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EVbot with Defibrillator for Medical Services in Smart Cities

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Abstract:- **A keen city is an urban improvement vision to incorporate data and correspondence innovation (ICT) and the Internet of things (IoT) innovation in a safe mode to deal with a city's benefit. Using sensors incorporated with continuous checking frameworks, information is gathered from nationals and gadgets – then prepared and broke down. The data and information assembled are keys to handling wastefulness. Time is a basic issue when managing individuals who encounter a sudden heart failure that tragically beyond words to detachment of the crisis treatment. Along these lines, a prompt treatment utilizing Automated External Defibrillator (AED) must be directed to the casualty inside a couple of minutes in the wake of falling. Subsequently, we have outlined and built up the Ambulance Robot, abbreviated as EVbot, which brings along an AED in a sudden occasion of heart failure and encourages different methods of operation from manual to independent working to spare somebody's lives in savvy urban areas. Points of interest of the plan and advancement of such robot are introduced in this paper.**

I. INTRODUCTION

The concept of high-tech machines that can serve the people well or relieve humans of tiresome chores has been an object of human imagination. It can be seen with many of today's occupations have been replaced by automation in order to help prevent manual handling injuries in the workplace. The smart world is expected to involve ubiquitous sensing, computing, and communication to achieve comprehensive interconnections of physical perception, cyber interaction, social correlation, and cognitive thinking. Increasing population density in urban environments demands adequate provision of services and infrastructure. This explosion in city population will present major challenges, including air pollution, traffic congestion, health concerns, energy and waste management. As an emerging platform for that domain, a mobile robot can be employed in order to facilitate the health care operation as a smart operating vehicle in the smart cities. In contrast, a mobile robot would be able to travel throughout the environment and can put their position wherever its condition. Mobile robot is an autonomous or semiautonomous machine that's capable to move around in their environment and also can perform various tasks either with direct or partial control by human supervision or completely autonomous. By using multiple sensors for navigation, this robot can navigate from a point to a given destination without losing the correct path or hitting obstacles. There are various sensor types used for autonomous navigation in the mobile such as vision and range sensors. Mobile robots are mostly used to investigate hazardous and dangerous environments where the risks of human operation exist. This robot can also be used to interact with human such as take care the elderly and doing household chores. In future smart cities, mobile robots can take over some tedious and time-consuming tasks. Most rescuers occur shortly after the event of a calamity happens. In that event, human rescuers will organize the rescue planning to get out to the calamity areas, find the victims, and help them as fast as possible. They have very short time to find the victims in any calamity situation; otherwise the likelihood of finding the victims still alive is nearly zero. In the case of health emergency, it is common to call the emergency hotline to seek for assistance which often the

ambulance will be dispatched to the scene in average of ten minutes time. Details of that information are depicted in Figure 1 for various territories. In practice, the advent time of ambulance is far above the ten minutes standard. This is owing to many obstructions during the process of dispatching an Ambulance and it may defer the patient from receiving the service on time. Substantially different factors prevail in this issue ranging from traffic congestion, difficulty to locate the address, long distance, and so forth. Any one of these delays can lead to increase response time. Meanwhile, it is a very hard task for bystanders to locate the nearest Automated External Defibrillator (AED) in a situation where someone is suffering from sudden cardiac arrest. To tackle these problems, we have designed and developed an ambulance robot (EVbot), which can place a small package containing an AED to save lives of cardiac arrest victim.

II. BACKGROUND

By considering instances where human failing could be exceeded by possible robotic alternatives, it is proposed a future where robots would be elevated in our society to function in roles beyond that of mere service entities, but actual allocators of resources and intenders of people. The Internet of Things revolution is redesigning modern healthcare with promising technological, economic, and social prospects. Hence it is required to develop new smart technologies to provide advanced healthcare service to the citizens of smart cities and in this paper, we aim to present one of feasible solutions for one of the critical problems of modern cities. Despite the very useful functionality of AED and even though this device is placed in various public areas nowadays, practical operation of AED still requires improvement which motivated us to develop a robot to perform such critical task in smart cities. Real case scenarios show that it is often difficult to find out the nearby AED when a panic situation occurs, bring and apply it to the victim. Several people are also required to get familiar with AED in advance.

