IoT Middleware Model for Time Sensitive Data: A Survey and Framework

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Abstract
Software like Internet of Things middleware will always indulge as an interface between components of the IoT, initially any components had not been designed to be connected with each other and will provide many services and functionalities that enable the integration, interoperability, and management of varied IoT devices, platforms, and applications. IoT platforms are also referred as IoT middleware. Communication middleware is the one component of IoT middleware and provide protocols and standard for data exchange. The enormous volume of information/data generated by IoT devices cannot be managed without IoT middleware. Various types of facts can be retrieved from IoT devices and time sensitive data is one of the very important type of data that needs to analysed keenly due to its versatile importance. In time-sensitive applications, perception of timing adopts another feather. The connected network has to assure bounded latency and jitter, along with real-time behaviour, well-defined as the capability to distribute the valuable data earlier a given timestamp, referred as deadline. As per metrological perspective every data essentially be sent before a given timestamp. Handling time-sensitive and exact dimensions is highly important and safety-critical applications can be easily managed.

Keywords: Time sensitive, Real-time data, IoT middleware, Time bound

1 INTRODUCTION

Middleware software is altered or transformed due to adjustments in the necessity of application, development, shortcomings alterations, and variation in atmosphere. Middleware software programs should accomplish the identical way as stated by the client after modifications are merged in software. With the rapid advancement in wireless technologies, a plethora of physical things (empowered with sensing and transmitting capabilities) are getting linked to the internet. A network of such things is termed as Internet of Things (IoT). The dissemination of IoT leads to multiple topologies, new knowledges, etc. like use novel protocol that can handle enormous requests, device integration mechanism for message passing, real time responses for efficient and automated system. Internet of things is extended version of internet where one can integrate multiple electronics, mechanical, civil, medical, etc gadgets or equipment that can connect with each other using internet. The said gadgets or equipment is referred as IoT devices that can be the part of internet of things. As size of IoT is growing so the number of IoT devices also increasing. All IoT devices are generating huge & different types of data and it is important to give attention to those data. We can get more meaningful information from those data. Some data need urgent attention as it may be real time data. Analysis of data is important and take action based on analysis of these generated data. Some data are time sensitive and some data are not. In this paper we will focus on data that needs to be take care within specific time. Time sensitive data may be hard or soft real time data, temporal data, time series data, etc. Time sensitive data may be generated by time sensitive IoT applications or any other. Each data will be generated by IoT devices that are connected with internet and we may incorporate timestamp for each generated data. For example, we can take example of accident on any highway. Data gathered from IoT devices installed on highway and from other cameras from different vehicles or from mobile recording if any on the road. Immediate information can be sent to all the mobile device users in the vehicles on Mumbai pune highway within 50ms time limit stating the reason of accident. All IoT devices will have diverse file format to store and generate data means heterogeneous data will be generated by IoT environment. Data analysis or conversion method should able to represent the heterogenous data into a single file setup so that the analysis can be done quicker. More time in data analysis is worthless because it leads to no impact on prevention of act [5]. It's all is dependent on IoT time sensitive framework. Edge computing is better than IoT and cloud is better than edge computing. The over-all data processing time is dependent on the location of data storage unit where the data analysis is executed at edge computing side or at cloud. The entire data communication time is dependent on concern network postponements involved in relocating IoT data to other resources. Edge computers can be installed at many places. Theses edge computers will act as gateway for IoT devices and data will be uploaded on cloud server. Edge computer should generate a common representation of IoT data and computations can be done if possible. Since very beginning the communication information enforces human actions. The information exchange between numerous devices like medical equipment, machines, alarms, etc through sensors, mobile phones, vehicles, industrial machines controllers and actuators becomes highly important. All types of sensors and all IoT devices send all information that they capture, it may include redundant data. Processing of these data is necessary to get data in desired format. Sending these data to the cloud additional data processing time and latency in communicating data to the cloud is required [6]. In time-sensitive data the dew computing will always play a vibrant role [7]. There is exponential growth in such IoT devices that is reaching tens of billions in 2023. 42.62 billions IoT devices, sensors, and actuators was used in 2022. A noteworthy growth from 30.73 to 35.82 billion during 2020 to 2021. This huge progress is foreseen to continue at full speed due to more IoT devices will be used in many new applications.

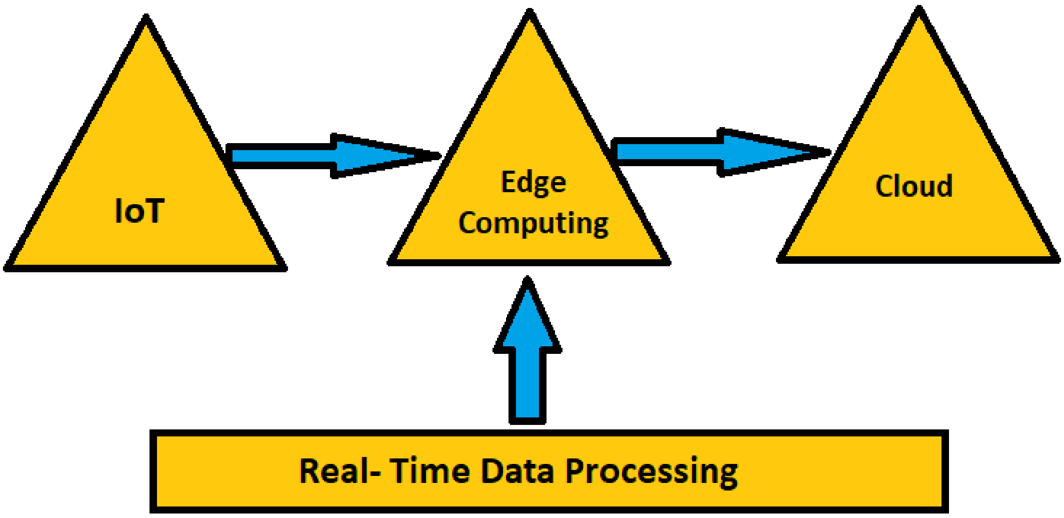

Fig. 1.1: Real time data processing for IoT data

A fast-rising amount and new diversity of IoT applications have been being familiarized around all sectors in the public sector as well as private sector to get appreciated insights by analysing the data generated by IoT devices. For time sensitive data if action will not be taken within specific time frame, then there is no use of that data after stipulated time. Vehicle accident prediction application, ICU maintenance application, Firefighting application, etc is a TS-IoT. All time sensitive IoT applications runs in heterogeneous distributed environment. As application is executed in heterogeneous environment so the IoT platform should be device independent and be able to handle time sensitive data.

