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Proposal For 6LoWPAN Wireless Network Protocol-Based Street-Light-As-A-Service (SLaaS) Framework To Power Campus Parking Services

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Abstract—A novel IPv6 Over Low Power Wireless Personal Area Network (6LoWPAN) protocol-based Street-Light-As-A-Service (SLaaS) research framework for an integrated cloud-based smart university campus parking platform is being proposed. The Intelligent Connected Street Light infrastructure currently in existence at University Sains Malaysia (USM) is being redesigned. As part of overall parking proposal, approaching object image and video data are being acquired using a range of sensors, including the passive infrared (PIR) and 3-D Light Detection and Ranging (LIDAR) motion sensors. To acquire and transmit vehicle instrumentation data, ELM327 Onboard Diagnostics 2 (OBD-II) Wi-Fi adapter is being used. For edge computing-based intelligent object detection model processing to synchronize license plate and facial recognition data with USM databases, Nvidia® Jetson Nano is being used. The framework is developed to effect multiple services, including to track and manage university vehicles, to detect and secure pedestrian movement, to trigger lighting commands based on approaching vehicle movement for on-demand parking illumination, to partition digital bounding box perimeter to predict potential vehicle collisions, to detect unregistered and excessive parking time to monitor unattended and illegal vehicles, to enable street-light-located parking-related kiosk services, and consolidate cloud-based human and vehicle data analytics into mobile form-factor dashboards. The proposed design will be evaluated and validated for end-to-end average data propagation rate, data integrity, object-to-human and object-to-vehicle synchronization success rate, electrical power consumption reduction and potential surface attack mitigation and avoidance throughout the network.

Keywords-6LoWPAN, smart street light, parking, wireless sensing network.

INTRODUCTION

According to the United Nations Department of Economic and Social Affairs Population Division (UN DESA) forecasts, the global population will increase from 4.2 billion or 55% of the total population in 2018 to 68% in 2050. The ongoing rural-to-urban human resettlement, together with the burgeoning global population, will demand the metropolises to house another 2.5 billion people, with 90% taking place in Asia and Africa in 2050 [1].

These unprecedented waves of migration brought about disruptive challenges, including waste management [2], environmental pollution [3], industrial infrastructure [4], urban services [5], and uncontrolled development [6], among other factors.

The above-mentioned challenges, and the staggering growth of worldwide urbanization, pave the way for an innovative city model to address the increasing intricacies of metropolitan life. In recent years, the smart city concept, alternatively known as "information city" [7] or "sensing city" [8], has earned considerable support for the ultimate objective of solving transportation, housing, energy, and other public necessities, in addition, to mitigate problems on unemployment, inequality and poverty, and maintain public order.

Street light systems comprise one fundamental component of an overall infrastructure that can potentially provide essential services to intelligent cities. In addressing the population's needs, public areas, including roads and parks, need to be provided with adequate illumination, especially at night, to facilitate visibility, comfort and security, which in turn, necessitates more optimum lighting resources. It is imperative to extend other economical, sustainable and environmentally friendly services, besides lighting [9].

To this end, Collaborative Research in Engineering, Science and Technology (CREST) with its Living Labs as Open-Innovation Networks proposal [10] had collaborated with Renesas Electronics Corporation (Renesas) with a grant from Microfacturing Institutes (MI), USA, to provide Universiti Sains Malaysia (USM) in Malaysia with a wireless Intelligent Connected Streetlight infrastructure encompassing 37 National Electrical Manufacturers Association (NEMA) connectors-outfitted LED lights on Internet Protocol version 6 (IPv6) Over Low Power Wireless Personal Area Network (6LoWPAN) mesh network with a Wi-Fi connection for Amazon Web Services (AWS) cloud-based data communication at Sains@USM Bukit Jambul campus, Penang, Malaysia (Fig. 1) [11] [12] [13].

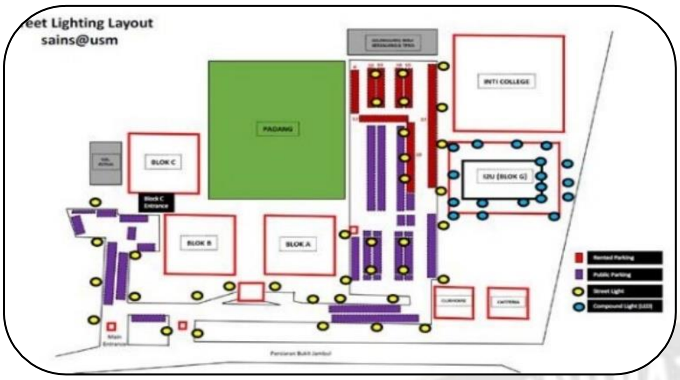

Figure 1: Intelligent Connected Streetlight at SAINS@USM

To further augment this infrastructure with higher research value for USM, a 5-year research is being proposed to implement a 6LoWPAN-based Street-Light-As-A-Service (SLaaS) framework to power strategic campus services and transform USM into a smart campus experimental parking testbed.

The smart campus can be defined as a constellation of technologies, applications and devices required to provide staff, smart students, visitors and vendors value-added experiences, efficiency and beneficial applications and services to enable multitasking in campus environments [14].

