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Robotic Automated External Defibrillator Ambulance for Emergency Medical Service in Smart Cities

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ABSTRACT Smart cities essentially require the state-of-the-art technologies that can provide smart service in various aspects, and robotic systems are one of the key solutions for such requirements. Time is a critical issue when dealing with people who experience a sudden cardiac arrest that unfortunately could die due to inaccessibility of the emergency treatment. Therefore, an immediate treatment using automated external defibrillator (AED) must be administered to the victim within a few minutes after collapsing. Hence, we have designed and developed the ambulance robot, which brings along an AED in a sudden event of cardiac arrest and facilitates various modes of operation from manual to autonomous functioning to save someones lives in smart cities. The details of the design and development of such robot are presented in this paper.

INDEX TERMS Smart healthcare, smart cities, emergency management, robotics.

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 It can be seen with many of todays occupations have been replaced by automation in order to help prevent manual handling injuries in the workplace.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 [1]. 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 [2]. 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 smart cities [3].

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 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 [4]. With using multiple sensors for navigation, this robot is able to 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 mobile such as vision and range sensors. Mobile robots are mostly used to investigate hazardous and dangerous environments where the risks for human operation exist. This robot can also be used to interact with human such as take care the elderly and doing household chores [5]. In future smart cities [6], 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 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 [7] 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.

In the case of health emergency situation, 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 [8]. 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.

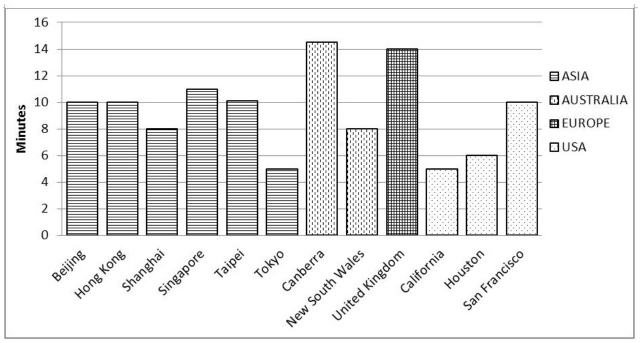

FIGURE 1. **Response times of ambulance services in various countries.**

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. In order to tackle these problems, we have designed and developed an ambulance robot (AmbuBot), which can place a small package containing an AED to save lives of cardiac arrest victim. Our developed robot is presented in Figure 2.

The rest of this paper is structured as follows. Important aspects of healthcare in smart cities and related background for AED, intelligent vehicle, rescue and medical robots are presented in Section II. The idea of ambulance robot for smart city is elaborated in Section III. The robot structure and mathematical model of the proposed robot is presented in Section IV. The operation of the Ambubot is presented in Section V. Navigation and sensor fusion aspects of the robot are presented in Section VI. Finally discussion and future works are discussed in Section VII.

II. BACKGROUND

By considering instances where human failing could be xed 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 inuencers of people [9]. To build the set of common multidimensional components we need to take a close look at many conceptual cousins of smart city and trace the roots of the terms popularly used. A variety of the labels can be largely categorized into three dimensions:

FIGURE 2. **The developed Ambulance Robot.**

technology, people, and community. The conceptual variants are mutually connected with substantial confusion in definitions and complicated usages rather than independent on each other [10]. In the process of providing better services to all citizens and improving the efficiency of administration processes, the concept of a smart city has been lauded as a promising solution for the coming challenge of global urbanization [11]. The main challenges for the healthcare domain of smart cities are using ICT and remote assistance to prevent and diagnose diseases, and deliver the healthcare service in addition to providing all citizens with access to an efficient healthcare system characterised by adequate facilities and services [12]. The Internet of Things revolution is redesigning modern healthcare with promising technological, economic, and social prospects [13]. 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.

A. 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 Ambubot as a platform to save someones life during cardiac arrest.

An emergency situation could arise at any time with no warning. It could jeopardize and bring significant injuries on a persons life. Saving someones 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 situation 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 ge-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 [14]. 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 [15]. It is due to the initial panic that often occurs when people are faced in such circumstances. In order to mitigate those problems and keep patient staying alive before the advent of ambulance, we utilize Ambulance Robot application to carry an AED and according to our long-term plan it would be able to perform CPR to a person in cardiac arrest. We believe that our application can mitigate the constraint of human ability to locate the AED at the nearest location of victim and increase the survival time of victim.

B. INTELLIGENT VEHICLE

Much attention has recently been paid to intelligent vehicle research to assist drivers and ultimately revolutionize the way vehicles and drivers communicate in the future of smart cities. One of the key concerns of developing an intelligent vehicle is to improve driver and vehicle safety. An intelligent vehicle generally defined as a vehicle enhanced with perception, reasoning, and actuating devices that enables the driver to driving automatically or to monitor a human driver and assist him in driving. This intelligent vehicle could warn the driver in case of a developing dangerous situation and can provide capabilities of avoiding collisions or mitigate the consequence if there is an inevitable collision. It also allows the traffic accidents majorally caused by the drivers negligence to be eliminated so that can save human lives. Moreover, this intelligent vehicle systems should be able to operate in all traffic situations wherever on highways or in crowded urban streets.

To help improve safety on our roads, the worlds 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 perceive 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 in order 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 drivers behavior or a vehicles performance [16], [17]. 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 inter-vehicle communication benefits and negatively affect application performance.