2.1 Automated External Defibrillator

Sudden cardiac arrest is a condition in which the heart abruptly and unexpectedly stops beating due to a lack of oxygen getting to the brain and other organs. This is one of the leading causes of death in both men and women worldwide. It can happen anywhere at work, at home or anywhere else. Cardiac arrest commonly arises in individuals who have not had any heart problems or not in the well-recognized high risk for heart disease. Automated External Defibrillators or AEDs are designed to help someone in cardiac arrest. These devices should be applied to the victim as rapidly as possible to minimize any serious side effects while paramedics are en route the scene. However, it may take a long time to get an AED at nearest scene of victims because AEDs are not available everywhere. Therefore, we have proposed EVbot as a platform to save someone's life during cardiac arrest.

An emergency could arise at any time with no warning. It could jeopardize and bring significant injuries on a person's life. Saving someone's life in many emergency situations demands sophisticated and organized rescue planning. The aim of this planning is to get out to the disaster areas, find the victims and help them as fast as possible. This emergency could be broken down into two basic categories, natural and manmade calamities. Natural calamity is the phenomena of nature caused by environmental factors that can bring catastrophic consequences. While the world population grows rapidly with increasing their concentration in hazardous environments without giving much consideration to the local geo-climatic conditions have exacerbated the devastation caused by natural calamities. Consequently, different forms of natural calamities like drought, earthquake, extreme temperature, mass movement wet, typhoon, and volcano strike according to the vulnerability of the area in the globe.

Meanwhile, the fate of patients cannot be influenced by waiting the ambulance but rather could be changed if some treatments could be given within a few minutes of the patients collapse. For instance, individuals suffering sudden cardiac arrest could be saved if the AED is applied within a few minutes after the occurrence of cardiac arrest. At the same time, someone who helps the patient must be able to perform CPR (Cardiopulmonary

Resuscitation) and attaches an AED to a person in cardiac arrest. The AED is small electronic portable defibrillator designed for minimally trained or untrained non-medical personnel. This device can generate single-phase and double-phase waveforms. Single-phase waveforms generate a high-energy output. It may cause damage to the heart and skin. In contrary, double-phase waveforms produce a low energy output.

According to the guideline of using the AED, the helping person needs to call for ambulance immediately even before applying the AED. In the case of existence of two helping people, one is advised to call for ambulance while the other one is dealing with the AED. Though AEDs are deemed as medical devices, yet lay people can use these. However, it would be better if these were doing by someone who has completed a first aid training course. Despite the fact that AEDs are located in many public places, in practice it is difficult for people to find these in an emergency situation.

Intelligent Vehicle

To help improve safety on our roads, the world's automotive manufacturers have developed and continue to develop a range of advanced driver assist technologies that are designed to prevent or correct driver errors and in some cases, take the human factor out of the equation altogether. For instance, when intelligent vehicles detect dangerous situations they will alert the driver to prevent accidents and increase crash survivability with incorporating automatic active vehicle safety techniques such as driver fatigue detection or warning mechanisms and other driver-assist tools into vehicles.

Intelligent vehicles are equipped with sensors to perceive their surrounding environment and with actuators to act in their environment. The basic sensing and actuation technologies for intelligent vehicles are readily available on the market. Automated systems in the intelligent vehicle must consider the control strategies associated with the sensor data processing and reasoning, including the interaction of the technology with the driver. Fundamental components of an intelligent vehicle are perceived and model the environment where it is moving, reason and decide about future actions to execute, and finally perform the actions. Perception plays a fundamental role in construction of an intelligent vehicle as it constitutes its first component and provides information to other components. Its objective is to interpret noisy and raw data of different sensors embedded on a vehicle to model environment and understand current situation to provide necessary information to decide future actions to execute. The quality of perception processing has an impact on the quality of the whole process.

