SMART TRAFFIC SIGNAL CONTROL SYSTEM FOR SMART CITY APPLICATIONS

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Abstract: *Inadequate space and funding to develop new roads and the steady increase in number of vehicles has prompted scholars to look for various solutions to the visitor crowds. One place gaining interest is using smart traffic control systems (STCS) to make site visitor routing decisions. These systems use real-time information and attempt to simulate human thinking, thus showing promise in managing and managing auto site visitors. In this paper, a smart traffic signal control (STSC) system is designed and implemented, it supports several smart city transportation applications including emergency vehicle signal preemption (EVSP), public transport signal priority (TSP), adaptive traffic signal control (ATSC), eco-driving supporting, and message broadcasting. The roadside unit (RSU) controller is the core of the proposed STSC system, where the system architecture, middleware, control algorithms, and peripheral modules are detailed discussed in this paper. It is compatible with existed traffic signal controller so that it can be fast and cost effectively deployed. A new traffic signal scheme is specially designed for the EVSP scenario, it can inform all the drivers near the intersection regarding which direction the emergency vehicle (EV) is approaching, smoothing the traffic flow, and enhancing the safety. EVSP scenario and the related control algorithms are implemented in this work; integration test and field test are performed to demonstrate the STSC system.*

Keywords: *Emergency vehicle signal preemption; vehicular network; adaptive traffic signal control.*

I. INTRODUCTION

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Traffic signal accessories, developed in 1912, are signalling devices designed to control traffic flow at street intersections, crosswalks, trains, and other locations. Traffic lights consist of three common-coloured lights: a green light allows visitors to continue on the indicated road, a yellow light warns motorists to stop briefly, and a red signal prevents traffic from continuing [1].

Nowadays, many countries have visitor congestion problems that affect city transportation mechanisms and cause critical dilemmas. Despite replacing visitor officers and teachers through computerized traffic structures, traffic congestion improvement is still a first-order problem that needs to be addressed, especially with multiple link nodes [2]. The rapid increase in the number of vehicles and the increasing diversity of road users is not accompanied by an infrastructure reinforced with sufficient resources. Partial solutions have been provided by constructing new roads, applying bridges and roads, developing ring roads, and rehabilitating active roads.

However, disturbing website visitors is quite complicated due to the involvement of various factors. First of all, traffic drift depends on the time of day as peak traffic hours are usually in the morning and afternoon; On weekdays, where weekends represent a minimum load, while Mondays and Fridays usually witness a heavy flow of visitors from cities towards their surroundings and in the opposite direction respectively; and time of the year as holidays and summer[3].

Secondly, modern traffic light hardware is implemented with coded delays in which the light transition times are mostly fixed and do not depend on real-time traffic flow. The third factor is related to the state of light at the intersection, affecting visitors' drift at adjacent intersections. In addition, the traditional visitor system no longer forgets the situation of accidents, road works, and vehicle breakdowns that exacerbate the crowds of visitors. Also, there is an important issue of clean movement through intersections of high-priority emergency vehicles, which include ambulances, rescue vehicles, fire brigades, police, and VIPs who can get caught in crowds. Finally, pedestrians passing through the lanes also disrupt the circulation system.

The traditional website visitor system needs to be upgraded to solve serious visitor congestion, ease transportation problems, reduce the number of visitors and preparation time, reduce the usual travel time, improve the protection and performance of engines, and expand the benefits in health, money, and the

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environment. This document proposes an easy, cheap, and real-time intelligent traffic control system to overcome many drawbacks and improve control over website visitors. The system is based on a PIC microcontroller that controls several operations, monitoring the volume of site visitors and drift intensity via infrared (IR) sensors and adjusting the lighting fixtures' transmission openings. In addition, a handheld device communicates wirelessly with the main traffic controller via XBee transponders if it wishes to perform the correct subsidiary actions and allow the smooth movement of emergency vehicles through the intersection [4].