Vehicle-to-vehicle communication can provide a data exchange platform, and facilitate active safety vehicle system development [18]. With using a wireless network, this communication enables automobiles send messages to each other with some useful information such as braking, speed, location and direction of travel, and loss of stability. Vehicle-to-cloud communication is specifically used to active driver assistance and vehicle tracking in network fleet management. Vehicle-to-roadside infrastructure communication is a platform that enables driver safety by providing the right information at the right time, such as speed limit, and weather condition information collected using various roadside sensors [19]. This communication provides a wireless exchange of critical safety and operational data between vehicles and highway infrastructure designed to assist vehicle operators avoid or mitigate vehicular crashes through specific advanced safety applications. Additionally, it enables a wide range of other safety, mobility benefits, and operational efficiency.

C. 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.

To be useful tools rescue robots have to be fairly small, not too heavy and maneuverable enough to enter into gaps and move through cracks or narrow spaces that are impossible for humans and even trained dogs. These robots must be capable of navigating in challenging situation both indoors and outdoor terrain to find the victims. Typically, robots are equipped with tele-operated so that they have a good communication with human rescuers to gather crucial information including the location of victims in a map and way that human rescuers can reach the victims. These robots commonly used to place a small package containing food, medication, and a communication device near the victim. Compared to military platforms, rescue robots have quite same structure, because they are using the same technology for searching, navigation, and control. But the difference that makes rescue robots unique than military robots is the rescue robots have more human robot interaction for civilian response. In addition, the strategy of rescuing for rescue robots is highly similar to the human way of rescuing.

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 (Unmanned Aerial Vehicles), UUVs (Unmanned Underwater Vehicles), and USVs (Unmanned Surface Vehicles) [3]. 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 underwater 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.

Rescue robots can further be divided in three groups, depending on the model sizes. When choosing the size it is important to know what the robot should be capable of and how soon after a disaster it might be used. The sizes are man-packable, man-portable, and maxi-sized. Man-packable robots are typically small and more likely to be used immediately after a calamity. These robots can also travel over debris and climb stairs into a calamity hot zone. The next larger size is man-portable robots that may need two people or a small terrain vehicle to be carried. Man-portable robots are increasingly being used for logistics support both in the hot zone and outside the hot zone. These robots often need to wait before the path is curved up. Maxi-sized robots are robots with the biggest size and they need trailers or other special transportation logistics.

Rescue robots had been used in the last few decades with the participation in the recent devastations, such as 2001 the World Trade Center (WTC) collapse, the 2004 Mid Niigata earthquake in Japan, the 2005 hurricanes Katrina in the United States, as well as the 2011 Tohoku earthquake and tsunami in Japan. Three species of small UGVs namely Inuktun micro-VGTV, Inuktun micro-Tracks, and Foster-Miller Solem were sent to find victims at the World Trade Center 9/11 disasters in New York City, United States [20]. In the former incident robots were used to explore and inspect the rubble of the twin towers. The wireless Foster-Miller was larger than the other two and primarily used to search for voids in the rubble. It was also used to detect the stability of insecure places. The other two Inuktun robots were attached to a lead.

On 23 October 2004 the largest earthquake hit the Niigata Chuetsu in Japan and thirty-nine people were reported dead and massive damage was done to the environment. The first snake robot of the Soryu III was developed to find victims at a calamity site and this robot had a length of 1.2 m, a weight about 10 kg, and a maximum speed of 0.37m/s [21]. There are three components mounted upon the robots namely a charge-coupled device (CCD) camera, an infrared camera (FLIR), and two-way audio as well as proprioceptive sensors. This robot is also supported with CO2 sensor to detect human breathing. In general, snake robots are effectively in manage navigation, but are fairly complex to build because of the synchronization along the skeleton of the snake. The worst hurricane has been happened in the southern Gulf Coast of the United States in 2005 and the 2000 lives reported to have died [22]. There were two UAVs used to get information about rural regions cut off by flash flooding in the aftermath of calamities. They were supposed to provide information directly to the responders rather than waiting for the information getting from the manned aerial vehicles.

Since some incidents of the aforementioned have attacked in some part of the globe, rescue robots have been widely used to help victims at calamities site where hu-man rescuers cannot enter. Such a situation was realized at the Fukushima nuclear reactors in Japan after the Higashi Nippon earthquake that occurred on 11 March 2011. These natural disasters hit the northeastern part of Japan and caused heavy casualties, enormous property losses, and a severe nuclear crisis with regional and global long-term impact. Because of high radiation levels around the damaged reactor buildings, robotic surveillances were demanded to respond to the accident. There were two robots used to explore areas inside the reactor buildings where humans could not enter such as Packbot [23], and Quince [24]. Packbot was controlled via a radio communication system, and the radio waves could reach only some parts of the first floor. However Packbot could not climb up or down the stairs. Therefore another robot, Quince, was used to go inside the reactor building because this robot has high mobility on rough terrains than Packbot. Quince was the only robot that can climb up the staircases and explore the upper floors at the reactor building. Moreover, images captured by Quince were very clear because of its high-resolution camera.

D. 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.

Medical robots can be classified into two categories follow its utilization which are medical robots to assist people and medical robots to assist medical staffs. There are two distinct groups of robots used for assisting people, such as rehabilitation and companion robots. Rehabilitation robots are dedicated to provide assertive equipment for those people with impairment following stroke. Hybrid Assistive Limb 5, Lokomat, and Bionic Limbs are most widely used in hospitals for rehabilitation. Hybrid Assistive Limb 5 (HAL5) has been developed in order to physically supports a wearers daily activities and heavy work. HAL5 weighs less than 10 kilograms and comes in size small, medium and large, and it helps elderly patients bound to a wheel chair walk [25]. Lokomat are designed to combine medical and engineering approaches to help patients regain mobility faster with less pain [26]. Bionic Limbs robot is created to replace a missing body part with an artificial part, which is electronically or mechanically powered [27].