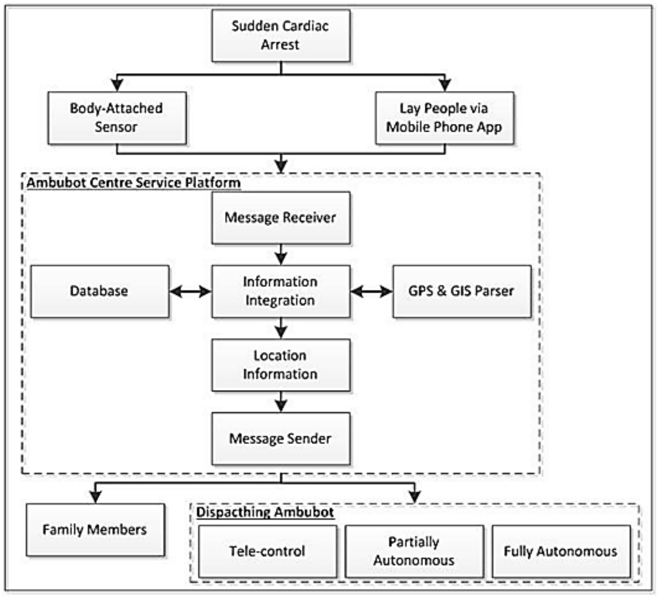
Intelligent vehicle can be related to intelligent transportation system (ITS) that consists of two parts, which are intra-vehicle and inter-vehicle area networks to assist driver safety. Intra-vehicle systems are becoming necessary components of vehicle where it deals with the data communication network of onboard equipment for assessing a driver behavior or a vehicles performance. These communications enable vehicle diagnostics where a technician can plug a tester into a port in the vehicle network and may be able to examine the operational state of various components of the vehicle as well as fluid levels and engine performance. Inter-vehicle communication is another key element of intelligent vehicle that includes vehicle-to vehicle, vehicle-to-cloud communication, and vehicle-to roadside infrastructure communication using roadside units. The main challenge of inter-vehicle communication is security and privacy protection. If the security or privacy protection provided is too high, this might reduce intervehicle communication benefits and negatively affect application performance.

2.2 Rescue robots

Most rescuers occur shortly after the event of a calamity happens. In that event, human rescuers will organize the rescue planning to get out to the calamity areas, find the victims, and help them as fast as possible. They have very short time to find the victims in any calamity situation; otherwise the likelihood of finding the victims still alive is nearly zero. In such a critical situation, technology can be used to support rescuers in different tasks. Intelligent mobile robots and cooperative multi-agent robotic systems are increasingly being used in many different ways to find and save the victims in a faster and more efficient way. The robot that can do such tasks is well known as rescue robot. Rescue robot is a robot that has been precisely designed to do rescuing jobs in situations that are hazardous for mankind to handle it, for instance rainstorms, collapsed buildings, obstructions, and dangerous substances. Rescue robots can be broadly divided into four different categories depending on modality and model size. There are four different groups of rescue robots based on modalities namely UGVs (Unmanned Ground Vehicles), UAVs (Un-manned Aerial Vehicles), UUVs (Unmanned Underwater Vehicles), and USVs (Unmanned Surface Vehicles). UGVs are typically placed on the ground to help human rescuers to find and interact with trapped or hurt the victims in areas that too dangerous for mankind. UAVs are developed to transport medical treatments to the victims. These robots can extract meaningful information about the surrounding conditions of its environment to the responders. Water-based robot also called as UUVs are designed to replace humans for working under-water where it is both dangerous and difficult for humans. These robots can search through water and find victims, and dangerous subject or substance. On the other hand, USVs have ability to work on the water surface. These robots can help rescuers to locate the victim and bring some equipment to victims.

Medical robots

Nowadays, most of robots that have been commercialized to the market are typically created for industrial sectors, such robots called as robot manipulators. With increasing development of technology in robotics, these robots have been widely used in companies to replace human laborers involvement in hazardous and harmful tasks. The number of robots used in industrial production has grown strongly within the past few decades. On the other hand, development of robots in service sectors is still limited. These robots are often called as service robots because they perform tasks for people instead of serving industrial manufacturer. Service robots are often mobile, capable of working independently, and interacting with humans. Moreover, these robots are comprised of various types and one of them is medical robot. In the recent years, application of robots in medicine has become a more interesting topic for both robotics researchers and general public. They have been used to fundamentally change interventional medicine with robots and bring some new techniques to support physical therapy, rehabilitation, and even perform more difficult procedures.