Time sensitive applications should do following things within stipulated time frame:

1. From each IoT devices, the data should be collected.
2. Data should be categorized as time sensitive data or not

a. If time sensitive data, then respond within stipulated time. If not responded within stipulated time, then the performance of system will drastically degrade and the effectivity of application will also decrease exponentially.

b. If not time sensitive then act as per requirement.

2 SELECTIONS OF PAPER

The entire survey has been done from 2013 to 2023 related to time-sensitive IoT data. The selected research articles for the survey is based on the sensitivity of continuous data stream or triggered data either generated by IoT devices or any other devices. This paper studies the methods and tactics that are related to sensitivity of data generated by any type of IoT devices. The encouragement of presented review and the literature considered in it have been selected in keeping with their extensive scope in IoT arena. Numerous tools available for testing the algorithms, IoT applications and IoT frameworks. More than 352 papers have been collected for providing a broad review with multiple perspective. All collected papers were related to time sensitive, time series, synchronous and asynchronous, and triggered multimedia IoT data and other data. Out of these papers, 44 papers and 7 web resources have been selected for presented review, based on handling and managing of time sensitive data. Papers have been investigated in the key technical sources, such as IEEE, ACM, Science Direct, Springer, Wiley Databases, and MPDI.

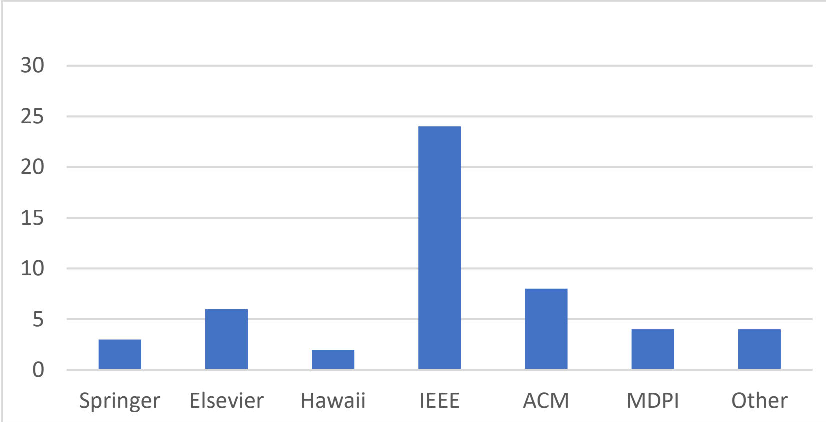

Fig. 2.1: Selected publications on Time sensitive data from IoT devices (2013-2023)