II. RELATED WORK

More than 98% of respondents encountered ambulances on public roads in Dearborn Heights, yet 82.9% reported at least one pleasure in not responding as emergency vehicles approached [5]. The document stated that in the United States, between 2004 and 2008, there were 3,708 accidents involving emergency vehicles. After the in-vehicle recording machine (including the onboard unit, smartphone, and radio), the general driving interference is more intense, trying to prompt the driving force to react slower to the emergency vehicle. Emergency vehicles want to respond quickly to save lives and property. Early response is very important in some emergencies to impact lifestyles and loss of life within seconds. For every minute that first aid is delayed for a patient, the chance of survival can be reduced by 7 to 10%. Half a minute per shutdown will double the fire for a home accident. For traffic accidents, about one-third of deaths related to vehicle injuries can be avoided by ensuring quick rescue of emergency vehicles, so quick rescue is an urgent and crucial dependency [6]. To reduce the delay in EV rescue, Savolainen et al. Use the LED to display emergency vehicle signals. When the EV processes the crossover, the EV's OBU will communicate with the signal control unit. Then the visitor signal controller triggers the emergency vehicle LED flash, and bystanders can respond early to the emergency vehicle technology, then prepare for early arrival. However, EV drivers must slow down gradually when driving through the intersection because the signal control unit does not help prioritize the emergency vehicle signal. In [7], the EVSP system was proposed to address this problem by extending the green period or reducing the red period to facilitate the passage of EVs through the intersection. Assign extraordinary weights to special electric vehicle types, including ambulances, chimney sweeps, and police

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cars, so that the signal control unit can serve different types of electric vehicles based on their priorities. However, the difficulty is max and minimum green period in traffic engineering is not discussed in this article.

Qin et al. [8] proposed an improved algorithm that reduces response time and minimizes the effects of general traffic by using two control strategies. The system changes the traffic state to EVSP transition 1 to reduce the traffic impact time, after transition 1, the system switches to EVSP transition 2 for traffic flow compensation

Ku et al. [9]. Proposed a new traffic control device for voice exchange coverage management, conversation control, and remote control and developed voice exchange protocols between RSU, OBU, and the cloud.

Dweik et al. [10] proposed a more convenient and scalable road module with a speed adaptive traffic controller, an adaptive pollutant traffic control (PATC) system, a weather logger, and a control center. Master (MCC). Its goal is to improve the flow of visitors to the site by creating or maintaining accurate routes through PATC and using the MCC to display weather, coordinate road maintenance shows, and drive and hold in inclement weather.

Kantawong et al. have designed a smart visitor to talk to vehicles using RFID, combined with image compression analysis algorithms to develop a novel traffic cone vehicle detection and popularity system [11]. This article makes use of wavelet image compression with vector quantization.

Sanghyun Ahn et al. proposed a new V2I decision-making mechanism based entirely on street segmentation [12]. This mechanism can effectively reduce the burden of transportation. During the exercise, the vehicle sends a packet of messages in a specified area. The message packet may be lost due to environmental elements, and the traffic light controller is now not getting the information from the vehicle.

Fogue et al. [13] proposed an electronic notification framework device that uses sensors (such as airbag popularity, accelerator reputation, and brake reputation) and algorithms to determine if a match has occurred. When the device detects the vehicle's matching site visitor, it announces the message to the RSU. The RSU receives fate data from site visitors and uploads the records to the cloud platform via mobile communications.

Pandita et al. [14] proposed an adaptive control of visitor signals using an "oldest

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first arrive" (OAF) approach using the AV (802.11p) network. The OAF algorithm controls traffic levels where the first stage divides cars into platoons using real-time vehicle positions, first maximizing platoon size, then minimizing the difference in platoon sizes. In the second phase, the OAF schedules each platoon to pass the intersection through the oldest-come-first-served principle. Simulation results show that the OAF rule set has first-class performance compared to traditional site visitor signaling programming algorithms, which include pre-programmed common sense and Webster strategies.

III. SMART TRAFFIC CONTROL SYSTEM (STCS)

An intelligent traffic-controlling system is a vital research topic. Researchers worldwide are inventing new processes and structures to solve this troubling problem. Models based mainly on mathematical equations are applied to estimate the waiting time for cars at an intersection, the number of cars in the ready queue, the length of vehicles waiting along the lane, and the most useful periods for inexperienced, yellow, and red lighting. Accessories that are excellent and healthy for the real situation and a real and effective combination of steering. The interdependencies between close intersections lead to a complex method with large parameters. These parameters are unintentional, dangerous, and systemic. The most dangerous factor is the variability of these parameters over time. So, finding a suitable, regular, and dynamic solution is quite impossible.