III. AMBULANCE ROBOT FOR SMART CITY

As mentioned earlier, we used EVbot as a platform to save someone's life during cardiac arrest. There are two techniques that can be used to keep cardiac arrest victims alive either by body-attached sensor or mobile phone application, as pictured in the sectional view Figure 3. Whenever one of them is used, they will immediately send out warning message and Global Positioning System (GPS) information to EVbot center. EVbot center will convert the longitude and latitude coordinates into a street map location using a GPS and GIS parser. in the case of using the body-attached sensor acceptable as fall sensor, this location could be integrated with other basic information about the victim such as personal contacts and characteristics, blood type, height, weight, and photograph to generate the complete information needed for search and assistance tasks.

After EVbot center processes this data packet, it will generate two commands namely a command for dispatching EVbot from the station to the scene as precaution to save patient life before ambulance arrives and other command for delivering an emergency message to family members via Global System for Mobile Communication (GSM) so they can obtain relevant information concerning the falling person via mobile phone. Family members will be alerted through this message in case of victims have been mounted with the body-attached sensor. We also consider informing ambulance from the nearest hospital after confirmation of the incident. EVbot is capable of driving up to 10 km/hour and passing slopes up to 45 degrees. With faster maneuverability, this robot can be driven on rough terrains and capable of climbing up the staircases to mitigate the late-ness problems of the ambulance.

The hardware design of the body-attached sensor mainly consists of a GPS satellite location module, a gyro sensor, a microprocessor, and a GSM communication module. The body-attached sensor could be integrated in the objects that a person frequently uses (e.g., glasses frames, belts, and watches) as a wearable device to give a convenience without disturbing the person daily lives. The dimension of the body-attached sensor is suitable for the fixation on the human body and produces low power consumption. The GPS satellite location module is used to provide satellite location information needed to find the shortest path of victims, such as longitude/latitude coordinates, time, and direction. The gyro sensor is integrated with accelerometer x, y, and z thus acceptable as fall sensor. This fall sensor is able to monitor a person's posture and movement so it may help either to identify people at risk of falls or to guide interventions to reduce risk of falls for individuals who have been identified at risk. This sensor will be concatenated with tag that contains the patient identification code. A patient can be identified by identification code once registered. Information including the patients name, date of birth, age, photographs, relatives contact information and personal health history will be generated by EVbot center to help ensure the patients safety. The microprocessor is in charge of computation and command execution as the main intelligent hardware module. When the gyro sensor sensed that the patient collapse, the microprocessor will transmit a short message to notify family members. The GSM communication module is used to provide a communication channel to transmit emergency rescue messages concerning the patient to EVbot center and receive commands from the server. Since the body-attached sensor requires a certain amount of power to function properly, it is important to have a power supply that can provide the right amount. When 10 % of the power is left, this function sends a message to family members to replace the battery so as to ensure the normal operation of the system.

3.3 Tele-control

Tele-control assists human operator to direct maneuvering EVbot using a visual display and a control pad. In general, the main function of tele-control system is to assist human operator to perform and accomplish complex, uncertain tasks in hazardous, and less structured environments. In this mode, an EVbot needs a people like driver who in charge to control the robot with using a remote-control device, which resembles a controller panel, and watch the real-time video stream from two surveillance cameras on EVbot to navigate, locate, and approach the victim. In this scenario, when EVbot approaches the victim, human operators from the control center provide detailed instructions to people near victim to operate the AED device carried by EVbot.