3 LITERATURE SURVEY

Standardization of TSN known as Time Sensitive Networking allow switched Ethernet with real time abilities was proposed by IEEE 802.1 Working Group [33]. This concept of real-time capabilities has been implemented to IoT environment. The concept of time-sensitive communications has hard real time necessities regarding latency and reliability, and asks complete synchronization of timing and timely transfer of data for all kind of applications related to real time [32]. Entire processing time of data and entire communication time of data will influence entire application execution time [3]. Location of resource is most important, from that data analysis should be performed will influence the data processing time. Edge computing play crucial role for time sensitive data. Response time is reduced using edge computing. The smart system (healthcare, traffic, etc.) comprises high quality camera, multiple types of sensors and controllers to store the hard and soft real-time signals of required data. A lot of real time data is generated by system so efficient storage techniques are required. A lot of data is time sensitive data and we need a specific mechanism known as edge computing to handle these time sensitive data [4]. Between the Mobile Edge Computing servers and the cloud computing server data processing and storage are harmonized. If the Mobile Edge Computing servers are idle then few data pre-processed otherwise, the data is automatically forwarded to servers of cloud computing [34]. Modifications in the middleware package is to be tested for authenticating its worth. The cost of middleware software development increases as the changes have been incorporated. A middleware was designed to handle the responsibilities of TS-IoT applications which will follow strict time bound requirement of the application [20]. Because of urgent requirement of many applications, time sensitive networking is in much demand [8]. IoT data analysis done by [16][17][18] but not considered time sensitiveness of application by following the time bounds. Distributed data processing of an IoT application can be evaluated by a real time IoT benchmark developed by researchers. Authors categorized four IoT benchmark and 27 common IoT tasks [19]. To efficiently distribute the tasks of TS-IoT application a framework has been designed for IoT devices and mid computing resources. Optimization techniques have been used by the framework to efficiently distribute the tasks [21]. Many tasks related to TS-IoT application is modelled as services across cloud data centres and mid computing resources will be found in an IoT framework which will mainly consider properties related to time. Problem of task distribution is formulated as an optimization problem modelled it as an INLP. Two greedy heuristics techniques (min-violation to minimize the violation of deadline and minimum cost to minimize the costs of communication, storage, deploying, and processing) was used to solve the optimization problem [22]. TIDA framework has been designed to meet the requirements of time-bound and time-sensitive IoT applications. A novel task sizing and dynamic distribution techniques was included in framework which will embraces a platform that implements techniques using Microsoft's Orleans framework [3][27]. An execution plan of task which meets the time-bounds requirement of an application was suggested by Harindu et.al. due to trade-off between IoT resources in distributed IoT environment to overcome with relevant communication delays. A resource model and application model were suggested to overcome with delays in communication between distributed IoT devices. Improved result found the time-bound violation ratio by 43.34% using dynamic task distribution and adaptation technique of TIDA on average as compared with greedy techniques [14]. Greedy techniques are the baseline of time sensitive task managing techniques. Data extraction from IoT devices is very important part. Adaptive extraction-based Independent Component Analysis (AeICA) was proposed to quicken the detachment and to reach a more detachment accuracy for applications related to time sensitive, which was the limitation of Blind Source Separation. AeICA retrieve the existing data as a part of an iterative separation process, with reduced separation time up to 50% [9]. Edge node having high computational power and less storage space. An abstract model for edge computing QoS paradigm for applications related to time-sensitive has been proposed by Jain et.al. [4] to resolve the difficulties in the medical sector for strict applications related to time-sensitive. The edge devices offer powerful computation resources to enable real-time and quick decision making for the IoT applications [25]. To make data accessible always and from all locations, dew computing made up of cloud and fog makes a cloud-dew architecture which can find the solution of issue. An effective mechanism for resource allocation was designed for properly allocating time-sensitive tasks. In dew-fog cloud computing the task allocation hierarchy was explained using iFogSim simulator [7]. A smart solution with better performance of consistent and time-sensitive Flows in Hybrid SDN-based Fog Computing IoT Systems (IHSF) was presented by Muhammad et.al. For time sensitive traffic stream flooded by applications related to IoT, a novel Reliable and Time-sensitive Deep Deterministic Policy Gradient algorithm that computes a forwarding path in hybrid SDN-F was proposed. This will not only predict the reliable path for time-sensitive for the FC IoT systems but also analyse and find consistent paths based on IoT requirements like delay and bandwidth using the proposed RT-DDPG algorithm. The accuracy of this model is 86.54 % which is very good [10]. Time-sensitive data is the type of data having timestamp to communicate within a specified time period will always have more priority than the non-time sensitive data whereas priority-based data is a specific type of data that will pass data from one level to another depending on the priority of the data. Data possess more priority will get preference during transmission. A Multi-layer, Priority-based, Dynamic, and Time-sensitive data processing and Scheduling approach was proposed in multi-layer networks. MPDTS works in device networks as well as cloud. The motivation to use MPDTS is reduction of redundant data and to implement priority-based data scheduling to be moved from multiple devices to the cloud and cloud to the applications related to smart city [6]. To detect anomalies in time-series data algorithms and approaches have been categorized into (i) Statistical and Probabilistic, (ii) Pattern matching, (iii) Distance based, (iv) Clustering, (v) Predictive, and (vi) Ensemble. To detect anomalies in time sensitive data major challenges are (i) Real-Time processing, (ii) Window or Incremental approaches, (iii) Online adaptive learning, (iv) Semi-supervised or Unsupervised, (v) Multivariate data, and (vi) Generalised Approach have been discussed by Andrew et.al. [11]. The concept of reactive programming is extended for time-series IoT application development. Reactive programming offers beneficial abstractions to react to events. Three reactive programming language requirements idented and those are (i) Enable the requirement of reactions that only apply to events with a particular time context (ii) Appropriately connect with anew generated actions from different sources based on their time context (iii) Recompute forecasts that were partially based on forecasts when late measurements reach from the corresponding sensors [31]. The growth of multimedia IoT applications is mainly due to availability of the wide range of cheaper IoT devices having exceptional audio and video sensors. These IoT devices consume more bandwidth and are time sensitive. Due to high velocity and volume of multimedia data more bandwidth will be consumed by IoT applications [12]. An investigation of time-sensitive wide area IoT using mobile edge computing empowered non-terrestrial network was done by Chengxiao et.al. Power allocation, Data stream scheduling, Joint resource orchestration, and Proposed process-oriented joint resource orchestration algorithm proposed with remarkable result [29]. TS-MIoT applications decomposed into multiple parts and executing them on the accessible IoT devices like edge, fog, or cloud [24]. This dispersed accomplishment of applications related to TS-MIoT [23] permits using the computing resources allowed by the presently free IoT devices. EmuFog is an emulator of huge IoT devices supports the emulation of time-sensitive IoT application tasks [12]. EmuFog is an expansion of CloudSim and it will archetypal TS-IoT applications as map-reduce applications. Performance of multiple time sensitive data analysis techniques in cloud environment will be evaluated by EmuFog. The major focus of performance evaluation is execution time and cost. Execution and control of applications related to TS-MIoT on existing IoT devices, close by computers & cloud data centres is managed by APOLLO middleware. The multi-layer of APOLLO platform is categorized in three parts. IoT infrastructure that have IoT devices and the networks that connect these resources with each other to the internet is the lowest layer of APOLLO platform. Middleware is mainly responsible for managing the component of any platform, answerable for handling the application execution across IoT infrastructure as well as monitoring the execution progress of the applications [12]. Work on highly time sensitive data like brain stroke, heart attack, accident, etc. was done and fog computing is used to forward the result to the individual immediately. A new architecture and its flow chart of Fog and Cloud using Sensors and IoT devices is suggested. Using proposed architecture within 25 second result will be received [26]. An effective mechanism for collection of data related to time-sensitive using extensive simulations on realistic mobility traces is explained. Mobile Crowdsourcing with Delay Constraint (MCSD) problem was identified as NP hard and feasible. Utility-Based Opportunistic Data Collection mechanism is explained to solve the problem of MCSD and retrieve 70% more accurate data than others [28]. Unmanned Aerial Vehicles helped time-sensitive IoT network with varied latency tolerances of sensors is proposed by Nanxin et.al. A cost function is designed by defining the priority keeping in mind durations of diverse latency tolerances. An algorithm is designed to tackle the problem called DQN-based trajectory planning. The cost of DQN is about 49.55% lesser than greedy and is about 10.29% lesser than Q Learning on average [30]. To manage time-series data a novel category of IoT applications was proposed the concept of Apache IoTDB is designed by Chen et. al. Edge and cloud versions was provided by IoTDB. It will provide an efficient and compact columnar file format for effective time-series data storage, and time-series database with more ingestion rate, low latency queries and data analysis support. Apache IoTDB manages time-series data in real-time and supports advanced analytics by integrating with Hadoop and Spark and provide end to end solutions for every kind of data management [35]. When multiple IoT devices same series of time stamp then it is worthless to store and analyze all data separately so, the concept of grouping time series data is introduced by Chenguang et.al. to save the storage space and not to analyze same data multiple times. Almost every time series DBMS, open source or commercial, such as Apache IoTDB [36], InfluxDB [37], OpenTSDB [38], Prometheus [39], and TDengine [40], are designed with columnar storage. Complex logic is used to manage their low latency and time-series nature of Time-series databases. Major challenges in time series data are (i) To generate grammatically-correct time-series queries (ii) finding exceptions handled implicitly found by Zhiyong et. al. Six time series open-source databases are widely used namely IoTDB, KairosDB, QuestDB, TDEngine, GridDB, and TimescaleDB. All databases are using SQL type grammar except KairosDB. First three are designed in Java language whereas latter two was in C++ and the last i.e., TimescaleDB was designed in C language. Schemas of these time series databases are tree-based, tag-based, column-based, table-based, tag-based and relational [41]. Chenguang et. al. proposed to delete, move and insert data points to patch-up dirty timestamps in a time series for regular intervals [42].

4 MOTIVATING APPLICATIONS OF TIME SENSITIVE IoT

The novel hospital, agriculture, industrial environment requires an automatic highly integrated system that can exchange data from and to all the devices involved in system. Wherever huge data generated then classification and characterization of data become extremely important for analysis purpose and for building automated environment. A data may be characterized in various ways e.g, Time sensitive data, time series data, hard and soft real time data, etc. Nowadays people are showing more interest in time sensitive data due to its important characteristic. Each device should generate timestamp or a middleware should be added that may include timestamp on every data generated by multiple IoT devices. IoT resources includes IoT devices resources (Webcam, camera, traffic signal light sensors, onboard GPS and vehicle sensors, temperature sensor, odour sensor, soil moisture sensor etc) and IoT computing resources (Cloud & mid computing resources). IoT devices are installed to sense the atmosphere and generate data. This data should be sent to computing devices. Mid computing resources are networking devices and computing resources. IoT gateways, routers, switches, Wi-Fi access points, roadside units, etc. are considered as mid computing resources and raspberry pie, personal computers, etc. are considered as computing resources.