Companion robots offer tremendous potential for enhancing the quality of human lives in the future. There are several examples of companion robotics, such as Lovotics refers to the research of human-to-robot emotional relationship [28], RIBA care support robot for lifting patients [29], and Paro robot. Paro is a therapeutic robot modeled on a baby harp seal. This robot is designed to have a positive psychological effect on people who interact with it [30]. In long-term trials by medical institutions, it is been confirmed that Paro robot has similar effects to animal therapy. This robot enables to display emotional responses to external stimuli, which are input via a range of tactile, light, audio and temperature sensors.

In addition, another three different groups of robots used for assisting medical staffs are tele-robotics, surgical, and pharmacy robots. Tele-robotics is enabling many participants to control the robot simultaneously that are situated in remote location or otherwise inaccessible. The list of tele-robotics that helps in medicine is including Remote Presence-Vita Robot and Nursebot. The Remote Presence-Vita Robot was designed to transform the delivery of acute care by expanding

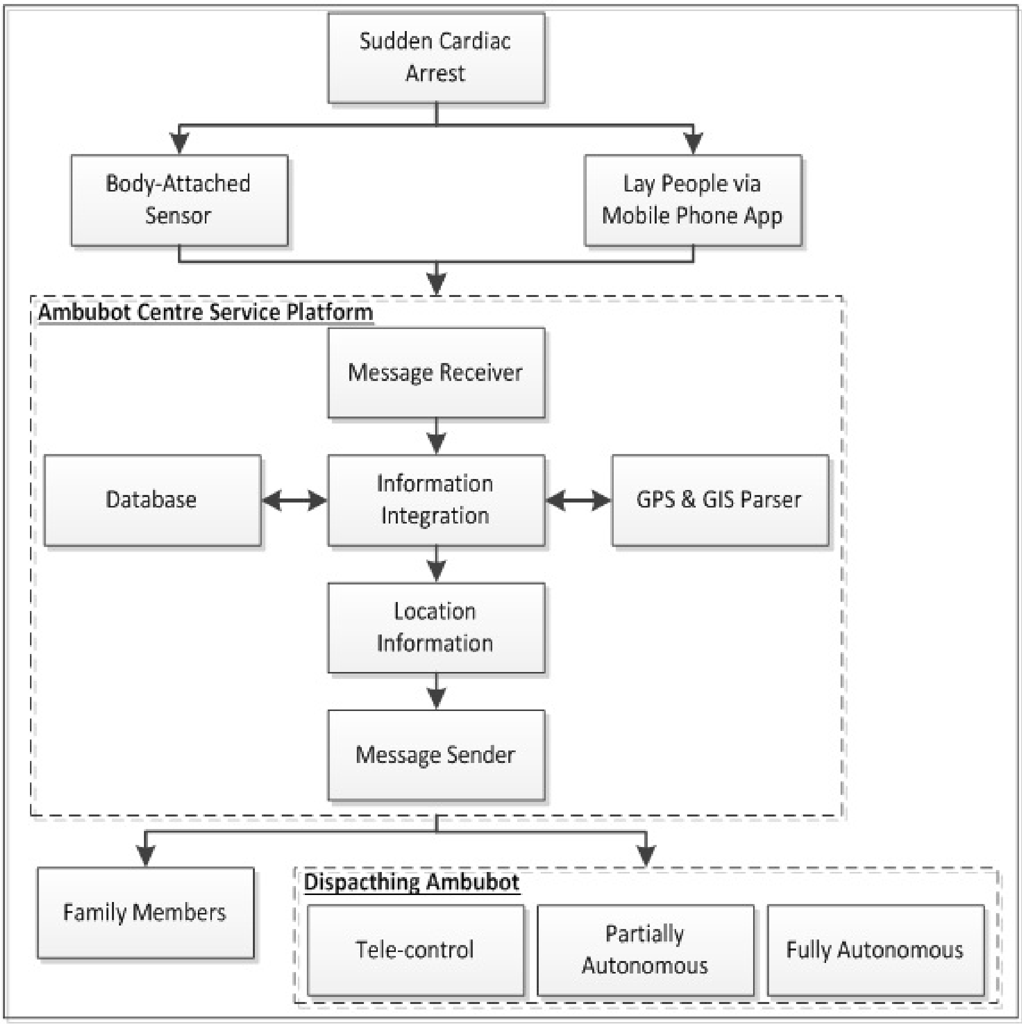

FIGURE 3. Overview of the system workflow.

the use of remote consults and increasing workflow efficiency. Surgical robotics can be categorized into two classes, which are robots that perform surgery, e.g. Cyberknife Radiosurgery [31], and robots that assist the surgeon in the surgery, e.g. Da Vinci robot [32]. Pharmacy robots can handle a wide range of tasks for preparing intravenous medications in a sterile environment such as packaging, and labeling of medications.

III. AMBULANCE ROBOT FOR SMART CITY

As mentioned earlier, we used Ambubot as a platform to save someones 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 Ambubot center. Ambubot 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 Ambubot center processes this data packet, it will generate two commands namely a command for dispatching Ambubot 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. Ambubot 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 [33] 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 persons 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 Ambubot 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 Ambubot 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.

There are various ways of dispatching Ambubot to reach a destination, such as tele-control, partially autonomous and fully autonomous.

A. TELE-CONTROL

Tele-control assists human operator to direct maneuvering Ambubot 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 Ambubot 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 Ambubot to navigate, locate, and approach the victim. In this scenario, when Ambubot approaches the victim, human operators from the control center provide detailed instructions to people in the vicinity of victim to operate the AED device carried by Ambubot.