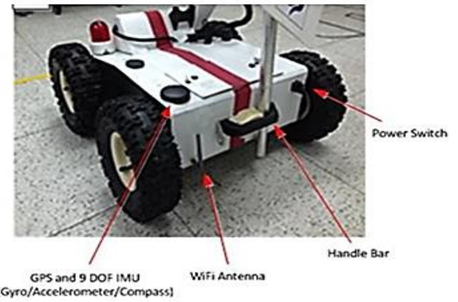
3.4 Partially autonomous operation

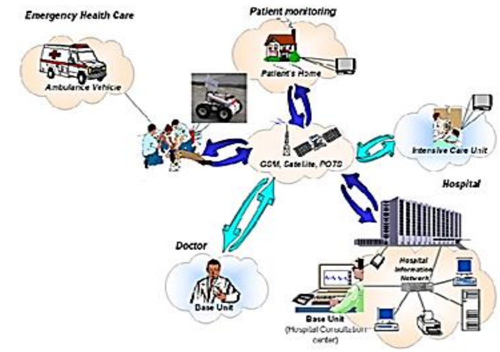
In this part, the task execution of EVbot utilizes both autonomous functions of the robot and direct maneuvering by human operators. The flexibility and human intelligence become key factors in controlling the robot for partially autonomous. It is due to the robot is not intelligent enough to make complete task plans and not capable of performing useful tasks in the real world for extended periods. However, if the environment is sufficiently stable and the disturbances to EVbot are not too severe, the robot can indeed perform useful tasks for extended periods. Safety issue is another concern. Hence, human operators should help in accommodating task procedures to the real environment and they will react independently to dynamic changes in the environment of EVbot so as to achieve the task robustly. Humans near the victim still play an important role to apply the pads of AED on victim's chest. When EVbot center receives the GPS information regarding the victim, the main server located in the server computes the shortest path and transmit it to the robot.

EVbot will carry an AED and follow the path for tracing the victim until the destination has been found. In contrast to previous mode where human operators should take full control of EVbot during movement, in this stage EVbot is in autonomous navigation and obstacle avoidance mode. EVbot reports the current situation and dis-plays the motion through streaming video by using two surveillance cameras mounted on the robot, one in front of the body and the other one on the arm. Such operation mode could improve the task of navigation compares to the manual mode. Additionally, it may help to reduce the stress of the operators because they can easily understand what the robot is going to do, how to send data to EVbot, and operators only take over the operation of EVbot when necessary. Although there is no human intervention in controlling the robot yet in this mode the operator assistance still needed to deliver some additional information to EVbot based on the circumstances.

3.5 Fully autonomous operation

While it has been shown earlier, the process of dispatching EVbot can be performed in tele control or partially autonomous, as the most advanced mode, it can have other practical use for delivering an AED to the location of victim through a fully autonomous navigation and the AED operation. In this mode, EVbot can move and perform desired tasks in frequently changing environments without continuous human guidance. The main difference lies on the execution of AED. In the previous sections, lay rescuers applied the pads of AED by themselves on victim's chest. However, in this mode EVbot executes AED by itself without continuous human guidance. In our future, EVbot will perform CPR as the first aid to save the victim life in cardiac arrest. EVbot grabber will execute these two tasks. The grabber has been de-signed well to be light enough to apply the pads of AED on victim's chest and strong enough to withstand an AED. One of the challenges here would be in the case that the victim is not in a suitable posture to apply the pads of AED. In this instance, a bystander can provide assistance with placing the victim in the recovery position in order to enable EVbot to gently attach the pads of AED on victim's chest.





IV. ROBOT OPERATION

In the process of developing EVbot, we first focused on the first mode namely tele-control to take complete control over the EVbot operation due to the difficulty of implementing other mode in real health care environment mostly because of safety issues. Such issue is practical when an accident occurs near EVbot station and in our experimental tests we have focused on the campus of National Taipei University in Taiwan campus. The map of the campus is illustrated in Figure 12 which can be considered as a smart supervising human operator and different sensor systems of the robot has opened a broad field of applications that cannot be achieved by a fully autonomous system. These various sensors play a vital role to adjust the behavior of the robot according to its surrounding situation. Aside from that the recognition and decision capability of a human is much better than an intelligent robot because human can easily identify objects and its geometric features while it is extremely difficult to be done by the robot.

Fig. 4. System structure of Ambulance Robot

In tele-control scheme, the operators must continuously operate and monitor EVbot. Subsequently,

EVbot accepts command tasks from human operator to move the robot from its initial position to its prescribed goal, and this task planning relies mostly on the human supervision. Nevertheless, the interaction between human operator and EVbot allow the operator to feel the remote environment and can control the motion of the robot intuitively. This kind of cooperation is acquired from visual and other feedback from different types of sensors so that can provide precious knowledge to the robot. In order to save someone's lives in cardiac arrest, human operator gives two commands through EVbot namely the motion command for controlling the robot so as the robot can deliver an AED and reach the location of the victim on-time while another command is in the voice commands for instructing people in the vicinity of victim to operate the AED device. Under instruction from the human experts in the main center the lay rescuers will dry the victim's chest and attach the AED pads by hemselves. With using two surveillance cameras mounted on the robot, one in front of the body and the other one on the arm, EVbot will report the current situation to operators and display the motion through streaming video. The tele-control mode includes the robot located in the station and the control server equipped with computer. EVbot center service platform consists of three servers, which are implemented on three independent server systems namely database server, message controller, and GIS server as illustrated in Figure 6. All servers are located within a firewall to enhance the system security. Database server is designed for data storage and management. A message controller server is connected to the telecoms short message server for enhancing the efficiency of message processing including the acceptance and transmission of a larger volume of short messages via network packets.

