Transaction Creation and Mining Process in Implemented BACTmobile Network

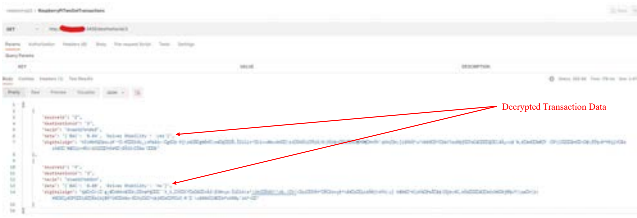
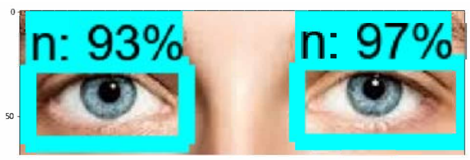


Fig. 20 Secure Data Access by Destination Node in Implemented BACTmobile Network



(a) Validation for Physical Data

Ex0 [100, 98.25, 6.285, 3.0, 92.568, 1.00,],	Example 0 prediction: <=0.04 (100.0%)
Ex1 [98.254, 104.25, 9.858, 0.00, 94.584, 1.00,],	Example 1 prediction: <=0.02 (100.0%)
Ex2 [72.584, 100.25, 11.254, 2.00, 96.254, 0.00,],	Example 2 prediction: Sober (100.0%)
Ex3 [99.457, 97.152, 8.7854, 4.00, 86.45, 1.00,],	Example 3 prediction: <=0.04 (84.1%)
Ex4 [114.875, 104.96, 1.254, 4.00, 87.256, 1.00]	Example 4 prediction: >=0.08 (100.0%)

(b) Validation for Physiological Data

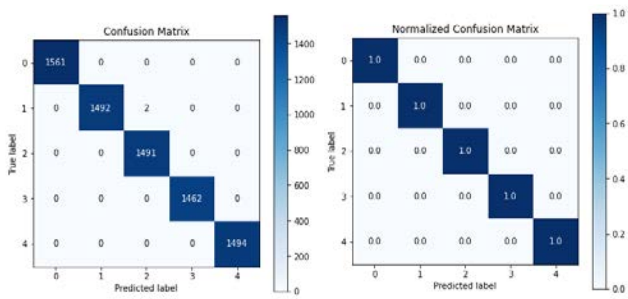
Fig. 21 Validation of the Proposed ML Models in BACTmobile.

10.2.1 Validation of Automated Blood Alcohol Concentration Monitoring for BACTmobile

For the validation of the models proposed in BACTmobile, unlabeled data, i.e., the data that is not used in either training and testing phases of the model is used as an input to the models. If the model could still classify with high accuracy, then the model is considered efficient. This implementation with unlabeled data as input is represented in Figure 21.

A confusion matrix determines how confused the model was while predicting the classes depending upon the input parameters. The regular and the normalized confusion matrix from the model are as shown in Figure 22. From this, the BACTmobile models were only confused twice for 1,491 samples of data.

From the above validations, it is evident that the ML models proposed in BACTmobile are highly effi-



(a) Confusion Matrix

(b) Normalized Confusion Matrix

Fig. 22 Confusion Matrix of the Proposed ML Models in BACTmobile.

Table 3 Block Fields and Their Description in Implemented Proof-of-Authentication based Blockchain Network.

Field	Description
Source ID	Unique to a node in the network and acts as an identifier
Destination ID	Source ID of destination node to which the transaction data is sent
Digital Signature	Digital signature generated by private key of the source node and used to determine the integrity of the transaction when transmitted in network
Nonce	Randomly generated whole number during proof-of-authentication process and appended to the block generated by miner
Current Hash	SHA-256 hash computed for the current transaction which helps in verifying the data included in generated block
Previous Hash	Acts as link between the generated blocks to form blockchain structure
Encrypted Transaction Data	Data being sent securely from source to Destination, can be accessed only after decrypting using destination private key.

cient and produce an accuracy of approximately 99%. The precision and recall are approximately 99% from Equations 6 and 7. The characteristics of the BACTmobile System are stated in Table 4.

Table 4 Characteristics of BACTmobile

Characteristics	Specifics
Data Analysis Tool	TensorFlow, TensorFlow Lite
Classifier	FCNN, SSD-MobileNet
BAC Level classification	5
Training Dataset	21200
Testing Dataset	5300
Accuracy	99%
Classification Error	0.02
Confidence Interval	0.02 +/- 0.0088

10.3 Validation of Secure Storage and Access

The multi-modal data used for BAC classification which is shared in the network is sensitive. Hence, the proposed secure storage and access mechanism is analyzed for different security threats to determine its effectiveness.