1. Passenger counting application: Counting of passengers is a global problem. No any standard universal expertise available for automatically counting of passengers. Most frequently used technologies are IR sensors and on-board cameras with measuring pressure inside the suspension system of vehicle or breaks system, stereo vision, passenger tracking via Wi-Fi, RGB-depth video, video-plus-depth, etc [52]. Accuracy of passenger counting application by multiple approaches was 67 % to 97.62 %. Passenger counting applications for a city in a specific route to know the actual demand passenger is real time. The counted data of passengers can be used by transporter authorities or application to schedule and allocate autos, buses or e-rikshaw to meet actual demand. Camera should be installed on each edge computer auto-stop point. Camera will catch the image of persons and on the basis of it demand of auto can be evaluated. At auto-stop points, passengers can be connected through their mobile phones GPS and this should also connect to edge computers [3]. Fig 4.2 is a general flowchart of travellers counting that can be implemented to count the number of persons in bus stand, auto stop, etc.

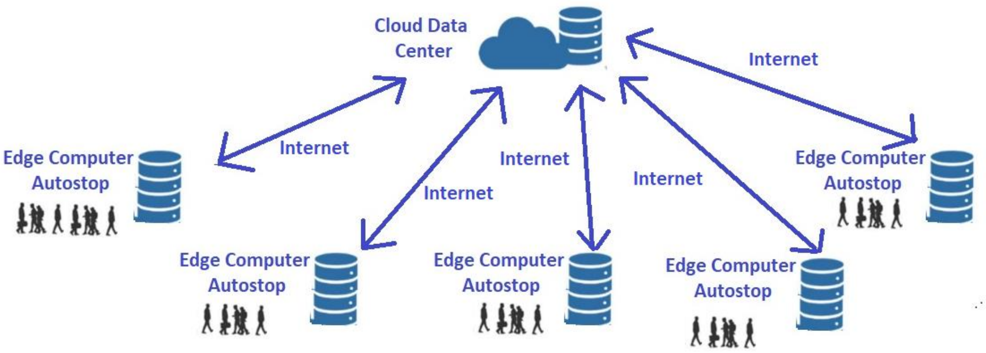

Fig. 4.1: Mechanism for distributed IoT environment at autostop point

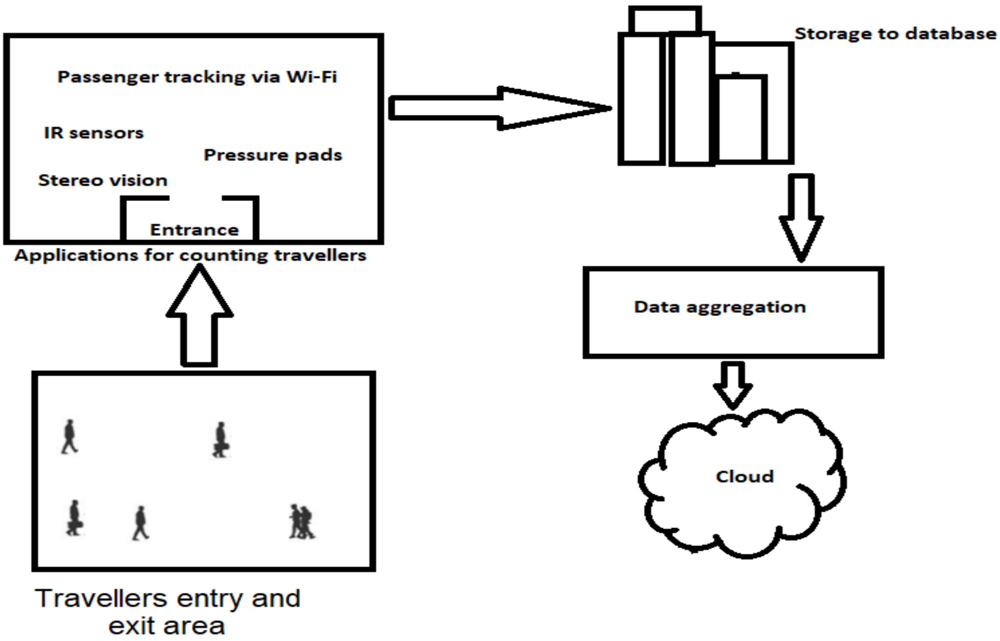

Fig 4.2: Flowchart of a traveller counting application

2. Healthcare Management Services System:

Collected data need to be analysed closer to the edge or sources of the data is also called edge computing. Instead of cloud, at edge level only all intelligent applications and analysis part should be executed. The basic motivation of edge computing technology to bring cloud computing features near to edge devices to produce result or trigger faster. Few data are highly time sensitive. These types of data specially found in healthcare system also. Edge devices which will include IoT devices, sensors, cameras, sensing machines, monitoring machines and smart devices will generate clinical data of the patient like temperature, heartbeat rate, blood pressure, etc. These type of data needs to be urgent attention. These edge devices are integrated with the edge node, which fetches data, to perform particular computation based on collected input of the health status of the patient. When the patient is taken into consideration to sense the clinical data, it produces a time series data, which desires to send quickly to an edge node for the analysis on gathered data and provide a response to the patients [4][6] [26].

3. Vehicle Accident Prevention System:

In India, every hour 18 people died and 47 accidents happen on road which will be around 1,57,000 people lost their lives on Indian roads in a year due to road accident. In 2021 total road accidents was 4,12,432 reported in India, claiming 1,53,972 lives and 3,84,448 peoples got injured. People of age ranging from 18 to 45 years is badly affected by road accidents which is of 67 % of total accidental death [50]. More than 1.3 million people lost their live every year due to road accidents. The number of deaths of pedestrians, cyclists, and motorcyclists is more than 50 % of total road traffic deaths. Low- and mid-income nations was badly affected & is around 93 % of total world's mortalities on the road's worldwide [51].

On highway or a busy crossing point in a city due to distributed and volatile nature of IoT system

gathering the data within specific time, computing, analysing and predicting and announcing the alert for an accident is not so easy. On highway or in a city all IoT device resources, mid computing resources, & available cloud computing involved in implementation of IoT technology [5]. We can also call IoT as IoE (Internet of everything) as it embedded or integrate with all kind of applications or devices. IoT applications collect generated IoT data from all IoT devices and will execute the following steps to find probable accidents:
1. Differentiate between multiple objects and categorize it as large vehicles, small vehicles, cyclists, and pedestrians from the video data generated from IoT devices at the highway or crossing points of road
2. continuously watching the suspicious vehicles by taking into account the way of driving, the speed, current location
3) predict near misses in the cross point or highway and
4) for any missing vehicles, connect with all to found that by sending multiple types of signal to the vehicles or cyclists or pedestrians and informing the person of a possible accident by sending the message on phone through GPS or vibrating the mobile devices or displaying the message on display board of highway and cross points.