All the materials for this research proposal are included in six sections. The first section outlines the problem statement, followed by the research objectives in the second section. The third section introduces an overview of current work focusing on smart cities and smart campuses in the literature and the Intelligent Connected Streetlight infrastructure at Sains@USM.

Subsequently, the fourth section describes the materials and methods, including the proposed 6 projects and hardware components used for conducting this research. The fifth section elaborates on some of the expected challenges faced by the conducted research. The last part summarizes the conclusions.

LITERATURE REVIEW

As USM transcends into uncharted frontiers in the new millennium, the university needs to provide more efficient, quality and cost-effective services to staff, students, visitors and vendors to continue being the top choice among Malaysian best universities.

With the skyrocketing number of staff and students both from local and foreign countries, USM is facing enormous challenges in maintaining its apex position by delivering best-in-class on-campus services while accommodating the steady growth in logistical demands including transportation and student, especially parking services.

As continuous improvement becomes necessary, there is a perceived need for an integrated framework for providing necessities, such as safe, secure and on-time USM parking services, and more detailed management and control of those services.

The objective of this research is to propose a novel Street Light-As-A-Service (SLaaS) research framework based on the 6LoWPAN protocol as an integrated platform for a set of 6 critical parking-related services:

- Intelligent University Vehicle Tracking System
- Intelligent Human Detection System
- Intelligent Vehicle Collision Detection System
- Intelligent Illuminated Parking System
- Intelligent University Pedestrian Road Safety System
- Intelligent Parking Services System

The objectives are as follows:

- To prepare the prototype by implementing control transport mechanisms using 6LoWPAN protocol for street-light-to-gateway transmission, MQTT (Message Queueing Telemetry Transport) protocol for AWS cloud service-to-gateway transmission, ELM327 OBD-II Wi-Fi adapter vehicle instrumentation data acquisition and AWS DynamoDB transmission, Nvidia® Jetson Nano edge computing for intelligent object detection model processing, and the installation of PIR and LIDAR motion sensors using respective protocol options for each particular system.

- To characterize the object detection model processing for object-to-human and object-to-vehicle synchronization to assess accurate matching of license plate and facial recognition data to AWS DynamoDB database element.

- To evaluate the accuracy and effectiveness of the on-demand parking illumination based on approaching vehicle movement trigger lighting commands execution versus the proposed work time lighting model and emergency lighting model.

- To evaluate the accuracy and effectiveness of digital bounding box perimeter partitioning to assess accurate prediction of potential vehicle collisions.

- To evaluate the accuracy and effectiveness of real-time unregistered vehicle detection and excessive parked vehicle detection for on-time trigger and notification to the users.

- To evaluate the accuracy and effectiveness of street-light-located parking-related kiosk services including online payment and long-time parking authorization.

- To study the 6LoWPAN versus other wireless protocols' performance regarding the end-to-end average data propagation rate, data integrity, object-to-human and object-to-vehicle synchronization success rate, electrical power consumption reduction and potential surface attack mitigation and avoidance.

From a technological perspective, a "smart city" can be described as a city built on a plethora of advanced techniques, such as mobile networks, data storage technologies, wireless actuators and sensors, smartphones, intelligent vehicles and intelligent meters [15], or an integrated municipal infrastructure constructed by information and communication technology (ICT) solutions to efficiently administering the city's resources [16].

Malaysian Government's Malaysia Smart City Framework (MSCF) proposal has propelled the smart city initiative in Malaysia into prominence. The 'Smart City Malaysia' idea promulgates innovative ICT and technological advances to confront metropolitan problems, including advocating quality of life improvements, economic expansion, and a safe and sustainable environment while championing efficient urban management practices [17] [18].

Initially accelerated with Industry 4.0 or "Industrie 4.0" introduction at Germany's 2011 Hanover Fair [19], a number of its fundamental principles, such as the Internet of Things (IoT) and cloud-based manufacturing, which facilitates fully digitized and intelligent manufacturing [20], has been adopted into smart cities concepts [21]. A fundamental smart city model consists of a smart economy, living, environment, people, governance, and mobility [22].

The smart campus concept is an extension of the smart city model [23] in terms of interdependencies, functionality, population and activities [14]. The smart campus paradigm also subscribes to the smart city's six smart domains (Fig. 2) [24].

Smart campus facilities are similar to smart city services but aligned more with campus requirements, such as mobility and transport services, resource efficiency, resident behavior monitoring, and energy monitoring. On the other hand, several unique smart city characteristics can be applied to smart campuses.

Since a smart campus is proportionately smaller than a smart city, like urban campuses located in the cities, the technological infrastructure required to be deployed is less than that needed for the smart city, resulting in reduced deployment costs [24].