Threat 1: An adversary node has entered into the network and is trying to send a transaction with manipulated data.
Solution: When a transaction is created, the source node which is responsible for generating this transaction should encrypt the data with the destination public key and also include a digital signature using the private key of the source, according to the proposed implementation. As the private key is is only known to the source node, an adversary will not be able to regenerate a digital signature with the manipulated data. Hence, when the miner verifies the digital signature, it will discard the manipulated transaction and this transaction will not be included in the block.

Threat 2: An adversary is trying to perform an unauthorized access of data from the proposed BACTmobile Blockchain.
Solution: Whenever a transaction is sent by the source, the transaction data is encrypted using the public key of the destination node. This data can only be accessed after being decrypted using the private key of the destination node. As the adversary or any other node will not have access to the private key of the destination node, accessing the encrypted data is not possible. Hence, the proposed method is robust to such kind of attacks.

Threat 3: An adversary is listening to the network data and is trying to retrieve data from eavesdropped messages.
Solution: All the data that is being shared in the network is encrypted by the source node using the public key of the destination node. Hence, the data is always encrypted while traveling in the network and is decrypted only by the destination node. Therefore, even if the adversary node gains access to these messages, without the aid of the private key of destination, no data can retrieved.

From the performed security analysis on the proposed secure storage and access for the BACTmobile, it is evident that this is robust and secure to all the common network attacks which could be performed by the adversary. As the BACTmobile application is time sensitive, performance analysis of proposed system requires to measure how fast the transactions are being processed. To measure the average time taken for each operation, 50 transactions are created and mined, and node registration times along with transaction creation and mining times are recorded for each transaction and the average of the times is computed to get the average time for different operations. Transaction time to retrieve the data is also evaluated andthe average time to access the data is also measured as shown in Table 5..

Table 5 Average Time for Each Operation Performed in Implemented Proof-of-Authentication Based Storage and Access for BACTmobile

Operation Performed	Average Operation Time (ms)
Node Registration and Broadcasting	447
Transaction Creation and Broadcasting	645.5
Mining New Block	434.3
Accessing Data From Chai	220

From this analysis, the time taken for each transaction mining is nearly 434.3 ms, which is significantly lower when compared with well established blockchain platforms like Ethereum, where each block is generated for every 12 to 14 seconds. The creation of a transaction has shown significantly high operation times as the source has to compute the digital signature and encrypt the data. From this analysis, it is evident the proposed system is fast and can process the transactions in near real-time.

Throughput is other important factor that needs to be measured for analyzing the scalability of the proposed system as there can be many vehicles who can try to participate in the network. This load test is performed using jmeter to send 1,000 transactions from 100 different nodes within a short span of 10 seconds to determine the throughput and average response time from each node. The average response time of each node is 2,533.01 ms when 100 nodes simultaneously try to send a transaction to a single node, as shown in Figure 23. The throughput of each node (SBC) is measured to be 16.67 transactions/second which is sufficient, as in the proposed model of BACTmobile the edge node is going to monitor only once every 5-10 seconds thereby creating a new transaction.

10.4 Comparison of BACTmobile with State-of-the-art

Table 6 provides a tabular comparison of the proposed BACTmobile system with existing state-of-the-art solutions.

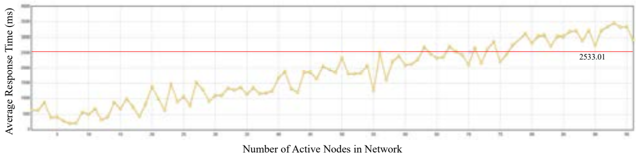


Fig. 23 Average Response Time Of Node Measured By Gradually Increasing Number Of Active Nodes trying To Send A Transaction

11 Conclusions and Future Research

The impact of alcohol consumption is severe on the functionality of a human being. Basic skills like driving and thinking are affected by the intake. In order to eliminate the occurrences of accidents under influence, Machine Learning based fully automated processing models has been proposed. These models accept various Multi-Modal data and generate predictions with the BAC classes. A total of 26,500 sample data is used for training and testing the models. The models produced very high accuracy of approximately 99%. Secure data storage and data access along with data sharing has been implemented. Thus, the phrase “Smart-Life” is given context through the BACTmobile Healthcare Cyber-Physical System.