Researchers from various disciplines are participating in discovering viable solutions that reduce visitor congestion. So, continuously different methodologies Numerous strategies have been proposed in the literature and implemented that take advantage of technological advances of microcomputers, state-of-the-art synthetic hardware and sensors, and progressive algorithms that are, as closely as possible, representative of traffic light concern. Infrared sensors are used in many traffic systems. The infrared transmitter and receiver are connected on both sides of the track. When a car on the street passes between the infrared sensors, the device is activated, and the automatic counter increases. Collected records about the traffic density of individual roads at an intersection are analysed if lane green light delays are to be dynamically adjusted for high traffic volume. The device can be managed through a PIC microcontroller or a PLC.

It is supported by radio frequency emitters that send warning alerts to radio transceivers at each light intersection to inform the site visitor machine of the arrival of emergency vehicles near the crossing. The visitor light fixture activation sequence is adjusted to provide one lane for emergency vehicles. Other researchers use GPS to talk to visitor light controllers and send priority signals. The ambulance is equipped with RF to talk to site visitors, a lighting control unit, and a GSM unit to document the clinic doctors' condition of the injured person and get messages about the method of treatment or restoration of the first resort. To be completed with the injured patient. Several works predict traffic intensity based entirely on image processing technology. But these strategies require purchasing accurate images determined by exceptional weather conditions, especially with rain and fog. Other researchers use state-of-the-art algorithms to model the many states of site visitors in combination with common sense and genetic algorithms.

The architecture of the proposed STSC system is shown in Figure 1, and it is composed by three subsystems including an RSU, an OBU, and a cloud centre. The RSU controller, connected to traffic signal control system, is the key component in STSC. It is implemented by an industrial computer designed by modularization concept where multiple external modules can be flexibly added onto the RSU by the general-purpose input/output (GPIO) interface. The supporting peripheral modules includes 802.11p V2X interface, GPS, changeable message sign (CMS), mobile communication (4G), And Wi-Fi/BT modules. In addition, the RSU has more GPIO for real-time traffic information extension, such as loop detector or video traffic analyser (smart AVI).

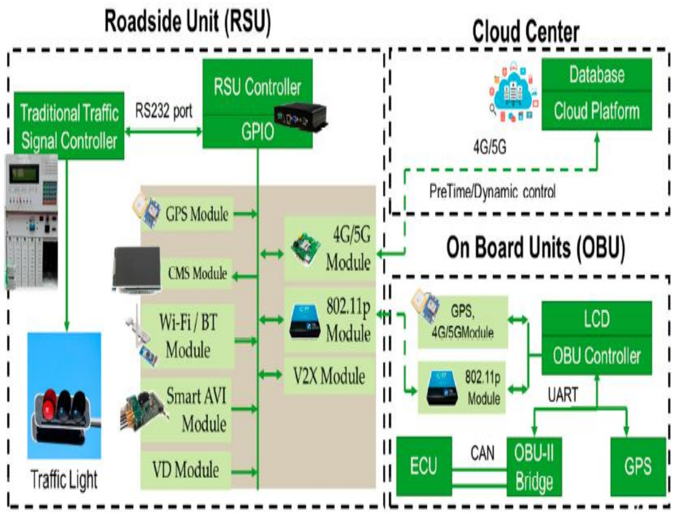

Fig.1 System architecture of the STSC system

For a quick and cost-effective STSC system installation, our idea is that the RSU should be compatible with existing infrastructure so that it is not desirable to replace traditional traffic controllers. The proposed RSU should easily connect to and manage the old signal control device while being considered as one of the peripheral devices. The modular device software structure is designed as shown in Figure 2, which is a five-layer hierarchical form of the RSU to achieve this intention.