To minimize road accident a vehicle accident prevention system was designed by method of alcohol detector by Mohamad et.al. In this prevention system, alcohol sensor MQ-3 with microcontroller is integrated and used to design the application. The ignition system of vehicle will work only if the driver will qualify the blood alcohol content (BAC) test from people breaths detected by alcohol sensor [46]. A competent, cheapest and instant solution to stop accident of vehicles is suggested by Kinage et.al by stopping the fuel supply to engine of vehicle. Microcontroller named Arduino which is used to regulate all other sensors in the system e.g., MQ-3 sensor, infrared sensor, accelerometer, and webcam. Eye blinking, detection of the multiple yawns from the noticed mouth, and speed bumpers was taken into consideration for designing the accident prevention system [47]. At every side of the U-turns sensors can be installed. It will help drivers to get knowledge about other vehicles through Buzzer, LED lights and Buzzer rings. These devices will get signal from sensors and Arduino about other vehicles [48]. Less visibility may lead to accidents among vehicles is another reason for slow speed traffic on fast scrolling roads. Corners, fog, smog, tunnels with scarce lighting, etc are the major issues which leads to visibility issues of driving persons [49].

4. Theft prevention IoT application:

Many theft cases in India or outside is not reported in any police station. Mostly people are not interested to report to police and daily thousands of people are directly affected by this act. If reported then in many cases can't be resolved due to many reasons. Prevention Is always better than cure so IoT can also be used to prevent potential theft at any shop. Any kind of thief can be controlled or caught by using IoT application. A person purchased something and went away without paying the amount. The thief can be caught through webcam installed on shop and stored in cloud database of thief, pickpocket, robbers, snatchers, kidnapers, etc. Next time whenever the person goes to shop the webcam installed on shop can easily catch the face and can alert the shopkeepers about the person [5]. Instead of barcode, RFID tag should be used for theft prevention suggested by Kowshika S et.al [43]. Two types of sensors used to know the vehicle is stolen and tracking can be done. Vibration and pyroelectric infrared sensors attached with vehicles, which are triggered, and location detail obtained on cell phone of owner, thus owners can check the position of the vehicle [44]. Three-tier architecture is proposed by Jinfeng Sun et. al. for intelligent anti-theft system based on IoT. This three-tier architecture having three layers Sensor layer, Transmission layer, Application layer. Sensor layer includes camera, temperature sensors, pressure sensor, flow sensor, Beidou, GPS, RTU RFID and many more. Transmission layer includes wired network, wireless network, & satellite network. Application level includes Real time monitoring systems, Early warning system, online diagnosis system, business analysis system, centralize databases, and data storage and analysis which will include SCADA, DCS, Cloud computing platform, web server, local server [45].

5 DETAILED ANALYSIS AND COMPARISON

A lot of approaches have been used for theft prevention, vehicle accident prevention system, passenger counting application and health care management services. These approaches include using the simulation tools, hardware devices including different types of sensors, algorithms, designing of 2 or 3 tier architecture of system, etc. A tabular representation of these all will be explained in this section. Different type of approaches taken by different authors to design middleware functionalities. Few researchers designed algorithm to handle time sensitive data and few researchers agreed on designing of IoT framework or algorithms implemented in a newly created architecture of IoT framework. A brief summary of 17 papers from 2017 to 2022 is tabulated in table 5.1.

Proposed Approach / Techniques	Reference / Year	Advantages	Disadvantages/ Limitations	Edge or Cloud	Type of Time sensitive data
Timestamp Repair Function, Application on analysis of frequency-domain & data compression	Chenguang et. al. [42] / 2022	Repairing of muddy timestamps in a time series for regular time interval done.	With the problem data values should be combined.	Not used	Time series data
TSN configuration models	Nurefsan et.al. [33] / 2021	Self-Configuration-TSN can effectively detect traffic characteristics with 97.85% classification rate.	Wastage of resources was done by wrongly tagged frames which uses optimal path.	Edge	Time sensitive N/W
The time-bound necessity of time sensitive IoT software was supported by TIDA framework.	Harindu et. al. [3] / 2021	On an average the TIDA progresses the entire execution time of an application by 46.96% and entire time of communication of data by 82.81%, compared to earlier cloud-based processing of IoT application for passenger count.	Dynamic task adaptation techniques to deal with cost effective and possible violations of time-bound and to compare TIDA platform's ability to meet timebound necessities with present solutions is missing.	Edge and Cloud	IoT applications considering Time-Sensitive data
ReactiveX framework, a suite of language for managing time	Stefanos et. al. [31] / 2021	Consequences explain that considering proposed reactive extensions minimizes the size of code by minimum 67% by removing crosscutting code to manage time.	Reactive extensions to distributed reactive programming frameworks is missing.	Not used	Time sensitive
Layered network architecture along with processing of data and scheduling mechanism	Nidal et. al. [6] / 2021	MPDTS approach is introduced.	Comparison of proposed approach with existing is missing. Comparison was done with traditional approach only.	Cloud	Time sensitive, Real Time
Apache IoTDB	Chen Wang et. al. [35] / 2020	High performance database for TS data. An inherent columnar file format TsFile is introduced for enhanced request outcome and efficiency of storage considering time-series oriented data.	Hardware dependence, other databases not supported, no mechanism for conversion of data to TsFile.	Edge and Cloud	Time Series Data, Real time data sent to cloud.
Linear regression model, MAE, MSE, RMSE and MAPE used as performance evaluator	R. Kumar et. al. [2] / 2020	By using air quality index, prediction of time series supports in decision making with historic datum.	Traffic density, sudden variations in climate, region specific constraints etc which will influence the accurateness was not taken into consideration for prediction.	Not used	Time Series Data, Real time data
Latency-aware green computing algorithm	DAO et. al. [34] / 2020	Allocation of ideal CPU frequency in latency-aware green mobile edge computing platform for unmodeled time-sensitive Internet-of-Things traffic within a 5G FRANs.	Not able to allocate CPU frequency when more than one CPU present.	Edge	Heterogenous Time Sensitive Data, Real time
Enhanced link adaptation mechanism, Interference-aware technique for SPS resource allocation	RENATO et. al. [32] / 2020	Developed dynamic packet scheduling and semi-persistent scheduling strategies. The SPS scheme supports 200 % and 76% more users for 20 bytes payload and 50 bytes respectively compared to dynamic packet scheduling.	Specially for 5G only.	Not used	Time-sensitive communications