Along with increasing the scope and expanding the domain, adding more features and making the process simpler and user friendly can be one of our future research directions.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and there was no human or animal testing or participation involved in this research. All data were obtained from public domain sources.

References

1. Al-Youif, S., Ali, M.A.M., Mohammed, M.N.: Alcohol detection for car locking system. In: IEEE Symposium on Computer Applications Industrial Electronics (ISCAIE), pp. 230–233 (2018)
2. Alberti, M.: ”3 Glasses Later,”. Online (2015). URL https://www.masmorrastudio.com/wine-project. Last Accessed on 06 Feb 2022
3. Arabi, S., Ketabchi Haghighat, A., Sharma, A.: A deep learning based solution for construction equipment detection: from development to deployment. Machine Learning (2019)
4. Arora, S.S., Vatsa, M., Singh, R., Jain, A.: Iris recognition under alcohol influence: A preliminary study. In: 2012 5th IAPR International Conference on Biometrics (ICB), pp. 336–341 (2012). DOI 10.1109/ICB.2012.6199829

Table 6 Comparison of BACTmobile with State-of-the-art Literature to Monitor BAC Levels

Research Work	Device Prototype?	Wearable or Non-Wearable?	Sensors	Number of Features	Automated Processing?	ML Model Used	Security and Privacy	Accuracy
Li, et al. [41]	No	NA	Temperature and Humidity	3	No	No	No	NA
Jayoung, et al. [35]	Yes- tattoo sensor	Wearable	Iontophoretic System	2	No	No	No	NA
Chen, et al. [24]	No	Wearable	Heart Rate and Respiration Rate	5	No	No	No	96.6%
Azizan, et al. [7]	No	Non wearable	Heart rate, biometric fingerprint	3	No	No	No	NA.
Aschbacher, et al. [36]	No	No	Breathe Analyzer	1	No	Yes	No	NA
Rachakonda, et al. [56]	Yes - a steering	Non wearable	Heart Rate, Temperature, Respiration and Blood Pressure	4	Yes	No	No	93%
Rachakondal, et al. [54]	Yes - Steering and Rear Mirror	Non wearable	Blood Pressure, Pupil Dilation and Eye redness	3	Yes	Yes - FCNN	No	95%
BACTmobile (Current Paper)	Yes	Non wearable	Heart Rate, Blood Pressure, Respiration, Humidity, SpO2	13	Automated Processing in Model	Yes - FCNN, SSD-MobileNet	Yes - Blockchain	99%

5. Avram, R., Tison, G.H., Aschbacher, K., Kuhar, P., Vittinghoff, E., Butzner, M., Runge, R., Wu, N., Pletcher, M.J., Marcus, G.M., Olgin, J.: Real-world heart rate norms in the Health eHeart study. NPJ digital medicine **2**(58), 1–10 (2019)
6. Azaria, A., Ekblaw, A., Vieira, T., Lippman, A.: MedRec: Using Blockchain for Medical Data Access and Permission Management. In: In Proc. 2nd International Conference on Open and Big Data (OBD) (2016). DOI 10.1109/obd.2016.11
7. Azizan, M.A., Rohismadi, A., Norhashim, N., Norizan, N.: Development of User Interface (UI) and User Experience (UX) for Smart Alcohol Detection System in Public Transportation. In: Human-Centered Technology for a Better Tomorrow, pp. 453–463 (2022)
8. BACtrack: Smartphone Breathalyzers (2018). URL https://www.bactrack.com/collections/smartphone-breathalyzers. Last Accessed on 06 Feb 2022
9. BACtrackSKYN: BACtrackSKYN (2018). URL https://www.bactrack.com/pages/bactrack-skyn-wearable-alcohol-monitor. Mobile application, Last Accessed on 06 Feb 2022
10. Baker, L.B.: Physiology of sweat gland function: The roles of sweating and sweat composition in human health. Temperature (Austin) **6**(3), 211–259. (2019)
11. Bapatla, A.K., Mohanty, S.P., Kougianos, E.: sFarm: A Distributed Ledger based Remote Crop Monitoring System for Smart Farming. In: 4th IFIP International Internet of Things (IoT) Conference (IFIP-IoT) (2021)
12. Bekman, N.M., Anderson, K.G., Trim, R.S., Metrik, J., Diulio, A.R., Myers, M.G., Brown, S.A.: Thinking and drinking: alcohol-related cognitions across stages of adolescent alcohol involvement. Psychology of addictive behaviors : journal of the Society of Psychologists in Addictive Behaviors **25**(3), 415–425 (2011)
13. Bhumkar, S., Deotare, V.V., Babar, R.V.: Intelligent Car System for Accident Prevention Using ARM-7. In: Semantic Scholar (2012)
14. Borne, P., Mark, A.L., Mion, N., Somers, V.K.: Effects of Alcohol on Sympathetic Activity, Hemodynamics, and Chemoreflex Sensitivity. Hypertension **29**(6), 1278–1283 (1997)
15. Breathometer: Breeze. URL https://www.brookstone.com/pd/breathometerthe-smart-breathalyzer/886606p.html. Last Accessed on 06 Feb 2022