The utility layer, which is the application software suite, supports six smart city programs, including Emergency Vehicle Signal Priority (EVSP), Traffic Signal Priority (TSP), Green Use by Signal Plan Sending, Road Works and Chance Warning, and Advance Time Management Signals and adaptive traffic signal processing (ATSC). The middle layer is the core of the RSU, in which seven core vendors are designed. The Traffic Statistics Agent and the Visitor Record Creation Agent are responsible for processing the statistics and integrating information gathered from external data assets (loop detector and smart AVI) to generate real-time visitor data for the ATSC. Five TX/RX messages on the OBU side, implemented by an embedded PC that communicates with various modules, such as 802.11p V2X interface, GPS, Mobile Voice Exchange (4G), and OBD-II interface. The OBD-II interface can study the vehicle data along with oil temperature, engine speed, speed, turn signal, etc. Cloud Center is designed with the help of a cloud platform and master database featuring control capabilities for all RSUs and OBUs. The RSU periodically publishes a plan of signals (lap time, green division, current phase, current countdown) and events (accident, street sign warning). Using an 802.11p interface, OBU-equipped vehicles can capture and interact with real-time statistics, including environmentally friendly driving and lane change recommendations. On the other hand, emergency vehicles equipped with OBU (ambulance, police car) will periodically publish a recent reputation for using the V2X interface. The RSU within the signal coverage range can collect EV messages and respond.

HostRSU Algorithm

The HostRSU algorithm determines whether or not the RSU should be responsible for an incoming emergency vehicle. As shown in Figure 2, while the RSU receives a message, it first tests the approaching position of the EV approaching angle ($\emptyset OBU_{(GPS,t)}$) and determines whether it is within the RSU's service angle. The message may be ignored if the angle of approaching EV traffic can no longer fit the RSU variety, so this EV may not drive into sections of that intersection. The algorithm then confirms the EVSP request by checking if the received OBU packets are more than a threshold ($C_{threshold}$). 0.33 test is the range of the carrier: the distance from the vehicle to the signal controller (δ) unit must fall on the provider number preset in the RSU; Otherwise, ignore the message. The RSU asserts that it is the host's RSU miles only if these evaluations are passed, returns reliability, and starts the EVSP system.

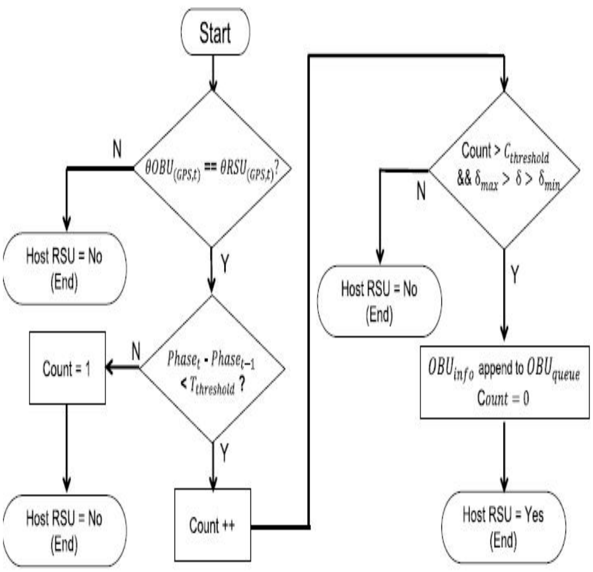

Fig.2 HostRSU algorithm.

Traffic Signal Control Algorithm

After the host RSU check, the RSU starts the EV signal preemption control process, where the control algorithm of this process is presented in Figure 3. RSU reads the current signal plan from the traffic signal controller, determining whether to extend the green period or cut off the red period to facilitate the EV passing through the intersection. The green mode (G_{mode}) indicates that the EV direction is currently in the green period and that it should remain green until the EV passes the intersection. If the EV direction is currently in red mode (Rmode), the signal controller should turn to green as soon as possible but still has to follow the minimum green constraints to ensure the safety of pedestrians.

A traffic signal guarding mode (Y_{mode}) is designed after the R_{mode} control is completed. The RSU judges the remaining green time G_{rt}) of the signal in the non-EV direction. If G_{rt} is smaller than minimum green protection time(G_{min}) R_{mode} , will continue until G_{rt} is greater than Gmin. It enters the traffic signal guarding mode (Y_{mode}), where the RSU will convert the non-EV traffic light from yellow to red. The RSU controls the signal into green mode (G_{mode}) after Y_{mode}, and stays in G_{mode} until the EV leaves.