B. PARTIALLY AUTONOMOUS OPERATION

In this part, the task execution of Ambubot utilizes both autonomous functions of the robot and direct maneuvering by human operators. The flexibility and human intelli-gence 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 per-forming useful tasks in the real world for extended periods. However, if the environment is sufficiently stable and the disturbances to Ambubot 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 Ambubot so as to achieve the task robustly. Humans near the victim still play an important role to apply the pads of AED on victims chest. When Ambubot 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.

Ambubot 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 Ambubot during movement, in this stage Ambubot is in autonomous navigation and obstacle avoidance mode. Ambubot 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 Ambubot, and operators only take over the operation of Ambubot 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 Ambubot based on the circumstances.

C. FULLY AUTONOMOUS OPERATION

While it has been shown earlier, the process of dispatching Ambubot can be per-formed 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 auton-omous navigation and the AED operation. In this mode, Ambubot 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 victims chest. However, in this mode Ambu-bot executes AED by itself without continuous human guidance. In our future plan, Ambubot will perform CPR as the first aid to save the victim life in cardiac arrest. Ambubot grabber will execute these two tasks. The grabber

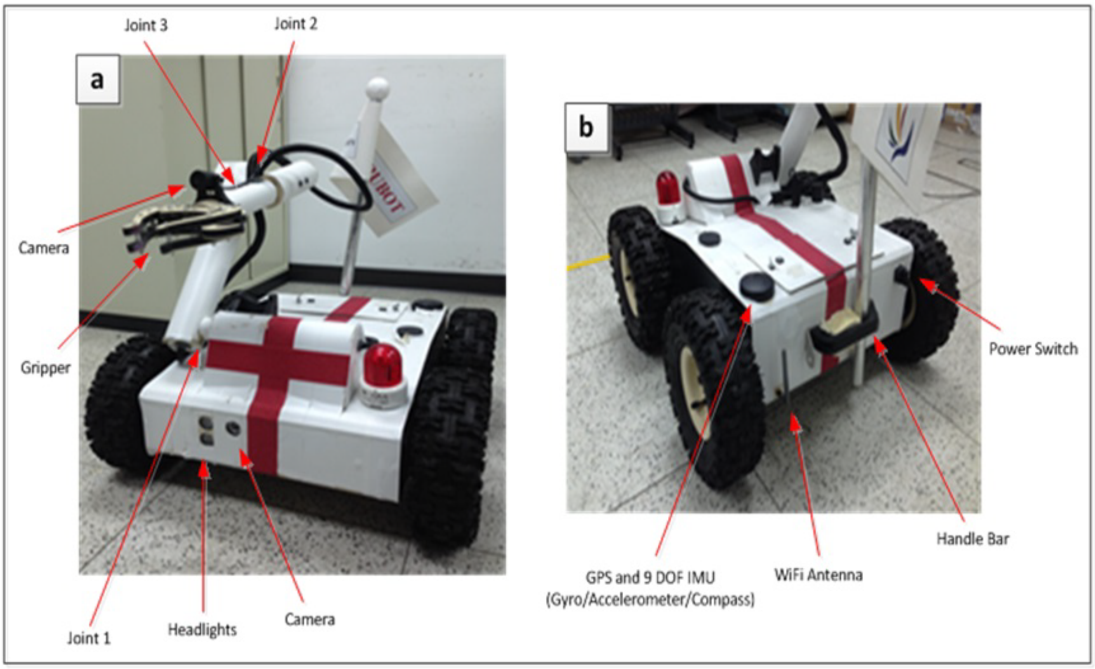

FIGURE 4. System structure of Ambulance Robot (a) Front view (b) Side view.

has been de-signed well to be light enough to apply the pads of AED on victims 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 Ambubot to gently attach the pads of AED on victims chest.

IV. ROBOTIC STRUCTURE

Ambubot is a mobile robot with simple in design yet reliable to operate in indoor and outdoor surfaces with good maneuverability. This integrates with 9 DOF IMU (Gyro/Accelerometer/Compass) and outdoor GPS for autonomous navigation. Ambubot is quipped with a light gripper that can lift up the objects weighing less than 10 kg. In addition, the gripper can be used for some tasks like handling and object inspection as well as an articulated sensor platform. Ambubot is integrated with two high-resolution video cameras enabling remote operator to zoom-in and out the objects. These cameras also provide remote operator detail information of the surrounding. Moreover, four powerful motors drive this robot one for each wheel, allowing Ambubot to move fast. These motors are designed for tough terrains and capable of running over vertical and climbing up low raise stairs. The key components of Ambubot are depicted in the sectional view Figure 4.

The developed Ambubot is in the form of a Skid Steering Mobile Robot (SSMR) [34]. The free body diagram, wheel velocities, and active and resistive forces of the Ambubot are presented in Figure 5.

Steering of a SSMR is based on controlling the relative velocities of the left and right side drives, similarly to differential drive wheeled vehicles. However, since all wheels are aligned with the longitudinal axis of the vehicle, turning requires wheel slippage. This locomotion system functions like that of a tracked vehicle [36]. Tracked locomotion usually provides better traction, but it is mechanically more complex [37].

Suppose that the robot moves on a plane with linear velocity expressed in the local frame as $v = \begin{bmatrix} v_x & v_y & 0 \end{bmatrix}^T$ and rotates with an angular velocity vector $\omega = \begin{bmatrix} 0 & 0 & \omega \end{bmatrix}^T$. The vector $q = \begin{bmatrix} X & Y & \theta \end{bmatrix}^T$ is the state vector describing generalized coordinates of the robot. The kinematic model of the robot can be written as:

$$\dot{q} = S(q)\eta \tag{1}$$

where

$$S^T(q)A^T(q) = 0 \tag{2}$$

and

$$S(q) = \begin{bmatrix} \cos\theta & x_{ICR}\sin\theta \\ \sin\theta & -x_{ICR}\cos\theta \\ 0 & 1 \end{bmatrix} \tag{3}$$

where ICR is Instant Center of Rotation, $\dot{q}$ is generalized velocity in null space of A and $\eta = \begin{bmatrix} v_x \\ \omega \end{bmatrix}$ is the internal velocity vector.