The other server is Geographic Information Server (GIS) used to convert the GPS longitude/latitude coordinates to location information in terms of street address and important landmarks, allowing family members and EVbot to efficiently acquire geographical spatial information concerning the falling patient and dispatch EVbot more effectively. In addition, this server is solely responsible to assist EVbot to find the possible shortest path between EVbot and victim. That topic is also part of our research to enhance efficient navigation system for the robot.

In the proposed technique, the body-attached sensor is recommended for use in patients who have had experience with cardiac arrest so that emergency prehospital care can be provided on-time by dispatching EVbot to the victims premises before land ambulance services arrive. EVbot system architecture involves ICT technologies to help relieve both survivors and victims family members in saving the victims life before reaching the hospital. Since our service center is connected to the GSM network, it allows the system to overcome the GPS problem in terms of invalid signal. The system utilizes GSM-locating service provided by a local GSM network company to trace the location of victim. Though it was not displaying the location of victim precisely but it can resolve the problem of not being able to locate the victim in bad weather conditions.The block diagram in Figure 7 shows the gradual implementation of dispatching EVbot that will arrive to the premises within ten minutes of collapse. With using telepresence, it allows an operator to remotely control the movement of EVbot to the scene. The control is given to the operator not only in the case of non-critical environment but also in a critical situation or bad visual feedback thus the operator can rapidly control EVbot. An emergency message and current position of victim will be generated by both of two applications, which are body attached sensor and mobile phone application. These data will be evaluated and thereupon transmitted automatically to EVbot center immediately after a sudden cardiac arrest happens. The majority of people use smart mobile phone. Therefore, the development of mobile phone application connected to EVbot center is convenient because it can provide on-time medical care to the victim. Alternative method in the case of lack of smart phone would be to call the EVbot center. In order to generate a street map location of victim, EVbot used GPS and GIS parser to convert the longitude and latitude coordinates to location information concerning place of victim with cardiac arrest. In EVbot center, history of victim during cardiac arrest is stored in database server. This is extremely useful for family members to elicit new sight and understand victims healthcare. Upon GIS server obtains the location information of victim, this server will track down the location of victim and convert it into important landmarks. It will produce the high precision and accuracy of information about victims current position thus allowing EVbot to be dispatched more effectively. Afterward, history and location information of victim will be integrated with message controller server. This server will hook up with telecoms short message server for the process of sending the message to family members. This message combines with other basic information of victim such as personal contacts and characteristics, blood type, height, weight, photograph, and health history of victim in cardiac arrest, while also will inform family members of the shortest path to reach the victim. After receiving detailed information of the collapsing victim, the operator will guide EVbot to locate the victim in short time as possible.


AMBUBOT
Ambulance Robot

Latitude: 43.8577276694 Longitude: -79.364895737

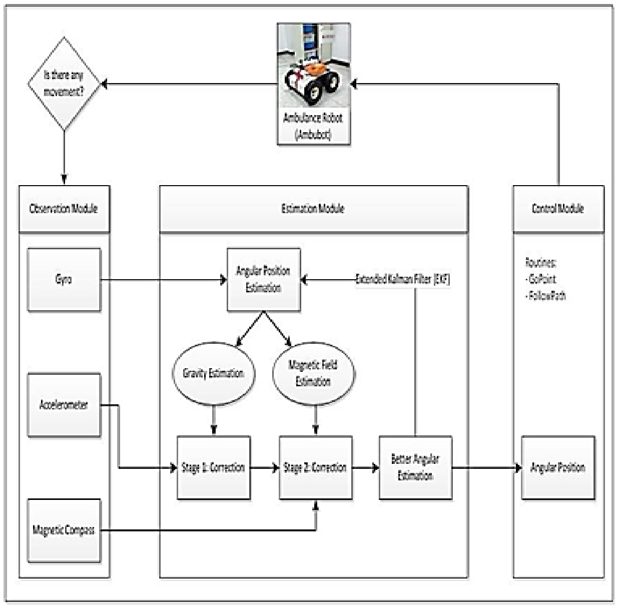
GPS & IMU
Latitude: 2456.75187
Longitude: 12122.30296
GPS COG: 340.4
GPS VOG: 0.04
GPS Quality: Non DGPS fix avaiable
IMU Raw Data: $44,-7,-2.236,7,-19,16,0,0,0#
GPS Raw Data: $GPRMC,031238.8,A,2456.75187,N,12122.302