Abstract Archetypal of Edge Computing QoS Standard for Applications related to Time-Sensitive	Arpit et.al. [4] / 2020	Intangible archetypal for edge computing QoS standard for time-sensitive applications is designed. This archetypal allows sensor-equipped edge devices and smart monitoring system to interrelate with the edge node to get the instant response in an emergency.	This archetypal may improve and improve the latency in applications related to time-critical. Blockchain technology may be used for meeting security aspect in distributed environment.	Edge	Time-sensitive, Time critical, Real time
A priority-oriented trajectory planning framework in a heterogeneous scenario.	Nanxin et.al. [30] / 2020	Unmanned Aerial Vehicle-aided time-sensitive IoT network in a heterogeneous situation where each sensor has its own different time slot. Authors adopted DQNbased trajectory planning algorithm to solve the problem.	Hard real time is missing in this work and can't be implemented in future also.	Not used	Time-Sensitive IoT Networks
Proposed Approach / Techniques	Reference / Year	Advantages	Disadvantages/ Limitations	Edge or Cloud	Type of Time sensitive data
TIDA platform for meeting time-sensitive IoT application time bound requirements.	Harindu et.al. [27] / 2020	TIDA middleware is the backbone of platform that will include many core engines that will collectively work together to encounter the timebound necessities of TS-IoT applications.	This is not cost-effective solution for dealing with unplanned time-bound violations. Improvement is required in task distribution and approximation techniques.	Not used	Time-Sensitive IoT applications
Proposed architecture (3-tier) of APOLLO platform specially for analysis of TS-MIoT applications	Harindu et. al. [12] / 2020	An innovative platform for the conduction of practical investigational assessment of Time-Sensitive Multimedia IoT applications. Will work on cloud level as well as close to computers i.e., edge computing.	Missing a task execution plan producing model that may be used to produce cost-effective and time-sensitive necessity satisfying task execution plans for TS-MIoT applications.	Edge and Cloud	Time-Sensitive Multimedia IoT applications
An innovative explanation that advances the performance of hybrid SDN-based FC architecture for applications related to IoT	Ibrar et. al. [10] / 2020	Smart Solution for Enhanced Performance of Unfailing and Time-sensitive Flows in Hybrid SDN-based Fog Computing IoT Systems (IHSF)	Improvement is required for prediction accuracy of legacy link reliability and testing in an additional accurate IoT set-up, considering all types of IoT node.	Cloud	Time-Sensitive
Adaptive extraction-based Independent Component Analysis (AeICA), aiming to speed up the separation and, simultaneously, to achieve a high separation accuracy, Fast ICA.	Huanzhuo et. al [9] / 2020	AeICA decreases the entire separation time by 50% to 75%, compared to the most amazing associated work. At 2000ms, the separation of AeICA has reached a 100% accuracy rate. In contrast, FastICA only reached the same accuracy at 9500ms. AeICA can reduce the separation time to 25% - 50% compared to FastICA. A growing number of sources, the performance of AeICA is stable.	Detailed study of initial extraction interval is among not discussed in research effort. Heterogeneous data is not considered by researchers.	Not used	Time-Sensitive Application
Resource allocation as per demand , Allocation of resource based on different types of task	Saddam et.al. [7] / 2019	Fog devices minimizes the network utilization compared to cloud. For dew devices network usages become minimum. Dew computing works well for time sensitive data.	Proposed resource allocation algorithms should be compared with other available algorithms.	Cloud	Real time, Time sensitive
Proposed fog and cloud architecture with Sensors and IoT device	Fatema et. al. [26] / 2017	Innovation with fog & cloud structures for time sensitive events. Smart algorithm was developed to allocate the user's request on priority basis.	Proposed model even should be more competent and cover more areas of interest.	Edge and Cloud	Brain stroke, heart attack, accident data is considered as time sensitive data.

Table 5.1: Detailed comparison of different applications

6 CONCLUSION & FUTURE WORK

This paper systematically reviewed the existing time sensitive IoT data related work. Real time responses and decisions play vibrant role for time sensitive applications. Decent excellence applications and software are vital in all aspect to the bottom layers users. Quality of application or software must be determined by the way it responds and works. The end user requires a good application or software that fulfil all the requirements of his need. The IoT engineering is profited if the product incorporated does not have any faults and strictly meets the critical time bound limitations of the applications in every situation. Many algorithms, module, framework and architecture were suggested by multiple researchers. In every kind of situation or applications some specific mechanism will work at its best. A single architecture or framework will not work at its best for all situations. Each and every technique has some advantages as well as limitations. We attempted to indicate the uninvestigated areas of existing work by analysing the research papers and representing them as future research.

A lot of work has been done for IoT time sensitive data. By analysing pros and cons we may use method or algorithms in various types of scenarios to get the best outcome. Future work will include comparison of techniques on heavy load only means when IoT devices generating IoT data at high rate. Type of IoT data will influence to choose the method, algorithm or framework of IoT model.

References

[1] Asif Ali Laghari, Kaishan Wu, Rashid Ali Laghari, Mureed Ali, Abdullah Ayub Khan (2021), A Review and State of Art of Internet of Things (IoT), Computational Methods in Engineering, CIMNE, Barcelona, Spain 2021, Springer

[2] Raghavendra Kumar, Pardeep Kumar, Yugal Kumar (2020) Time Series Data Prediction using IoT and Machine Learning Techniques, Procedia Computer Science 167 (2020) 373–381, 1877-0509 © 2020 The Authors. Published by Elsevier B.V.

[3] Harindu Korala, Dimitrios Georgakopoulos, Ali Yavari, Prem Prakash (2021). A Time-Sensitive IoT Data Analysis Framework, 978-0-9981331-4-0, Proceedings of the 54th Hawaii International Conference on System Sciences, Australia

[4] Arpit jain, Dharam Singh Jat (2020). An edge computing paradigm for time sensitive application, 978-1-7281-6823-4/20/2020 IEEE, 2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4)

[5] Harindu Korala, Dimitrios Georgakopoulos, Prem Prakash Jayaraman, Ali Yavari (2022). A Survey of Techniques for Fulfilling the Time-Bound Requirements of Time-Sensitive IoT Applications, ACM Comput. Surv.

[6] Nidal Nasser, Nargis Khan, Lutful Karim, Mohamed ElAttar, Kassem Saleh (May 2021). An efficient Time-sensitive data scheduling approach for Wireless Sensor Networks in smart cities, Computer Communications 175 (2021) 112–122, 0140-3664 Published by Elsevier B.V.