The dynamic model of the robot can be presented as:

$$\overline{M}\dot{\eta} + \bar{C}\eta + \bar{R} = \bar{B}\tau \tag{4}$$

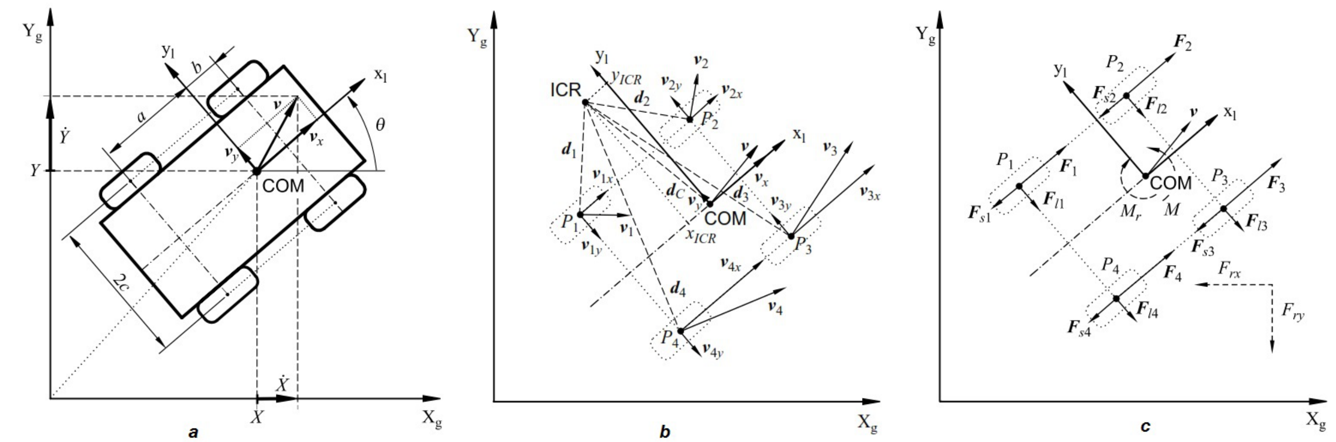

FIGURE 5. (a): Free body diagram, (b): Wheel velocities, and (c): Active and resistive forces [35] of the Ambubot.

where

$$\bar{C} = S^T M\dot{S} = mx_{ICR}\begin{bmatrix} 0 & \dot{\theta} \\ -\dot{\theta} & \dot{x}_{ICR} \end{bmatrix}, \tag{5}$$

$$\bar{M} = S^T MS = \begin{bmatrix} m & 0 \\ 0 & mx_{ICR}^2 + I \end{bmatrix}, \tag{6}$$

$$\bar{R} = S^T R = \begin{bmatrix} F_{rx}(\dot{q}) \\ x_{ICR}F_{ry}(\dot{q}) + M_r \end{bmatrix}, \tag{7}$$

$$\bar{B} = S^T B = \frac{1}{r}\begin{bmatrix} 1 & 1 \\ -c & c \end{bmatrix}. \tag{8}$$

where m denotes the vehicle mass, M is the mass matrix, B is the input transformation matrix [35].

V. ROBOT OPERATION

In the process of developing Ambubot, we first focused on the first mode namely tele-control to take complete control over the Ambubot 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 Ambubot 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 city environment with advanced technologies. Integration of a 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. Because of these reasons tele-control technique has been suggested as a useful scheme to operate the robot in the harsh environment. We aim to improve this system from remote control, to semi-autonomous and later fully autonomous behavior.

In tele-control scheme, the operators must continuously operate and monitor Ambubot. Subsequently, Ambubot 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 Ambubot 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 someones lives in cardiac arrest, human operator gives two commands through Ambubot 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 themselves. With using two surveillance cameras mounted on the robot, one in front of the body and the other one on the arm, Ambubot 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. Ambubot 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