Stuck Detect 🟩
Battery(V): 23.42
☑ Motor Protect

	Encoder Pos	Velocity	T(°C)
Left Front	26213	0	28.84
Right Front	6099	0	28.69
Left Rear Wheel	25941	0	29.25
Right Rear Wheel	7074	0	28.63

Fig. 9. EVbot controller interfaces.

EVbot has the ability to autonomously carry out simple instructions however human supervision is still needed to take over additional control of EVbot during a loss of communication. As delineated in Figure 8 two operators in EVbot center use a suitable input device such as a control pad and a computer to control the movement of the robot. The two surveillance cameras on the EVbot enable the human operator to assess the remote situation and make a safe and continuous operation possible. Although the cameras on the robot provide different views of the environment but they could not cover the whole scene. At the remote site, one operator acts as a mission planner while another operator acts as a supervisor to monitor EVbot in executing its task. Furthermore, human operators use their perception, planning, and control capabilities to influence EVbot. Despite human operator directly controls EVbot operation but this mode gives two major problems such as the time delay between operator input and robot execution as well as degraded perception from the single video feedback at the operator site (EVbot center). Additionally, the need of the full concentration of the operator also imposes a limitation on this scheme. Future research should therefore focus on increasing the functionality of the robot where EVbot acts not merely as a passive transporter but it can also make its own decision according to the external situations while under the user guidance. Therefore, the sensors of EVbot could be used to actively affect the behavior of EVbot and reflect the situations at the control station, which may not be perceived by the operator.



VI. SENSOR FUSION AND NAVIGATION

EVbot is able to navigate in challenging situation both indoors and outdoors terrain to find the victim. This robot is equipped with tele-operated thereby having a good communication with human rescuers to gather crucial information including the location of victim in a map and way those human rescuers can reach the victim. When EVbot is navigating through the environment, the robot needs to determine its locomotion before moving to different positions because the robot does not know its initial position and the robot must localize itself from scratch. Plenty of different approaches have been introduced to help robots in navigation and guidance processes. Selection of particular approach in mobile robot is based on the type of sensor, the required applications, and the environment in which the robot is operating. Whilst the robot performs satisfactory for outdoor localization by relying on the GPS sensor, one of the main challenges was positioning the robot in the indoor environments such as shopping malls and underground transit hubs. To help EVbot to achieve its prescribed goals, we employed the Extended Kalman Filter for indoor localization. This mechanism enables the robot to determine and estimate its position at all times in unknown environment. We have utilized the Inertial Measurement Unit (IMU) of EVbot, which consists of 9 Degree of Freedom, to bolster performance of Extended Kalman Filter. EVbot loop could be categorized into three different modules, EVbot path or control module, the observation module provided by IMU sensor, and the estimation module with using EKF. As the IMU of EVbot has 9 DOF, this sensor can output the roll, pitch, and yaw estimations. The pitch and roll estimations are generated by the accelerometer and gyroscope, respectively, while compass generates yaw estimation. The entire loop of EVbot is delineated in Figure 10. Throughout system modeling and design, we designed an Extended Kalman Filter as sensor fusion algorithm, and a quaternion to represent angular position data. With using quaternions, the system can be easily linearized and converted to other rotation representation methods. Thereupon, quaternions are more flexible than Euler angles. In order to allow flexibility and simplification in our system, we utilized two correction stages of the EKF namely the first correction stage used data from the accelerometers to correct the system state, and the second one used data from the magnetic compass for angular position correction. Based on our simulation, the EKF was performed well to EVbot than moving average with a small error effect to the angular position.