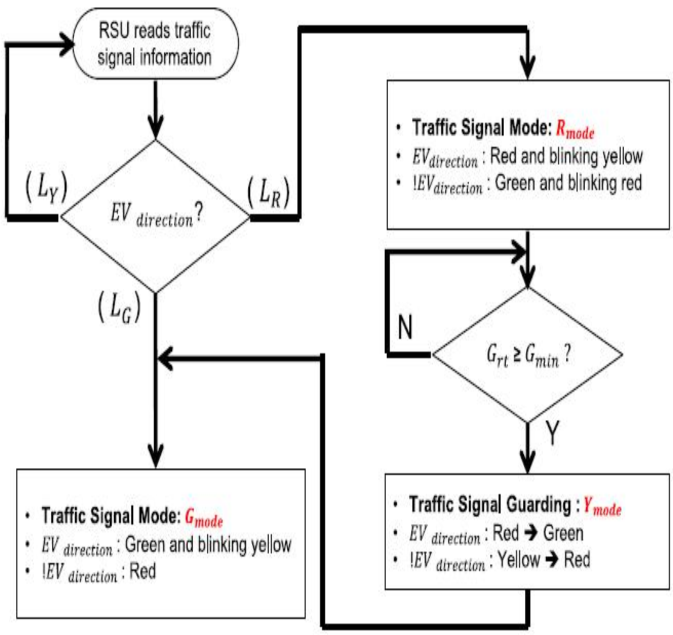

Fig.3 Traffic signal control Algorithm

A new traffic signal processing mechanism was designed to make operating the EVSP

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machine easier. It consists of two flashing visitor signal modes: R_{mode} and G_{mode}, as shown in Figures 10 and 11, in which R_{mode} is responsible for processing the signal manipulation action while the EV direction signal is red, and G_{mode} is responsible for the state in which the signal is green. Unlike a traditional green/yellow/purple light, a hybrid signal scheme is designed to notify all nearby vehicles and pedestrians that an EV event has occurred and displays records about which direction the EV came from. For example, the sign will appear pink with a yellow flash at the same time inside the direction of the EV to let all motors know where the EV is going. The sign will change to green as quickly as possible and green with a flash of yellow to make it easier for the EV to pass through the intersection.

IV. ELECTRONIC COMPONENTS

The circuit of the smart signal traffic control machine is mainly implemented based on various electronic components consisting of a programmable intelligent controller (PIC) 16F877A microcontroller, microcontroller, an LCD device, XBee transceivers, a pair of infrared sensors, button pushbuttons (EA, EB, and 1 to 4) and several colored LEDs representing the three lights (pink, green, and yellow) of the A and B visitor lights associated with lane 1 and a pair of plus the two lights (pink and green) of the R and L visitor lights associated with the right turn and left onto the track from lanes 3 and 4.

a) Microcontroller PIC 16F877A

The PIC 16F877A [19-23], a proprietary family of Harvard frame microcontrollers manufactured by Microchip, is an integrated circuit (IC) consisting of a simple central processing unit (CPU), RAM, ROM, and EEPROM. It also has a clock, timers, A/D converters, and 5 I/O ports. On the contrary, its 35 instructions make it smooth and easy to program. In addition, its power consumption is low and has a wide operating voltage range (2V to 5.5V) while its input clock runs up to twenty MHz. The pinout of the PIC 16F877A microcontroller is shown in Figure 2. The 5 bi-directional I/O ports can be classified as follows: A is a 6-bit common cause port that can also be configured as an analog-to-digital (A/D) converter; B, C, and D are 8-bit general-purpose ports, while port E is just a 3-bit port. These ports are used to input stats generated from the keyboard, sensor, push button, switch, and many more. Or to provide command or data indications to output devices along with LCD, 7 phase, LED, motor driver, relay, etc. Each port has a personal TRIS record associated with it. The configuration of these TRIS

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registers is to choose the data transmission path between the microcontroller and the privileged peripherals over the ports. When the TRIS register is cleared, the corresponding port acts as an output. Otherwise, it acts as an input.