16. Brown, B., Adams, A.J., Haegerstrom-Portnoy, G., Jones, R.T., Flom, M.C.: Pupil size after use of marijuana and alcohol. Am J Ophthalmol. **3**(83), 350–4 (1977)
17. Buckman, J.F., Eddie, D., Vaschillo, E.G., Vaschillo, B., Garcia, A., Bates, M.E.: Immediate and Complex Cardiovascular Adaptation to an Acute Alcohol Dose. Alcohol Clin Exp Res. **39**(12), 2334–44 (2015)
18. Canziani, A., Paszke, A., Culurciello, E.: An Analysis of Deep Neural Network Models for Practical Applications. Computer Vision and Pattern Recognition (CoRR) **abs/1605.07678** (2016). URL http://arxiv.org/abs/1605.07678
19. Capito, E.S., Lautenbacher, S., Horn-Hofmann, C.: Acute alcohol effects on facial expressions of emotions in social drinkers: a systematic review. Psychol Res Behav Manag. **10**(1), 369–385 (2017)
20. Castro, J.J., Pozo, A.M., Rubino, M., Anera, R.G., Jiménez Del Barco, L.: Retinal-image quality and night-vision performance after alcohol consumption. J Ophthalmol **70**(4), 823 (2014)
21. Centers, A.A.: Signs of Drug Use in the Eyes: Pupil Dilation and Redness. Online (2019). URL https://americanaddictioncenters.org/health-complications-addiction/signs-drug-use-eyes. Last Accessed on 06 Feb 2022
22. Chen, B., Tan, Z., Fang, W.: Blockchain-Based Implementation for Financial Product Management. In: International Telecommunication Networks and Applications Conference (ITNAC) (2018). DOI 10.1109/atnac.2018.8615246
23. Chen, Y., Lin, C., Lin, Y., Zhao, C.: Non-invasive detection of alcohol concentration based on photoplethysmogram signals. IET Image Processing **12**(2), 188–193 (2018)
24. Chen, Y., Xue, M., Zhang, J., Ou, R., Zhang, Q., Kuang, P.: DetectDUI: An In-Car Detection System for Drink Driving and BACs. IEEE/ACM Transactions on Networking pp. 1–15 (2021). DOI 10.1109/TNET.2021.3125950
25. Emanuele, N.V., Swade, T.F., Emanuele M., A.: Consequences of alcohol use in diabetics. Alcohol Health Res World **22**(3), 211–219 (1998)
26. ePermitTest: The Physiology of Intoxicated Driving: Vision, Motor Skills and Reaction Time. Online (2020). URL https://www.epermittest.com/drivers-education/physiology-intoxicated-driving. Last Accessed on 06 Feb 2022
27. Firm, N.L.: Effects on Operating a vehicle. Online. URL https://www.nysdwi.com/dui-foundation/drunkdriving/impairment/operating/. Last Accessed on 06 Feb 2022
28. Floome: Floome (2018). URL https://www.floome.com/. Mobile application, Last Accessed on 06 Feb 2022
29. Geneva, I.I., Cuzzo, B., Fazili, T., Javaid, W.: Normal Body Temperature: A Systematic Review. Open Forum Infect Dis. **6**(4), 0–32 (2019)
30. GinerLabs: WrisTAS (2018). URL https://www.ginerinc.com/wrist-transdermal-alcohol-sensor. Last Accessed on 06 Feb 2022
31. Goodman, G.D., Kaufman, J., Day, D., Weiss, R., Kawata, A.K., Garcia, J.K., Santangelo, S., Gallagher, C.J.: Impact of Smoking and Alcohol Use on Facial Aging in Women: Results of a Large Multinational, Multiracial, Cross-sectional Survey. The Journal of clinical and aesthetic dermatology **12**(8), 28–39 (2019)
32. Gupta, N., Lata, H., Kaur, A.: Effect of glare on night time driving in alcoholic versus non-alcoholic professional drivers. . Int J Appl Basic Med Res., PubMed **2**(2), 128–31 (2012)