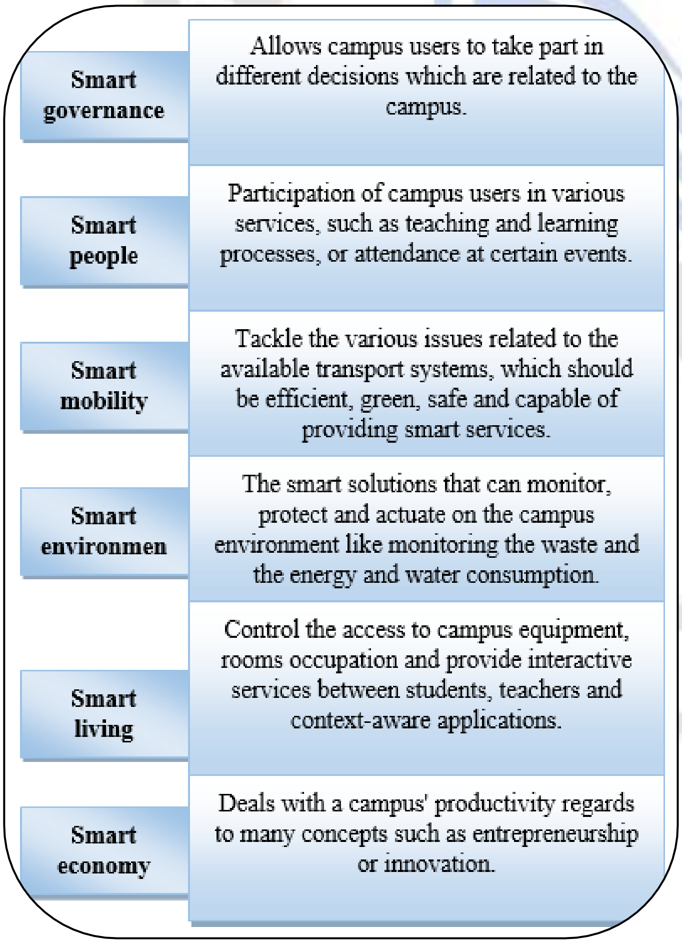

Figure 2. Smart Campus domains [24]

The campus size factor affects campus traffic congestion and is made worse by vehicles cruising for parking spaces. Zhu et al. found between 9 and 56 per cent of the traffic was cruising for parking with a 6.03-minute average search time. Multiple factors including high acceleration frequency, volume, low speed, and cruising cars lane-change times contributed negatively by increasing the travel time of the normal traffic flow [25].

The smart campus smart mobility initiative encourages the use of smart lights [21]. Hence, in USM Intelligent Connected Streetlight design, the MS 825: Part 1:2007 specification-compliant LED street lights [26] were outfitted with the 60W Alfa Roadway Lighting luminaires designed with Color Rendering Index (CRI) value of ⩾ 70 Ra and Color Correlated Temperature (CCT) value of 3000 to 6000 K.

These LED Category A street lights are superior to the normal HPSV (High-Pressure Sodium Vapor) street lights with higher performance in terms of more accurate color rendering for maximum visibility and uniformity [27] as well as 50% energy savings to USM [28].

The LED street lights are equipped with the Renesas-built Integrated Context Engine for City Illumination (ICE CIL), a 6LowPAN wireless-based on standard NEMA pluggable 7-pin lamp JL-241J base dome with ON/OFF function, 0V to 10V power and Digital Addressable Lighting Interface 2 (DALI 2) protocol to control streetlighting similar to those proposed by Bellido et al. [29].

The LED streetlights form a meshable 6LowPAN wireless network connected via 6LowPAN to the Raspberry Pi gateway. In turn, the gateway is linked to the USM-owned, CREST-managed IoT Cloud Data Centre (ICDC) Research Laboratory server center, which permits light control via USM's Amazon Web Service (AWS) cloud services (Fig. 3) [30].

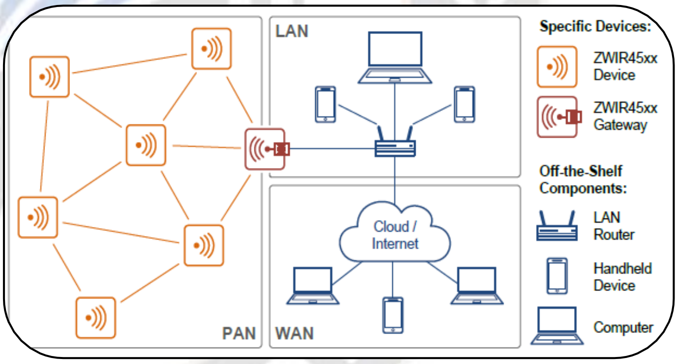

Figure 3: Intelligent Connected Streetlight wireless sensor network design [30]

The AWS IoT Core module authenticates all the 6LowPAN sensor nodes placed at each streetlight using certificate ID and Amazon Registration Number (ARN) for the cloud operation via the Raspberry Pi gateway. This configuration is similar to the Wireless Sensor Network (WSN) method proposed by Fernandes et al., where data from each sensor node (similar to the 6LowPAN sensor node at the streetlight) is relayed to the receiver node are redirected to the Control Centre (similar to AWS) via GPRS protocol (similar to Wi-Fi) for smart lighting applications [31].

Both the Raspberry Pi gateway and all the streetlights' 6LowPAN sensor nodes permit the formation of wireless sensor networks (WSN) using the Renesas ZWIR4512 module on the network [30].