The IMU is very sensitive to its working environment. Hence, in order to evaluate the comparative performance of EVbot, we tried two different algorithms, which are a moving average algorithm and the EKF. The performance was evaluated in terms of the angular displacement between the measured and estimated positions from different algorithms. The error of the angular displacement was calculated from a time of 1 second to 10 seconds for the simulation with moving average and the EKF, as shown in Figure 11. Subtracting the value of measured angular position from the value of estimated position derived the error and we used the absolute value to plot in the table.

The high computational cost of the distance transform and skeletonizing methods makes them infeasible for large maps and has led to the development of probabilistic methods. These methods sparsely sample the world map and the most well-known of these methods [41] is the Probabilistic Roadmap or RPM method [42]. We have employed such approach for trajectory planning of the robot. The probabilistic roadmap planner consists of two phases: a construction and a query phase. In the construction phase, a roadmap (graph) is built, approximating the motions that can be made in the environment. First, a random configuration is created. Then, it is connected to some neighbors, typically either the k nearest neighbors or all neighbors less than some predetermined distance. Configurations and connections are added to the graph until the roadmap is dense enough. In the query phase, the start and goal configurations are connected to the graph, and the path is obtained by a Dijkstra’s shortest path query.

VII. DISCUSSION AND FUTURE WORK

In this paper, we presented a usage of smart vehicle for smart city which can be implemented to intelligent vehicles based on their architecture using a simple sequence of three steps: sense, plan, and act (SPA). Some of that technology has readily available on the market today and the rest of them are still on the investigation step to guarantee safe and reliable operation. For the purpose of sensing, several sensors such as camera, ultrasonic sensor, and laser scanner are common modules for a mobile robot, which can be employed to intelligent vehicles. The camera for intelligent vehicles is generally concatenated with Lane Keeping System (LKS) to minimize fatal accidents, which can either try or prevent them altogether. This technology allows the car to detect any change of lane on both sides of the vehicle. On the other hand, ultrasonic sensor is concatenated with parking assistance systems to intelligent vehicles in order to assist drivers in parking their vehicle. Laser scanners are mostly used for safety and driver assistance purpose such as Adaptive Cruise Control (ACC), collision avoidance, and pedestrian detection.

Advanced technologies for planning in mobile robots can also be implemented to intelligent vehicles in order to organize and plan more intelligent behaviors. These technologies are composed of path planning, obstacle avoidance, optimization, multi-agent collaboration and trajectory identification. In addition, following trends in mobile robots can change regarding action, behavior, and structure of the intelligent vehicles. For instance, the common four-wheel cars can be modified into different actuation mechanisms in order to perform the vehicle with different degrees of freedom and flexibility. These trends in actuation can be adapted to vehicles to achieve novel architecture in future cars. Furthermore, from the power point of view, current oil based power systems can be changed to electrical or solar energy, which is not practical yet.

The proposed ambulance robot for smart cities provides the service of ambulance with AED to help someone having a cardiac arrest. Sudden cardiac arrest occurs when the heart has stopped beating effectively due to an electrical malfunction of the heart. This occurs instantly or shortly after symptoms appear. Early access to AED can be a life saving measure in the event of someone suffering a cardiac arrest. To have the absolute best chance of survival, immediate treatment must be carried out in the first few minutes after someone collapses from a cardiac arrest. In this research, EVbot was intended to improve on manual search assistance of finding AED with the help of the information technology so that an immediate treatment can be delivered to assist victims in cardiac arrest.

The process of dispatching an EVbot to reach location of victims can basically get executed by three different modes, which are tele-control, partially autonomous, and fully autonomous. All of these modes could be constructed with information network technology to improve on past-passive and manual search assistance schemes. In tele-control, remote operator uses a remote-control device to control EVbot. Human operator watches the real-time video stream from two surveillance cameras to locate and approach the victim. These two high-resolution video cameras allow remote operator to zoom-in and out the objects. On the other hand, EVbot is in autonomous navigation and obstacle avoidance mode when it comes to navigation planner partially and fully autonomous. The major difference in these two modes lies on the execution of AED. In fully autonomous, EVbot executes the AED by itself with no human intervention and vice versa in partially mode needs laypeople to apply the AED pads to bare chest of victim.

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