33. Husain, K., Ansari, R.A., Ferder, L.: Alcohol-induced hypertension: Mechanism and prevention. . World J Cardiol. **6**(5), 245–252 (2014)
34. Indiegogo: PROOF-Alcohol Tracking Wearable. URL https://www.indiegogo.com/projects/proof-alcohol-tracking-wearable/. Last Accessed on 06 Feb 2022
35. Kim, J., Jeerapan, I., Imani, S., Cho, T.N., Bandodkar, A., Cinti, S., Mercier, P.P., Wang, J.: Noninvasive Alcohol Monitoring Using a Wearable Tattoo-Based Iontophoretic-Biosensing System. ACS Sensors **1**(8), 1011–1019 (2016)
36. Kirstin, A., H. Christian, S., Geoffrey, T., H. Judith, A., Robert, A., Jeffrey, M., Olgin, E., Gregory, M.: Machine learning prediction of blood alcohol concentration: a digital signature of smart-breathalyzer behavior. npj Digital Medicine **4**(1), 2398–6352 (2021)
37. Klatsky, A.L., Friedman, G.D., Siegelaub, A.B., Gérard, M.J.: Alcohol Consumption and Blood Pressure. New England Journal of Medicine **296**(21), 1194–1200 (1977). PMID: 854058
38. Krumpe, P.E., Cummiskey, J.M., Lillington, G.A.: Alcohol and the respiratory tract. Med Clin North Am **68**(1), 201–19 (1984)
39. Lange, J.E., Voas, R.B.: Defining binge drinking quantities through resulting blood alcohol concentrations. Psychology of Addictive Behaviors, **15**(4), 310–316. (2001)
40. Lapka: Breathe Alcohol Monitor. URL http://about.mylapka.com/bam/product/overview/. Last Accessed on 06 Feb 2022
41. Li, B., Downen, R.S., Dong, Q., Tran, N., LeSaux, M., Meltzer, A.C., Li, Z.: A Discreet Wearable IoT Sensor for Continuous Transdermal Alcohol Monitoring - Challenges and Opportunities. IEEE Sens J **21**(4), 5322–5330 (2021)
42. Lim, H.W., Song, Y., Kim, J.H., Shin, Y.U., Hwang, S.J., Hong, S.: Normal Range of Eye Movement and Its Relationship to Age. Investigative Ophthalmology and Visual Science **58**(8), 747–757 (2017)
43. Ling, J., Heffernan, T.M., Buchanan, T., Rodgers, J., Scholey, A.B., Parrott, A.C.: Effects of Alcohol on Subjective Ratings of Prospective and Everyday Memory Deficits. Alcohol Clin Exp Res **27**(6), 940–974 (2003)
44. Mathot, S.: Pupillometry: Psychology, Physiology, and Function. J Cogn **21**(1), 1–16 (2018)
45. Mohanty, S.P., Choppali, U., Kougianos, E.: Everything You wanted to Know about Smart Cities. IEEE Consumer Electronics Magazine **5**(3), 60–70 (2016)
46. Morten, S.M., Daniel, T., Morthen, M., Snieder, H., Jansonius, N., Utheim, T.P., Hammond, C.J., Vehof, J.: The relationship between alcohol consumption and dry eye. The Ocular Surface **21**, 87–95 (2021)
47. Myers, R.D.: Alcohol's effect on body temperature: hypothermia, hyperthermia or poikilothermia? Brain Res Bull. **7**(2), 209–220 (1981)
48. Nakamoto, S.: Bitcoin: A Peer-to-Peer Electronic Cash System. Cryptography Mailing list at https://metzdowd.com (2009)
49. Neal, D.J., Carey, K.B.: Association between alcohol intoxication and alcohol-related problems: an event-level analysis. Psychology of addictive behaviors : journal of the Society of Psychologists in Addictive Behaviors **21**(2), 194–204 (2007)
50. NPR: Looking At What The Eyes See. Webpage (2011). URL https://www.npr.org/2011/02/25/134059275/looking-at-what-the-eyes-see: :text=Transcript-,We move our eyes three times a,over 100,000 times each day. Last Accessed on 06 Feb 2022