The Raspberry Pi gateway functions as a network bridge, effectively merging the WSN into the ICDC server center and the rest of the network attached to the gateway. Theoretically, since the bridge is connected to the WSN, any computer on the Internet would access all the nodes in the WSN with its unique IPv6 address. For communications from the Internet up to all the nodes via the Raspberry Pi gateway, standard IPv6 transmission is sufficient. Interfacing with the sensor nodes at the streetlights is possible since the 6LoWPAN standard (RFC 4944) has been developed to carry IP packets over IEEE 802.15.4 networks.

The WSN comprises individual IP-addressable nodes that maintain a self-healing mesh network connectivity with 128-bit data encryption and multiple-pathways router functionality to enable network resiliency against unexpected failure. In an unexpected case of any node getting disengaged from the network, and the destination node is not directly accessible from the originating node, the packets will be automatically re-routed via available nodes [11].

Kospenda observed majority of street lights systems utilized the self-healing and self-configuration mesh network communication protocol [32], similar to Elejoste et al.'s street lights-to-central controller unit communication [33], and Yusoff et al.'s WSN-based Waspmote solution [34], which is also applicable to 6LoWPAN-based networks (Fig. 4) [35].

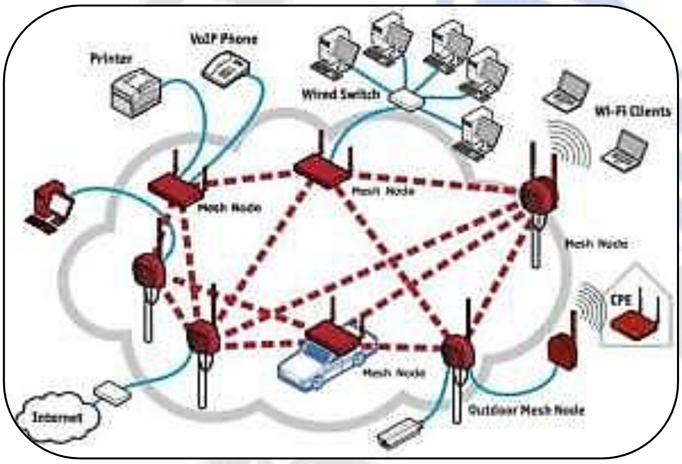

Figure 4: Mesh network communication protocol [33]

Sikder et al. proposed the smart city's IoT-enabled Smart Indoor and Outdoor Lighting Systems (SiLS, SoLS) which effectively reduced power consumption by up to 33.33% vs. conventional system [36].

Smart Indoor Lighting System (SiLS) consists of short-range wired protocol communication which are Power Line Communication (PLC) [37] and Digital Addressable Lighting Interface (DALI) [38]. Smart Outdoor Lighting System (SoLS) comprises short-range protocols such as ZigBee [39], JenNET-IP [40], and 6LoWPAN [41].

METHODOLOGIES

A. System Architecture

The 6LoWPAN protocol-based Street-Light-As-A-Service (SLaaS) research framework derives from the WSN self-healing and self-configuration mesh topology comprising mesh client

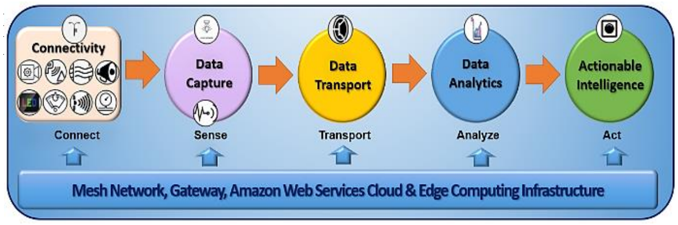

Figure 5: Street-Light-As-A-Service (SLaaS) research framework

Sensors at the mesh client's nodes acquire approaching object information such as vehicles, humans or animals as image and video data. Upon data acquisition, the data is relayed by the mesh client nodes to the edge computing via the network.

Since each node is uniquely addressable, the data packets 'hopped' from one node to another in the mesh network with equal transmission accessibility. In the instance that one of the nodes is non-accessible, the data will be routed via a different pathway until it reaches its destination.

In contrast, a lightweight, publish-subscribe model that utilizes MQTT transport protocol between AWS IoT Core to the subscribed IoT devices (Fig. 6).

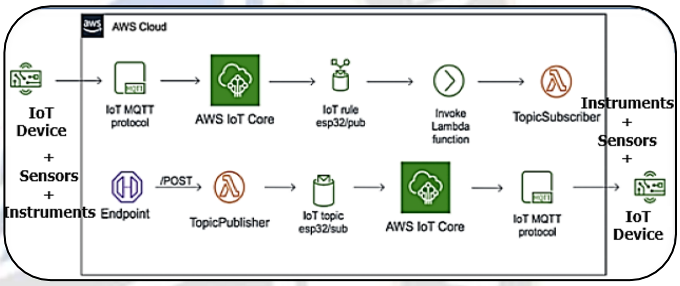

Figure 6: The publish-subscribe model architecture

The proposed framework will include passive infrared (PIR) and 3-D Light Detection and Ranging (LIDAR) motion sensors to acquire approaching object images and video data. It will also incorporate the ELM327 Onboard Diagnostics 2 (OBD-II) Wi-Fi adapter to acquire and transmit vehicle instrumentation data to the Amazon Web Services (AWS) DynamoDB database.