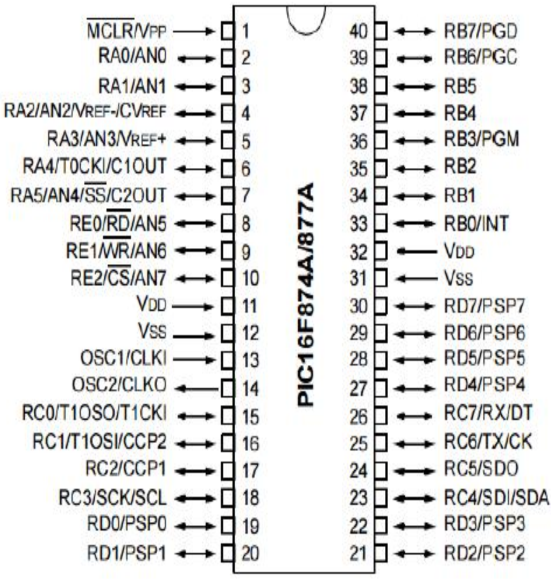

Fig.4 Pin configuration of the PIC 16F877A microcontroller

b) LCD display

A liquid crystal display (LCD) is a flat, dimmable, electricity-efficient, and truly programmable display that can be used in many virtual and digital circuits. It uses a matrix structure where the active details that make up the traveling pixel are placed within the intersection of two electrode strips. In particular, the 16×2 LCD screen used in the applied prototype could display records in two lines, each of sixteen characters. Register patterns are used to configure the LCD; Command recording is generally recommended for processing commands such as LCD initialization, screen scanning, cursor positioning, and screen control. The login records contain the ASCII code of the characters that appear quickly in the program..

c) IR sensor

An infrared sensor is an electronic device implemented to detect boundaries or distinguish between objects based on their properties. Usually, it is used to measure body temperature or movement [25]. The infrared sensor emits or receives infrared radiation (430 Hz - 300 GHz) that is not visible to the human eye. An LED (Light Emitting Diode) can also act as an infrared emitter. In contrast, an infrared detector is a photodiode element sensitive to infrared light of the same frequency as the emitted radiation. The operating concept is simple: when the infrared radiation from the LED reaches the photodiode, the output voltages are exchanged according to the value of the infrared light.

d) XBee transceivers

The XBee transceiver module, series 2, allows the development of complex mesh

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networks based on ZigBee firmware. It supports easy and secures full duplex communication between microcontrollers via a serial port start switch. The XBee's features (2mW output, 120m range, built-in antenna, max data rate of 250kbps, and eight digital I/O pins) are adequate for our purpose. In addition, XBee supports point-to-point communication using a single traffic light controller and multi-agent networking to support using more than one site visitor controller. In an XBee setup, the worker connected to the handheld console acts as a server, while the light console attached to the site visitor is populated in host mode. XBee's features provide immunity to interference from neighboring structures and prevent interaction from closer systems limiting interruption to their offerings.

STSC SYSTEM HARDWARE IMPLEMENTATION

The OBU is implemented through an embedded PC (Raspberry Pi 3), which connects 802.11p GPS modules and a small LCD to display messages, as shown in Fig. 5a,e. The 802.11p Speech Exchange Unit (IWCU V4.2) developed by the Industrial Technology Research Institute (ITRI), shown in Figure 5b, is used for V2X communication. The unit's hardware interface consists of PCIe Gigabit Ethernet interfaces, an RS232 port, and USB2.Zero ports. It is a Linux-based boot device with an SDK and cross-compiler. On the STSC device, we implement the 802.11p module both in the RSU, and the OBU prepared in the EV.

A small commercial computer is followed as an RSU (SEM-6338), as shown in Figure 5c, where the main components include a SOC (AMD® G-Series), 8G DDR3 RAM, 2 RS232 ports and 1 RS232/422/485 port, and an Ethernet interface and four USB ports.

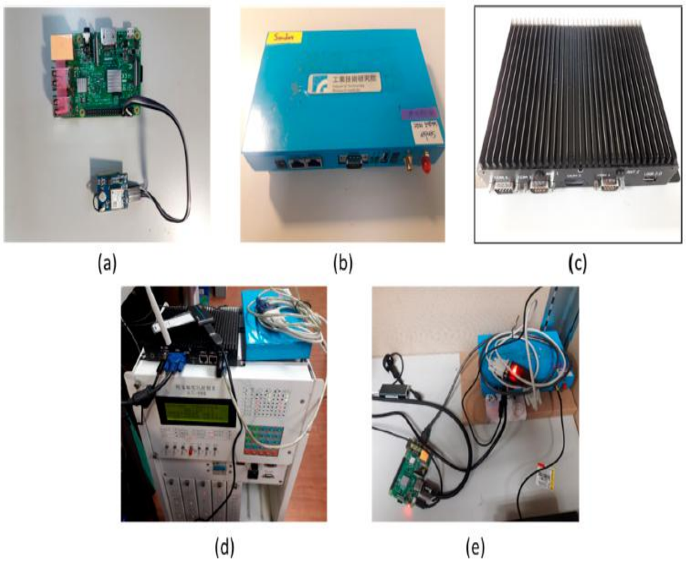

Fig.5 STSC system hardware implementation: (a) OBU embedded computer, (b) 802.11p module, (c) RSU controller, (d) RSU prototype system, (e) OBU prototype.