51. Ping, S., Chen, Y., Guo, M., Yu, H.: Acute Effects Of Alcohol On Heart Rate Variability: Time-Related Changes and Gender Difference. Biomedical Engineering: Applications, Basis and Communications **26**, 1450048 (2014)
52. Preetham, D.A., Rohit, M.S., Ghontale, A.G., Priyadarsini, M.J.P.: Safety helmet with alcohol detection and theft control for bikers. In: International Conference on Intelligent Sustainable Systems (ICISS), pp. 668–673 (2017)
53. Rachakonda, L., Bapatla, A.K., Mohanty, S.P., Kougianos, E.: SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits. IEEE Transactions on Consumer Electronics **67**(1), 20–29 (2021)
54. Rachakonda, L., Mohanty, S.P., Kougianos, E.: DonotDUEye: An IoT Enabled Edge Device to Monitor Blood Alcohol Concentration from Eyes. IEEE International Symposium on Smart Electronic Systems (iSES) (Formerly iNiS) pp. 87–92 (2019)
55. Rachakonda, L., Mohanty, S.P., Kougianos, E.: iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT. IEEE Transactions on Consumer Electronics **66**(2), 115–124 (2020)
56. Rachakonda, L., Mohanty, S.P., Kougianos, E., Sayeed, M.: Smart-Steering: An IoMT-Device to Monitor Blood Alcohol Concentration using Physiological Signals. In: 2020 IEEE International Conference on Consumer Electronics (ICCE), pp. 1–6 (2020)
57. Shivani, R., R. Jeffrey Goldsmith M., D., Robert M. Anthenelli, M.D.: Alcoholism and Psychiatric Disorders. Alcohol Research and Health **26**(2), 90–98 (2022)
58. Silva, J.B.S., Cristino, E.D., Almeida, N.L., Medeiros, P.C.B., Santos, N.A.D.: Effects of acute alcohol ingestion on eye movements and cognition: A double-blind, placebo-controlled study. PLoS One. **12**(10) (2017)
59. Sullivan, E.V., Harris, R.A., Pfefferbaum, A.: Alcohol's effects on brain and behavior. Alcohol research & health : the journal of the National Institute on Alcohol Abuse and Alcoholism **33**(1-2), 127–143 (2010)
60. Tapadar, S., Ray, S., Saha, H.N., Saha, A.K., Karlose, R.: Accident and alcohol detection in bluetooth enabled smart helmets for motorbikes. In: IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC), pp. 584–590 (2018)
61. Thomas, T., Porter, R.: An Essay, Medical, Philosophical, and Chemical on Drunkenness and its Effects on the Human Body (Psychology Revivals), 1 edn. Routledge (1988)
62. Toffaletti, J.G., Rackley, C.R.: Chapter Three - Monitoring Oxygen Status, *Advances in Clinical Chemistry*, vol. 77. Elsevier (2016)
63. Uzairue, S., Ighalo, Joshua, Matthews, V., Nwukor, Frances, Popoola, S.: IoT-Enabled Alcohol Detection System for Road Transportation Safety in Smart City. Computational Science and Its Applications pp. 695–704 (2018)
64. Van Dyke, N., Fillmore M., T.: Alcohol effects on simulated driving performance and self-perceptions of impairment in DUI offenders. Exp Clin Psychopharmacol **22**(6), 484–493 (2014)
65. Vangala, A., Das, A.K., Kumar, N., Alazab, M.: Smart Secure Sensing for IoT-Based Agriculture: Blockchain Perspective. IEEE Sensors Journal pp. 1–1 (2020)
66. Vardhman, R.: Car Accident Statistics in The U.S. – 2019 (Infographic). Web page (2019). URL https://carsurance.net/blog/car-accident-statistics/infographic. Last Accessed on 06 Feb 2022
67. Viera, A.J.: The New Normal Blood Pressure: What Are the Implications for Family Medicine? The Journal of the American Board of Family Medicine **20**(1), 45–51 (2007)
68. Vive: Vive. URL https://www.vive.com/eu/. Last Accessed on 06 Feb 2022
69. Wetherill, R.R., Fromme, K.: Alcohol-Induced Blackouts: A Review of Recent Clinical Research with Practical Implications and Recommendations for Future Studies. Alcohol Clin Exp Res. **40**(5), 922–935 (2016)