Nvidia® Jetson Nano edge computing component will be added for intelligent object detection model processing to synchronize license plate and facial recognition data with USM databases to track and manage university vehicles, and to detect and secure pedestrian movement.

Python lighting commands will be programmed to trigger on-demand parking illumination based on approaching vehicle movement, to partition digital bounding box perimeter to predict potential vehicle collisions, to detect unregistered and excessive parking time to monitor unattended and illegal vehicles, to enable street-light-located parking-related kiosk services, and consolidate cloud-based human and vehicle data analytics into mobile form-factor dashboards.

The visually oriented dashboards will be used to function as a platform to control and monitor the proposed system in real time.

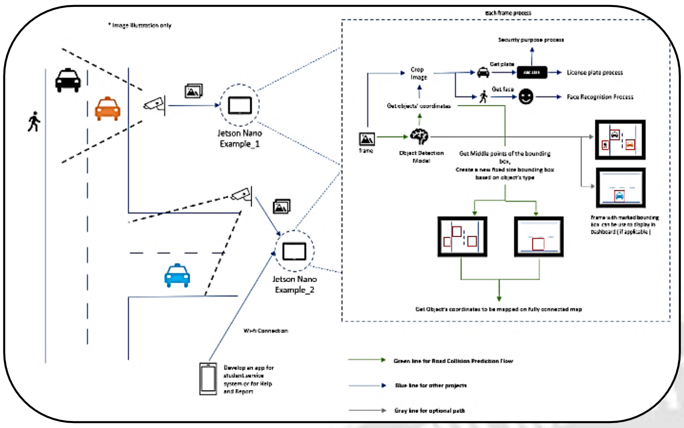

Figure 7: Overall framework functionality

The proposed framework will be equipped with a Jetson Nano edge computer, a camera and any required modules. The camera will provide a live feed to Jetson Nano with each camera frame being the input to the object detection model. If the model detects the frame to contain a vehicle or human footprint, it will output a frame with a digital bounding box on the detected objects. It will also provide the digital bounding box coordinates for the other processes (Fig. 7).

B. *Intelligent University Vehicle Tracking System*

Vehicle data are captured from OBD-II ports through a Wi-Fi Adapter which is connected to a smartphone. A Python program is developed to connect and acquire the complete vehicle instrumentation data and to transmit to the AWS Cloud DynamoDB database at certain periodic intervals, for example, one transmission per hour. The vehicle data is sorted in such a way that the unique ID is based on its plate number. In addition, since the smartphone is GPS enabled, it will also append the GPS information onto the data to enable vehicle location tracking accordingly. Data resolution is achieved by decreasing the interval to the point based on the user requirements (Fig. 8).

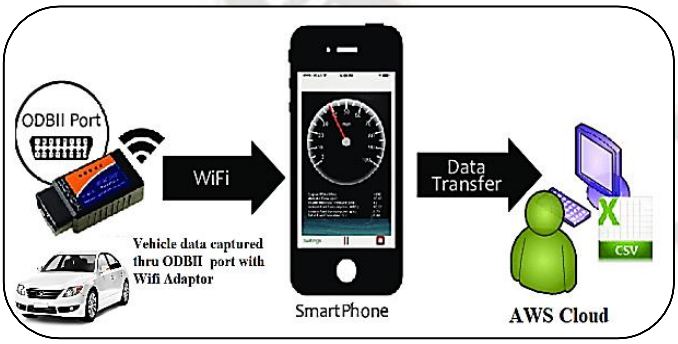

Figure 8: OBD-II to AWS Cloud DynamoDB database transmission

Once an object is sensed by the motion detector, it will relay the signal to Jetson Nano through 6loWPAN, then it will trigger the camera using Wi-Fi or LAN to capture the image in a certain delay time which is tuned to the best flat captured from the front of the object. Jetson Nano will perform image processing to determine whether it is a vehicle, human or animal.

If the object is determined to be a vehicle, an optical character recognition (OCR) algorithm will be executed to identify the vehicle's plate number. Once the vehicle's plate is obtained, it will use the plate no as the unique ID to read the vehicle data from AWS cloud at the most recent data to plot the GPS location and retrieve mileage, speed, revolutions per minute (RPM), engine data and other user-defined information (Fig. 9).

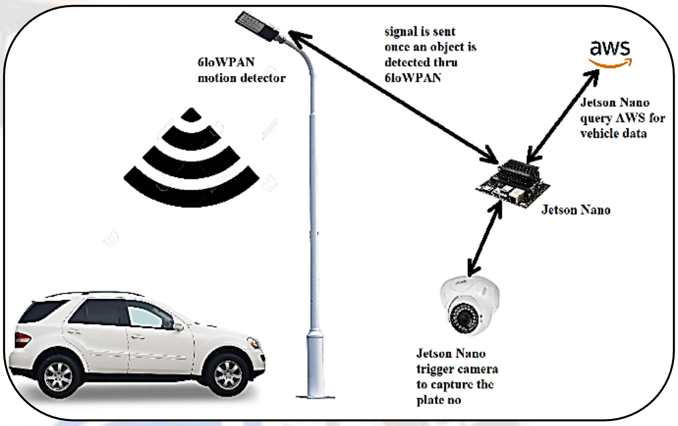

Figure 9: Vehicle object detection and image capture trigger

C. *Intelligent Vehicle Collision Detection System*

For the collision prediction process, for each street light, the system will process the bounding box coordinates to produce the middle point. It will map the middle point on a pre-generated 2D map, which is the street area within the camera's street light view. The system will generate a new digital rectangle with a fixed size based on the detected object on the 2D map from the middle point. It will extract the 4-point coordinates from the rectangle and relay them to the Raspberry Pi gateway via the 6LoWPAN network to the AWS Service (Fig. 10).