[7] M Saddam Hossain Khan , Puloma Roy , Fatema Khanam , Farzana Hannan Hera , Amit Kumar Das (2019). An Efficient Resource Allocation Mechanism for Time-Sensitive Data in Dew Computing, 978-1-5386-8448-1/19/ IEEE, DOI: 10.1109/ICAIIT.2019.8834633

[8] Tommaso Fedullo, Alberto Morato, Federico Tramarin, Luigi Rovati and Stefano Vitturi A Comprehensive Review on Time Sensitive Networks with a Special Focus on Its Applicability to Industrial Smart and Distributed Measurement Systems, Sensors 2022, 22, 1638. https://doi.org/10.3390/s22041638, MDPI

[9] Huanzhuo Wu, Yunbin Shen, Jiajing Zhang, Hani Salah, Ievgenii A. Tsokalo and Frank H.P. Fitzek (2020). Adaptive Extraction-Based Independent Component Analysis for Time-Sensitive Applications, 978-1-7281-8298-8/20, LOBECOM 2020 - 2020 IEEE Global Communications Conference | 978-1-7281-8298-8/20/$31.00 ©2020 IEEE | DOI: 10.1109/GLOBECOM42002.2020.9348166

[10] Muhammad Ibrar, Lei Wang, Gabriel-Miro Muntean, Jenhui Chen, Nadir Shah, and Aamir Akbar (2021). IHSF: An Intelligent Solution for Improved Performance of Reliable and Time-sensitive Flows in Hybrid SDN-based FC IoT Systems, INSPEC Accession Number: 20468464, Volume: 8, Issue: 5, IEEE Internet of Things Journal, May 2020

[11] Andrew Cook, Goksel Mısırlı, and Zhong Fan, ¨ Senior Member, IEEE (2019). Anomaly Detection for IoT Time-Series Data: A Survey, DOI 10.1109/JIOT. 2958185, IEEE Internet of Things Journal, 2327-4662 IEEE

[12] Harindu Korala, Prem Prakash Jayaraman, Ali Yavari, Dimitrios Georgakopoulos (2020). APOLLO: A Platform for Experimental Analysis of Time Sensitive Multimedia IoT Applications, Conference, MoMM '20: The 18th International Conference on Advances in Mobile Computing and Multimedia DOI:10.1145/3428690.3429176

[13] Pranvera Kortoci, Abbas Mehrabi, Carlee Joe-Wong, Mario Di Francesco (2021). Incentivizing Opportunistic Data Collection for Time-Sensitive IoT Applications, 978-1-6654-4108-7/21, Institute of Electrical and Electronics Engineers Inc. Incentivizing Opportunistic Data Collection for Time-Sensitive IoT Applications.

In: 2021 18th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON). Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ, pp. 1-9. ISBN 9781665431118, 9781665441087

[14] Harindu Korala, Dimitrios Georgakopoulos, Prem Prakash Jayaraman and Ali Yavari (2021). Remote Sens. 2021, 13, 4148. https://doi.org/10.3390/rs13204148. Managing Time-Sensitive IoT Applications via Dynamic Application Task Distribution and Adaptation, MDPI

[15] H. Gupta, A. Vahid Dastjerdi, S. K. Ghosh, and R. Buyya (2017), "iFogSim: A toolkit for modeling and simulation of resource management techniques in the Internet of Things, Edge and Fog computing environments," Software: Practice and Experience, vol. 47, no. 9, pp. 1275-1296,.

[16] E. Siow, T. Tiropanis, and W. Hall, "Analytics for the internet of things: A survey," ACM Computing Surveys (CSUR), vol. 51, no. 4, pp. 1-36, 2018.

[17] S. Wang, J. Xu, N. Zhang, and Y. Liu, "A survey on service migration in mobile edge computing," IEEE Access, vol. 6, pp. 23511-23528, 2018.

[18] C. Puliafito, E. Mingozzi, C. Vallati, F. Longo, and G. Merlino, "Virtualization and migration at the network edge: An overview," in 2018 IEEE International Conference on Smart Computing (SMARTCOMP), pp. 368-374, Taormina, Jun 2018.

[19] A. Shukla, S. Chaturvedi, and Y. Simmhan, "RIoTBench: An IoT benchmark for distributed stream processing systems," Concurrency and Computation: Practice and Experience, vol. 29, no. 21, 2017.

[20] S. Shckhar, A. Chhokra, H. Sun, A. Gokhale, A. Dubey, and X. Koutsoukos, "URMILA: A Performance and Mobility-Aware Fog/Edge Resource Management Middleware," in 2019 IEEE 22nd International Symposium on Real-Time Distributed Computing (ISORC), pp. 118-125, Valencia, May 2019.

[21] B. Donassolo, I. Fajjari, A. Legrand, and P. Mertikopoulos, "Fog Based Framework for IoT Service Provisioning," in 2019 16th IEEE Annual Consumer Communications & Networking Conference (CCNC), pp. 1-6, Las Vegas, Jan 2019.

[22] A. Yousefpour et al., "FogPlan: a lightweight QoS-aware dynamic fog service provisioning framework," IEEE Internet of Things Journal, vol. 6, no. 3, pp. 5080-5096, 2019.

[23] Flavio Bonomi, Rodolfo Milito, Preethi Natarajan, and Jiang Zhu. 2014. Fog computing: A platform for internet of things and analytics. Springer, 169–186.

[24] Ola Salman, Imad Elhajj, Ayman Kayssi, and Ali Chehab. 2015. Edge computing enabling the Internet of Things. In 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT). IEEE, 603–608.

[25] Y. Wu et al., "Dominant data set selection algorithms for electricity consumption time-series data analysis based on affine transformation," IEEE Internet of Things Journal, vol. 7, no. 5, pp. 4347–4360, 2020

[26] Fatema Tuz Zohora, Md. Rezwanur Rahman Khan, Md. Fazla Rabbi Bhuiyan, Amit Kumar Das, Enhancing the Capabilities of IoT Based Fog and Cloud Infrastructures for Time Sensitive Events, International Conference on Electrical Engineering and Computer Science (ICECOS) 2017, 978-1-4799-7675-1/17/$31.00 ©2017 IEEE

[27] Harindu Korala, Ali Yavari, Dimitrios Georgakopoulos, Prem Prakash Jayaraman, Design and Implementation of a Platform for Managing Time-Sensitive IoT Applications, 2020 IEEE 6th International Conference on Collaboration and Internet Computing, 987-1-7281-4146-6/20 2020 IEEE

[28] Pranvera Kortoci, Abbas Mehrabi, Carlee Joe-Wong, Mario Di Francesco, Incentivizing Opportunistic Data Collection for Time-Sensitive IoT Applications, 978-1-6654-4108-7/21, 2021 18th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON). Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ, pp. 1-9. ISBN 9781665431118, 9781665441087