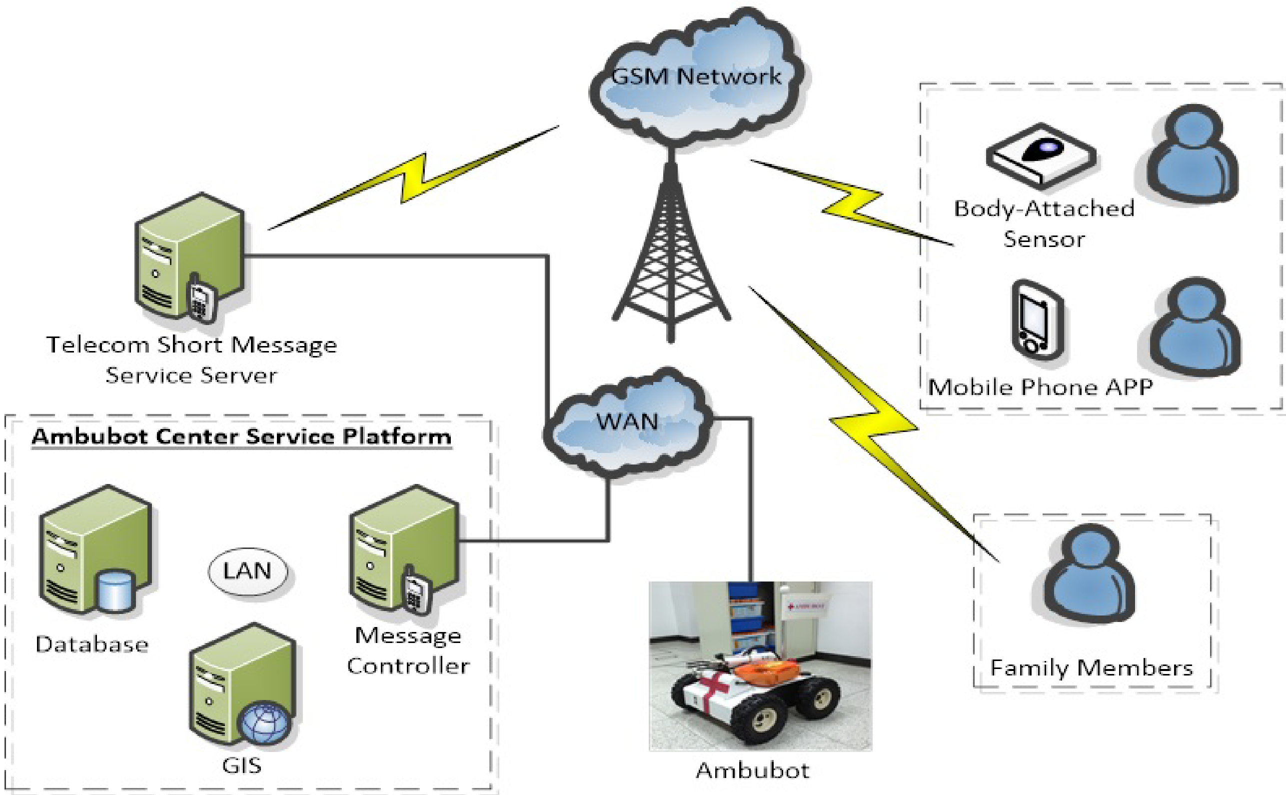

FIGURE 6. System architecture of Ambubot center.

and Ambubot to efficiently acquire geographical spatial information concerning the falling patient and dispatch Ambubot more effectively. In addition, this server is solely responsible to assist Ambubot to find the possible shortest path between Ambubot 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 pre-hospital care can be provided on-time by dispatching Ambubot to the victims premises before land ambulance services arrive. Ambubot 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 Ambubot that will arrive to the premises within ten minutes of collapse. With using telepresence, it allows an operator to remotely control the movement of Ambubot 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 Ambubot. 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 Ambubot 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 Ambubot 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 Ambubot center.

In order to generate a street map location of victim, Ambubot used GPS and GIS parser to convert the longitude and latitude coordinates to location information concerning place of victim with cardiac arrest. In Ambubot 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 in-formation 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 Ambubot to be dispatched more effectively.

FIGURE 7. The entire scenario of dispatching Ambubot to the scene.

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 Ambubot to locate the victim in short time as possible.

Ambubot has the ability to autonomously carry out simple instructions however human supervision is still needed to take over additional control of Ambubot during a loss of communication. As delineated in Figure 8 two operators in Ambubot 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 Ambubot 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 Ambubot in executing its task.

FIGURE 8. Remote operations of Ambubot in Ambubot center.

Furthermore human operators use their perception, planning, and control capabilities to influence Ambubot.

As shown in Figure 9, the high-resolution video and audio integrated in our robot is used to visually provide human operators with information of the surrounding so they can guide Ambubot to avoid any obstacles on the way of

FIGURE 9. Ambubot controller interfaces.

dispatching the robot to the scene. Moreover the integration of the operator with video streaming in the Ambubots controller provides an opportunity to interactively communicate with the lay rescuers on the premises. When Ambubot arrives in the location of victim, human operator instructs lay rescuers to apply the pads of AED to victims chest. The commands issued from the operators will be mixed with the multisensory feedback in the IMU of Ambubot to assure a correct response to the world.

Despite human operator directly controls Ambubot 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 (Ambubot 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 Ambubot 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 Ambubot could be used to actively affect the behavior of Ambubot and reflect the situations at the control station, which may not be perceived by the operator.

VI. SENSOR FUSION AND NAVIGATION

Ambubot 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 [38]. When Ambubot 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 Ambubot 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 Ambubot, which consists of 9 Degree of Freedom, to bolster performance of Extended Kalman Filter. Ambubot loop could be categorized into three different modules, Ambubot path or control module, the observation module provided by IMU sensor, and the estimation module with using EKF. As the IMU of Ambubot 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 [39]. The entire loop of Ambubot 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 Ambubot 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 Ambubot, 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 skeletonization methods makes them infeasible for large maps and has led to the development of probabilistic methods [40]. 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,