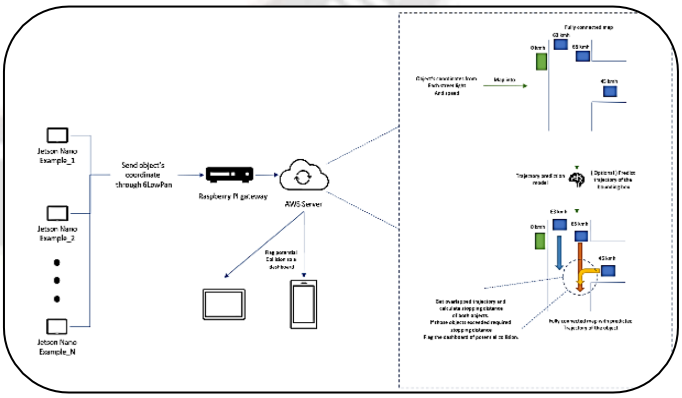

Figure 10: Vehicle collision prediction process

The system will process each data from each street light comprising the objects' coordinates and other related data in JSON-compatible format. The system will use those available coordinates to generate several rectangles on a fully connected map.

It will feed the updated map using a deep learning model to predict the rectangles' trajectories or motion. The system will then search for any overlapping trajectories of the rectangles. If it is found, the system will calculate the stopping distance using the speed of those rectangles. If those rectangles exceed a certain threshold, the system will flag a potential collision to the dashboard or client.

D. Intelligent Illuminated Parking System

Similar to the other systems, once an approaching object is sensed by the LIDAR motion sensor, and the object is determined to be a vehicle, it will relay the signal to Jetson Nano through 6loWPAN, and trigger to adjust or change the light's dimming level or switch ON the light (Fig. 11).
With no approaching vehicle, the standard work-hour time model is observed where day-time mode operation time is from 7:00 a.m. to 7:00 p.m. and alternately for night-time mode when all the street lights would be switched on. The emergency time model is only activated when the emergency status is set in the system.

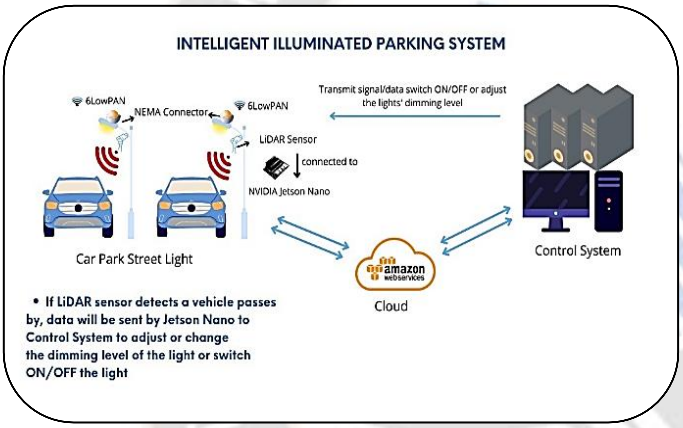

Figure 11: Intelligent Illuminated Parking System

E. Intelligent Human Detection System

By using a smart street light system combined with Jetson Nano camera image processing capability (Fig. 15) it will process the approaching pedestrian image to determine whether it is a vehicle, human or animal which will be classified and categorized into separate data sets.

Through the data sets, the captured person's image will be analyzed for facial recognition using Jetson Nano camera (Fig. 15) mounted on street light poles and index the faces to determine gender, race and age information, as well as performing facial matching against databases using artificial intelligence Fast R-CNN image processing technique, then the data will be relayed to Jetson Nano through 6loWPAN to AWS DynamoDB database (Fig. 12) [42] [43].