RSU Controller and Signal Controller Integration

The RSU communicates with the signal control device and periodically reads the site visitor's signal plan, which includes signal field information, section spacing, steps, seconds, and control strategy. The RSU can send instructions to the signal control unit, including extending the green duration or decreasing the red duration. The RSU periodically publishes the signal plan in real-time via 802.11p, Bluetooth/Wi-Fi interface, OBU, or smartphone APP in various radio signal coverage. It can obtain the signal plan statistics and interact with the signal plan. For example, cars can take action before the signal changes and turns green or redirects. The integrity check test is performed using the EVSP case, as shown in Figure 15, where an LED signal simulation board is connected to the signal engine to simulate the key output of the control algorithm. We simulate the EV graphic near the intersection, and the message sent by the OBU is collected through the RSU and displayed on the screen (lower left element). The EVSP processing algorithm sends commands to the signal controller to execute the complete EVSP methods (reduce the right part). SENSORS 2020, 20, x FOR PEER REVIEW Output 16 of 19 from the designed processing base set. We simulate an EV plot near the intersection, and the message sent by the OBU is grouped using the RSU and displayed on the screen (left pane decreasing), EVSP control.

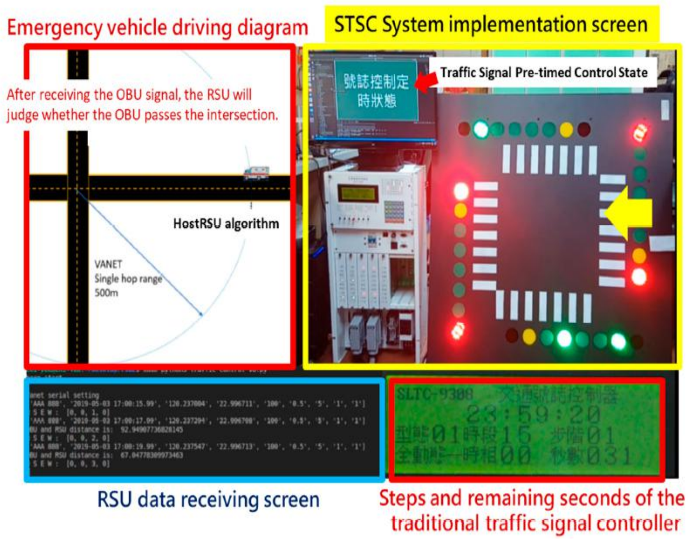

Fig.6 Testing EVSP functions in the lab

Some module verifications in the RSU are performed, including state transmission test, RSU host algorithm, in-country EVSP signal control check, and emergency vehicle departure judgment feature. The features within the OBU consist of checking the GPS and 802.11p units and stating the facts continuously at a fixed frequency (1 Hz). We also conducted an in-depth test on HostRSU's selection check feature, long-running processing mechanism, distance threshold judgment mechanism, segment perspective matching mechanism, and multiple dedication checks. Emergency vehicle application.

V. CONCLUSION

This paper proposes a multi-modal smart traffic control system (STSC) for smart city infrastructure, which can be widely implemented for smart transportation machines in smart city software. Major components within the proposed STSC include the RSU, OBU, signaling control unit, and cloud center. It supports many smart city applications, including EVSP, TSP, green usage, ATSC, pre-signal management, and R2V messaging. The RSU is the core of this work, where we discuss the system architecture, middleware, peripheral hardware units, and control algorithm in detail.

The proposed smart traffic system consists of a traffic signal controller that manages lighting for visitors to the "+" intersection of one-way roads. The system can estimate the density of visitors using infrared sensors placed on both sides of the road. Accordingly, the time spent on a green light will either be extended to allow most cars to move ahead of the flow of cars if a traffic jam occurs or reduced to avoid useless waiting times while there are no cars on the road. Reverse.

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