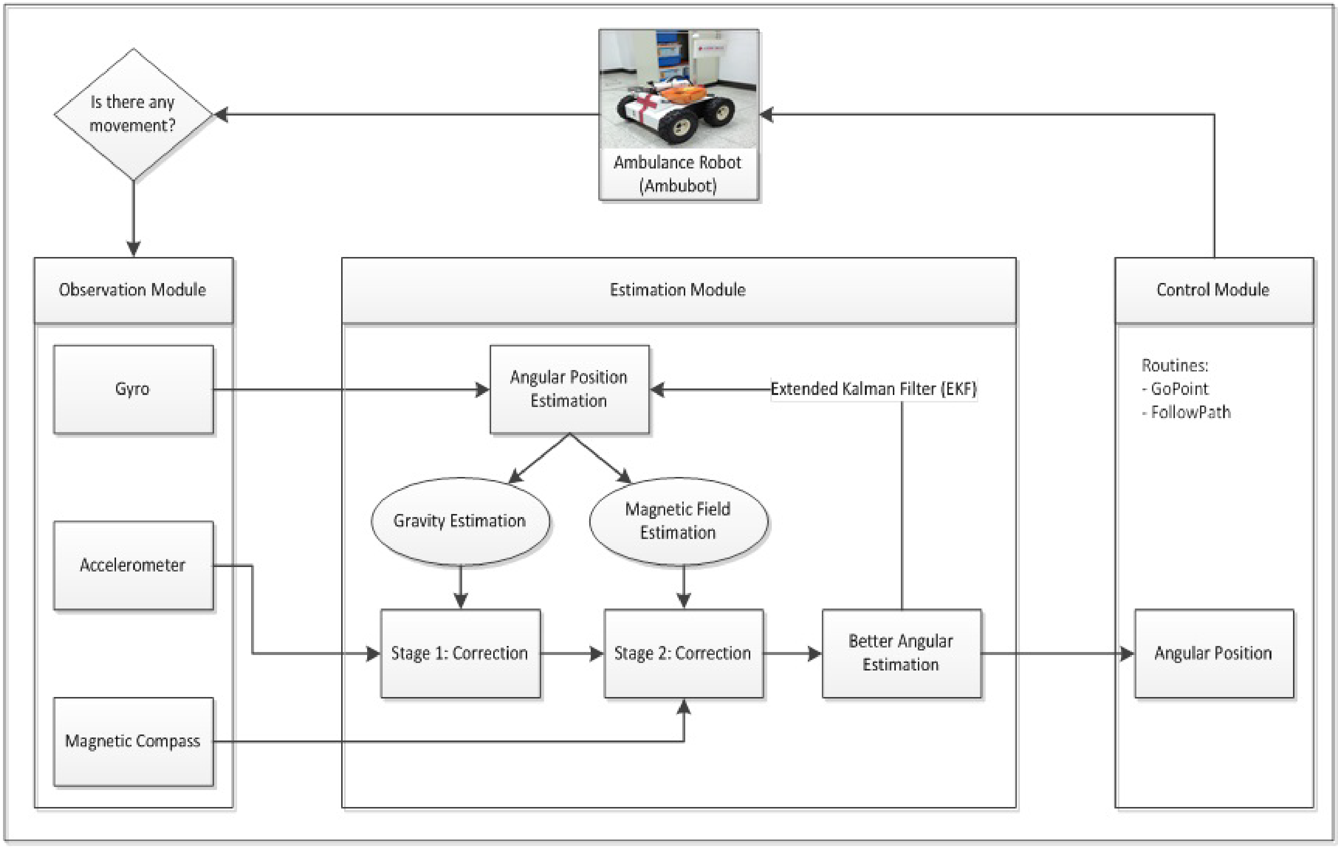

FIGURE 10. Sensor fusion architecture of ambulance robot.

Time (Second)		1	2	3	4	5	6	7	8	9	10
Angular Position (Radian)		**1.8**	**4.3**	**8.6**	**12.7**	**20**	**28.8**	**39.4**	**50.2**	**62.1**	**77.5**
Moving Average	Estimated	4.8	4.3	8.6	17.4	19.5	30.9	38.2	50.2	63.9	77.8
	Error	3	0	0	4.7	0.5	2.1	1.2	0	1.8	0.3
EKF	Estimated	1.78	4.28	8.65	12.7	20.18	28.8	39.46	50.3	62.1	76.8
	Error	0.02	0.02	0.05	0	0.18	0	0.06	0.1	0	0.7
EKF (Bias: 2.05)	Estimated	1.8	4.35	10	12.71	20	27.9	39.5	51.1	62.4	76.5
	Error	0	0.05	1.4	0.01	0	0.9	0.1	0.9	0.3	1

FIGURE 11. Comparison of the angular displacement errors in different approaches.

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.

In our experiment, we have used National Taipei University campus as the experimental environment for our developed robot as presented in Figure 12. The navigation planner of Ambubot modified that map as illustrated in Figure 13 for path planning as presented in Figure 14. It can be seen that the trajectory is planned for the robot to move from the main entrance of the campus to the dormitory. In the real case the

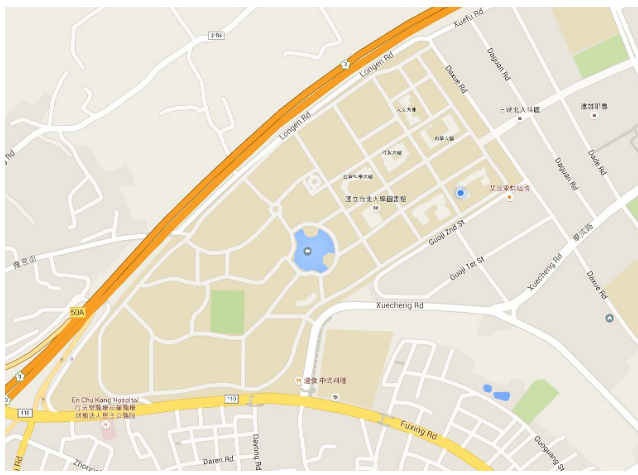

FIGURE 12. The map of National Taipei University campus as the experience environment of the proposed ambulance robot.

AED is located in the main entrance of the campus at the security office. Our aim is that Ambubot can be located there and be dispatched to any location is the university in the case of emergency.