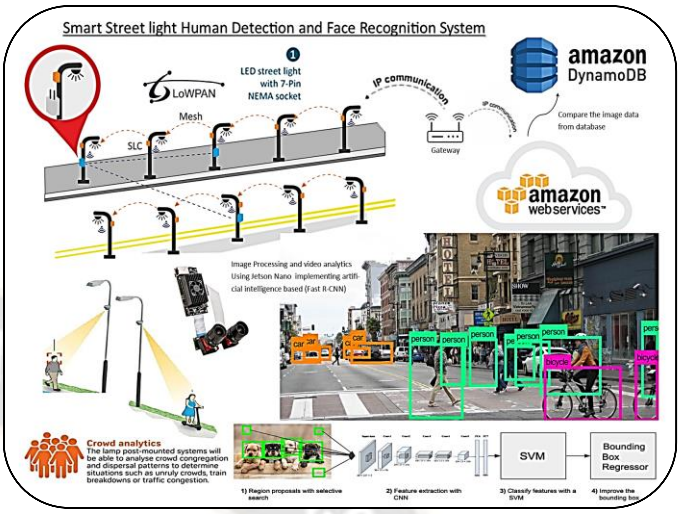

Figure 12: Intelligent Human Detection System

F. Intelligent Campus Safety Management System

This system is designed so that upon vehicle entry to the dedicated premise, the captured vehicle's image will be processed using OpenCV to extract the car plate, color and check-in timestamp and capture it into the AWS database. USM Security will be able to review the incoming vehicle real-time information as USM's staff or student's or outsider's vehicle via the dashboard. A similar process is applied for check-out vehicles.

Security will also be able to track outsider's vehicles with more than 12 hours residing inside USM's premises by relaying the vehicle plate and color to all SLaaS-enabled street light poles. Upon receipt, all SLaaS-enabled street light poles will capture the image of vehicles adjacent to each street light pole.

OpenCV will process the captured image to match the vehicle using the vehicle plate number or color. If the image comparison matches, the respective street light poles relay back the street light pole location and trigger the USM Security with vehicle plate number, color and street light pole location information (Fig. 13). Vehicle current speed and excess speed limit can also be monitored to warn vehicles upon approaching the pedestrian crossing lane.

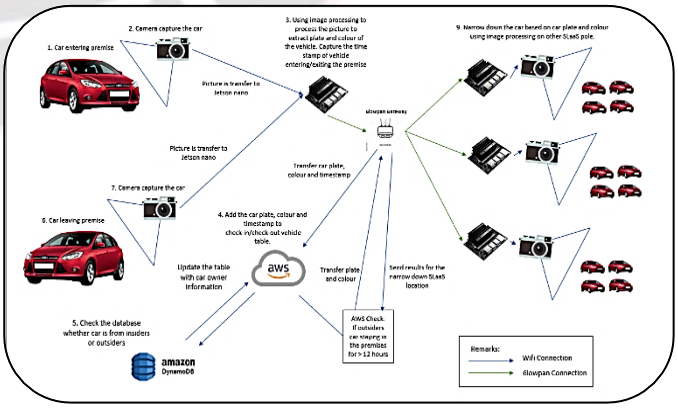

Figure 13: Intelligent Vehicle Security Management System

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G. Intelligent Parking Services System

Intelligent Student Services system focuses on the automated parking system. An ultrasonic sensor will detect an approaching object and have its image captured to be processed to determine whether it is a vehicle. Once confirmed it is a vehicle, the vehicle plate number in the captured image will be transmitted to AWS in the form of JSON array format to be processed for validating the vehicle registration status in the AWS DynamoDB database. Unregistered vehicle owners can proceed to register their vehicles using the nearby street light-based kiosk or using a website (Fig. 14).

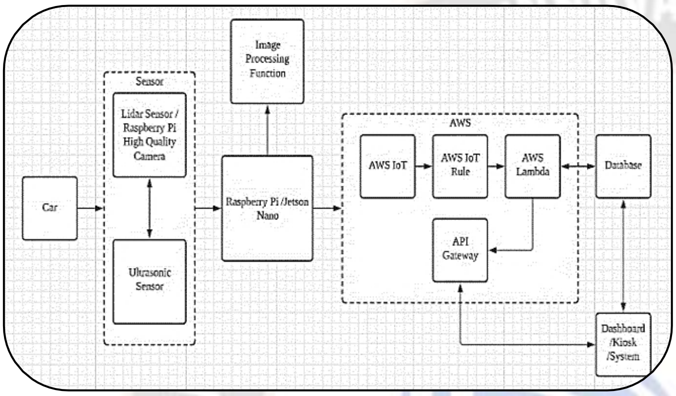

Figure 14: Intelligent Parking Services System

H. Proposed Hardware Components

1) Jetson Nano Developer Kit

NVIDIA Jetson Nano Developer Kit is a small-scale yet powerful and easy-to-use computer platform that enables the parallel execution of multiple neural networks dedicated to object detection, image classification, speech processing and segmentation applications.

Jetson Nano delivers 472 GFLOPS with a quad-core 64-bit ARM CPU, a 128-core integrated NVIDIA GPU, and 4GB LPDDR4 memory, running only as little as 5 watts to simultaneously process several high-resolution sensors to support lightning-fast modern AI algorithms.

Jetson Nano is also supported by NVIDIA Jetpack, which includes a board support package (BSP), CUDA, cuDNN, and TensorRT software libraries for deep learning, computer vision, GPU computing, multimedia processing, and much more.

The software development kit (SDK) also includes the ability to natively install popular open-source Machine Learning (ML) frameworks such as TensorFlow, PyTorch, Caffe/Caffe2, Keras, and MXNet, enables the developers to integrate their favorite AI model/AI framework into products fast and easily. The Jetson Nano will be used as the central processor to process the sensors' data and produce the output accordingly (Fig. 15).