[29] Chengxiao Liu, Wei Feng, Xiaoming Tao, Ning Ge, MEC-Empowered Non-Terrestrial Network for 6G Wide-Area Time-Sensitive Internet of Things, https://doi.org/10.1016/j.eng.2021.11.002, 2095-8099/2021 THE AUTHORS. Published by Elsevier, Engineering 8 (2022) 96–107

[30] Nanxin Wang, Yifei Xin, Jingheng Zheng, Jingjing Wang, Xiao Liu, Xiangwang Hou, and Yuanwei Liu, Priority-Oriented Trajectory Planning for UAV-Aided Time-Sensitive IoT Networks, IEEE International Conference on Communications Workshops (ICC) 2020, ISBN:978-1-7281-7441-9, DOI: 10.1109/ICCWorkshops49005. 2020.9145119

[31] Stefanos Peros, Danny Hughes, Reactive Programming Extensions for Time-Sensitive IoT Applications, IEEE Xplore, 2021 17th International Conference on Distributed Computing in Sensor Systems (DCOSS)

[32] RENATO B. ABREU, GUILLERMO POCOVI, THOMAS H. JACOBSEN, MARCO CENTENARO, KLAUS I. PEDERSEN, AND TROELS E. KOLDING, Scheduling Enhancements and Performance Evaluation of Downlink 5G Time-Sensitive Communications, VOLUME 8, June 2020, IEEE Access, Digital Object Identifier 10.1109/ ACCESS.2020.3008598

[33] Nurefsan Sertbas Bulbul , Doganalp Ergenc, Mathias Fischer, SDN-based Self-Configuration for Time-Sensitive IoT Networks, 2021 IEEE

46th Conference on Local Computer Network, 73-80, 2021
[34] NHU-NGOC DAO, THI-THAO NGUYEN, MINH-QUAN LUONG, THUY NGUYEN-THANH, WOONGSOO NA, AND SUNGRAE CHO, Self-Calibrated Edge Computation for Unmodeled Time-Sensitive IoT Offloading Traffic, June 2020, IEEE Access (Volume: 8), 110316 - 110323, ISSN: 2169-3536
[35] Chen Wang, Xiangdong Huang, Jialin Qiao, Tian Jiang, Lei Rui, Jinrui Zhang, Rong Kang, Julian Feinauer, Kevin A. McGrail, Peng Wang, Diaohan Luo, Jun Yuan, Jianmin Wang, Jiaguang Sun, Apache IoTDB: time-series database for internet of things, ACM Digital Library, Proceedings of the VLDB Endowment 2020, Volume 13, Issue 12, ISSN 2150-8097. doi:10.14778/3415478.3415504
[36] CHENGUANG FANG,SHAOXU SONG, HAOQUAN GUAN, XIANGDONG HUANG, CHEN WANG, BNRist, JIANMIN WANG, Grouping Time Series for Efficient Columnar Storage, Proc. ACM Manag. Data, Vol. 1, No. 1, Article 23. Publication date: May 2023, 2836-6573/2023/5-ART23, https://doi.org/10.1145/3588703
[37] InfluxDB. https://www.influxdata.com/.
[38] OpenTSDB. http://opentsdb.net/.
[39] Prometheus. https://prometheus.io.
[40]TDengine. https://github.com /taosdata/ TDengine/.
[41]Wu Z, Liang J, Wang M, Zhou C and Jiang Y. Unicorn: detect runtime errors in time-series databases with hybrid input synthesis. Proceedings of the 31st ACM SIGSOFT International Symposium on Software Testing and Analysis. (251-262), 2022 Association for Computing Machinery. ACM ISBN 978-1-4503-9379-9/22/07
[42] Fang C, Song S and Mei Y. (2022). On repairing timestamps for regular interval time series. Proceedings of the VLDB Endowment. 15:9. (1848-1860). Online publication date: 1-May-2022. https://doi.org/10.14778/3538598.3538607
[43] Kowshika S, Madhu mitha S.S, Madhu Varshini G, Megha V, Lakshmi K IoT based Smart Shopping Trolley with Mobile Cart Application, 2021 7th International Conference on Advanced Computing & Communication Systems (ICACCS), 978-1-6654-0521-8/21, 2021 IEEE
[44] Zhigang Liu, Anqi Zhang and Shaojun Li Vehicle Anti-theft Tracking System Based on Internet of Things, 978-1-4799-0380-1/13, Proceedings of 2013 IEEE International Conference on Vehicular Electronics and Safety
[45] Jinfeng Suna, Zhiyue Zhang, Xiaoli Sun The intelligent crude oil anti-theft system based on IoT under different scenarios, 1877-0509, Procedia Computer Science 96 (2016) 1581 – 1588, ELSEVIER, 10.1016/j.procs.2016.08.205
[46] M.H Mohamad, Mohd Amin Bin Hasanuddin, Mohd Hafizzie Bin Ramli Vehicle Accident Prevention System Embedded with Alcohol Detector, Volume 1 - Issue 4 October 2013, International Journal of Review in Electronics & Communication Engineering (IJRECE)
[47] Vivek Kinage, Piyush Patil IoT Based Intelligent System For Vehicle Accident Prevention And Detection At Real Time, 978-1-7281-4365-1/19, Proceedings of the Third International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2019) IEEE Xplore Part Number:CFP19OSV-ART; ISBN:978-1-7281-4365-1
[48] Nookala Venu, Govindu Rakesh, Kunta Maneesha, Kusumba Anusha, Samantha Merugu, Abbas Mohammad Smart Road Safety and Vehicle Accidents Prevention System for Mountain Road, Vol 11 Spl Issue 06, Jul 2022, ISSN 2456 – 5083, Page no. 86-91, International Journal for Innovative Engineering and Management Research
[49] Antonio Celesti, Antonino Galletta, Lorenzo Carnevale, Maria Fazio, AimeLay-Ekuakille, and Massimo Villari An IoT Cloud System for Traffic Monitoring and Vehicular Accidents Prevention Based on Mobile Sensor Data Processing, 1558-1748, IEEE Sensors Journal (Volume: 18, Issue: 12, 15 June 2018), http://www.ieee.org/publications_standards/publications/rights/index.html (data on 02-07-2023)
[50]https://morth.nic.in/sites/default/files/RA_2021_Compressed.pdf (data on 02-07-2023)
[51]https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries (data on 02-07-2023)
[52] Ivan Grgurevic, Karlo Jursic, and Vinko Rajic Review of Automatic Passenger Counting Systems in Public Urban Transport, 5th EIA International Conference on Management of Manufacturing systems pp1-15, Springer Innovation in Communication and Computing