The map is represented as an occupancy grid map using imported binary data. When sampling nodes in the free space of a map, PRM uses this binary occupancy grid representation to deduce free space. Furthermore, PRM does not take into

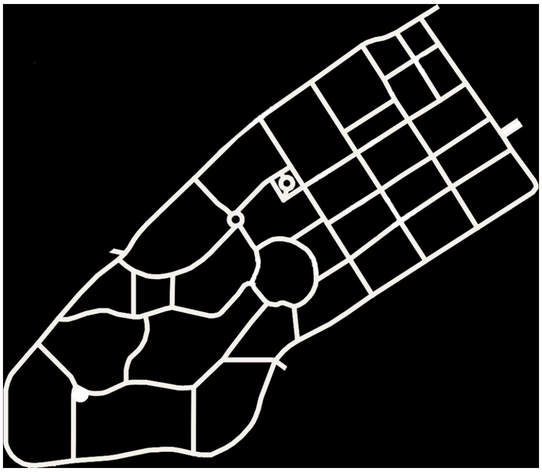

FIGURE 13. The modified map of the National Taipei University in Ambubot navigation planning unit.

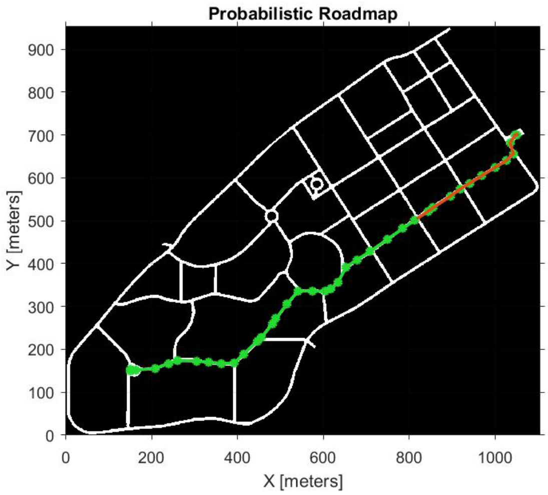

FIGURE 14. The Probabilistic Roadmap calculated by Ambubot navigation planner.

account the robot dimension while computing an obstacle free path on a map. So the map should be inflated by the dimension of the robot, in order to allow computation of an obstacle free path that accounts for the robot's size and ensures collision avoidance for the actual robot. By having the start point as the initial location of the robot in Ambubot center and the end location as the victims location the PRM path planner finds an obstacle free path.

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, Ambubot 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 Ambubot 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 Ambubot. 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, Ambubot is in autonomous navigation and obstacle avoidance mode when it comes to partially and fully autonomous. The major difference in these two modes lies on the execution of AED. In fully autonomous, Ambubot 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.

However, tele-control robot was a major focus of our current research due to the safety issues and difficulty of implementing other modes in real health care environment. Such issue is practical when the accident occurs near the Ambubot station and in our case we have focused on the campus of National Taipei University. In this mode, Ambubot operator guides a lay first responder through the entire process of applying AED before the ambulance arrives. To help keep the cardiac arrest victims alive, the body-attached sensor and mobile phone application were used to prevent them from suffering any misfortune. Due the body-attached sensor was acceptable as fall sensor, this device is able to monitor a persons 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. In addition the ability to detect a fall by someone who is suffering from cardiac arrest, this body-attached sensor also leads to reduce both the physical as well as the psychological trauma of the event in a shortened interval before the advent of medical assistance. For data management an Ambubot center service platform consisting of database server, message controller, and H-GIS server is constructed to let Ambubot and family members acquire the relevant information about the victim.

Regarding to the health care systems for smart cities, cost and the need for more care and monitoring of the patients in cardiac arrest requires involvement of ICT technologies. In our research Ambubot was developed to implement emergency dispatching of robot with medical treament and also to conduct cardiac arrest prevention tasks in public health. Our future efforts will primarily focus on increasing the autonomous operation of the robot while working on two extra aspects. One is adding the ability of the body-attached sensor to monitor condition of the patient and then transmits some helpful information to specialists who would evaluate the patients health conditions. Aside from telemonitoring services about the health condition of the patients, we consider also to utilize this embedded system as predictive diagnostic systems that can provide the patients with diagnosis of their health status at home. In order to ensure this proposed system meets the objectives, different types of pluggable medical transducers for patients with different illnesses will be connected to the interface of the embedded system so that allows ongoing in-home health monitoring of individual patients.

With using this system the patients do not have to spend precious time and pay inconvenient visits to have health checking at either hospitals or clinics because they can know about their health status directly at home. Patients can check their health by them-selves easily and advices about their health status are displayed to them immediately. According to the type of biomedical signals that needs to be obtained from the patients, different types of pluggable medical transducers will be connected to the embedded system for signal acquisition. By feeding the digitized biomedical signals to our body-attached sensor, relevant parameters will be extracted out by using promising techniques like wavelet transforms. Finally these parameters will be sent to the expert system with updatable knowledge base for diagnosis of the health status. Primary diagnosis results directly related to discomfort possibly occurred or disease likely to encounter are displayed as a preliminary advice to the patients. Patients have a clearer idea about their health and can pay visits to their physicians only if their problem gets necessary.

In future we aim to improve the hardware of the AmboBot to more flexible structure such as omnidirectional [43], [44]. We also consider improve the system from robot to multiple robots for collaborative performance [45]. We even consider equipping the current mobile robot, with a drone robot partner [46] which can fly in collaboration with the current system for faster performance in addition for operation in higher elevations.

Moreover, we have also considered the possibility of adding more advanced features such as integrating the body-attached sensor with portal service so that external user will be able to monitor the patient wherever they are. This portal service will ask users for some personal information during sign-up in order to keep their account secure. Furthermore this system will prompt the user to key-in a username and password before the user can have access to the data/information in the system. We believe that this research will result in better way to save someones life during cardiac arrest and reduce the burden of lay rescuers to find an AED on the premises so that can bring more practical and commercial value to our society and hopefully future smart cities.

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