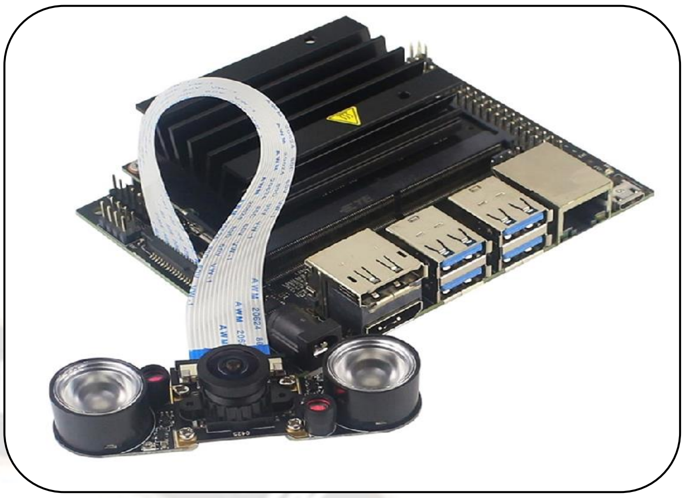

Figure 15: NVIDIA Jetson Nano Developer Kit

2) PIR Motion Sensor

Passive infrared (PIR) motion sensors to detect the approaching pedestrians' vehicles for adjacent-object monitoring, wireless Wi-Fi or Bluetooth sensor using CAN-BUS protocol to acquire vehicle's Onboard Diagnostics 2 (OBD-II) data (Fig. 16).

Figure 16: PIR Motion Sensor Module

3) LIDAR Sensor

The light-dependent resistor (LIDAR) sensor function is to detect light intensity based on the acquired variable resistance. When the light level is high, the LIDAR resistance increases. Similarly, when the light level is low, the LIDAR resistance decreases (Fig. 17).

Figure 17: LIDAR Sensor

4) Renesas/IDT ZWIR4512 Secure Low-Power Wireless IPv6 Module

6LoWPAN (IPv6 over Low Power Wireless Personal Area Network) is an IPv6-compatible low-power wireless mesh network protocol with its own IPv6 address to connect directly to the Internet using open standards. The ingenious 6LoWPAN idea is to enable Internet Protocol to apply to the smallest device form factor possible with limited-processing low-power devices to participate in the Internet of Things (IoT) (Fig. 18).

6LoWPAN advantages include the compatibility with open IP standards like TCP, HTTP, and WebSocket, among others, end-to-end IP addressable nodes without the need for a gateway, small 127-byte data packets for efficient and low transmission power, top performance in long-range communication, the capability of detecting signals below the noise level, and IEEE-compatible high-security standards suitable for IoT implementation.

Figure 18: Renesas/IDT ZWIR4512 Secure Low-Power Wireless IPv6 Module

5) Onboard Diagnostics 2 (OBD-II)

Onboard Diagnostics 2 (OBD-II) is the vehicle's self-diagnostic and signalling technology to permit vehicle subsystem status access by competent personnel. Since its 1990s introduction, the early generation of SAE J1850 PWM/PWV and ISO 9141-2 OBD-II protocols allowed up to 36 available parameters. On the other hand, the newer CAN-BUS-compatible OBD-II enables up to 100 generic vehicle-related parameters (Fig. 19).

Figure 19: Onboard Diagnostics 2 (OBD-II)

Expected Challenges

There are many technical challenges concerning using the 6LoWPAN protocol for data and control transmission. For the 6LoWPAN protocol, the packet loss was observed to start at around 35 devices with a corresponding delay of around 700 milliseconds. At 30 devices, the 6LoWPAN topology started to suffer packet loss with Packet Loss Ratio (PLR) at more than 5 per cent of the maximum 50 installed devices. It was concluded that the average delay is acceptable for a delay-tolerant system like a parking lot since it is reasonable to acquire parking space vacancy status within one or two seconds [44].

Malaysian Communications and Multimedia Act 1998, section 169 requires these devices to operate within the Industrial, Scientific and Medical Device spectrum [14]. Since the ZWIR4512 module operates at the 868 to 915MHz frequency band range, discussions with MCMC may be required to determine the equipment status.

TABLE I. Class Assignment No. 1 Of 2021 [45]

Applications	Frequency bands	Maximum transmit power/ field strength/Conditions	Reference/Remarks
Industrial, Scientific and Medical (ISM) device	6765 kHz to 6795 kHz	500mW EIRP	Refer to Fourteenth Schedule detailed conditions of operation and channelling plan
	13.553 MHz to 13.567 MHz		
	26.957 MHz to 27.283 MHz		
	40.66 MHz to 40.70 MHz		
	2400 MHz to 2500 MHz		
	5725 MHz to 5875 MHz		
	24 GHz to 24.25 GHz		
	61 GHz to 61.5 GHz		
	122 GHz to 123 GHz;		
	244 GHz to 246 GHz		

Conclusions

Pending experimental results, the proposed Street-Light-As-A-Service (SLaaS) research framework may be able to accept future extensions to the system to accommodate requirements for new smart campus services. By leveraging the cloud and edge computing intelligence, the proposed design can provide opportunities that offer flexibility, quicker time-to-market, and reduced service introduction cost, to position USM as the full-fledged cloud-based smart campus platform.

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