Research Track 2
Research Line
State of the art Analysis of the Smart Ambulance "AmbuBot"

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1 Abstract

Technological advancement has resulted in substantial changes in nearly every field and branch of science. As technology progresses in the medical area, numerous devices and robots are being introduced to help human operators to complete particular and difficult tasks in hazardous situations. Robotic systems are one of the key solutions for providing smart services in smart cities. One such robot is "AmbuBot", which brings along an AED (Automated External Defibrillator), a small electronic portable defibrillator to help lay rescuers for saving patients' life in a sudden event of cardiac arrest, overcoming the problems related to hypothetical delays of the emergency vehicle due to intense traffic. When dealing with those who have a sudden cardiac arrest, time is very important, since it might lead to the victim's death if emergency treatment is not available promptly. In smart cities, AmbuBot is favored for a quick treatment utilizing an AED to administer the casualty within a few minutes after collapsing by supporting multiple modes of operation from manual to autonomous functioning to save someone's life. This document contains information on the details, design, and development of such a robot.

KEY WORDS: Robot, Smart Healthcare, Smart Cities, AED.

2 Introduction

An emergency scenario is defined as any unexpected catastrophe that might endanger or severely injure a person's life. This scenario may be divided into two categories: natural and man-made disasters. A natural catastrophe is a natural phenomenon induced by environmental conditions that can have disastrous results. While the world population continues to rise quickly, increasing its concentration in dangerous locations without much regard for local geo-climatic variables, the damage caused by natural disasters has intensified [JAI+19]. Furthermore, increasing population density in urban areas necessitates proper service and infrastructure provision. This surge in city population will present significant issues such as air pollution, transportation congestion, health concerns, energy, and waste management [KP18]. Natural disasters are largely unavoidable and widespread around the world, killing thousands of people and destroying billions of dollars in habitat and property each year. According to data from the International Disaster Database (EM-DIT), the number of reported deaths is decreasing, but the number of persons impacted by natural disasters is growing drastically. It was owing to global warming and the fact that technological growth has increased the frequency of global tragedy. As a result, lowering the rate of death is commonly regarded as the most successful method to keep in mind when developing a new technology in the sector [GS18]. A mobile robot can be used to facilitate health care operations as a smart operating vehicle in smart cities in which people, technology, and community must be interconnected. In case of a calamity, human rescuers would coordinate the rescue strategy to go out to the disaster zones, and find the victims, whereas a mobile robot would be capable of moving across the environment, performing various tasks either with direct or partial control by human supervision or completely autonomous and place their position wherever it is in the condition. This robot can navigate from a given place to a specified destination using several sensors without losing the correct path or colliding with obstacles [Gaj17]. Vision and range sensors are two types of sensors used in mobile autonomous navigation. Mobile robots, such as rescue robots, are mostly employed to study hazardous locations where human operation is risky. Robots can be used for completing several tasks, interacting with people, doing household chores, and helping workers to complete hard and heavy work. In this regard, since traffic congestion and tidal flow are important factors that cause ambulance delays, **AmbuBot** (Ambulance Bot) was created to provide advanced healthcare service to the citizens of smart cities and, according to the long-term strategy, it could do CPR on someone in cardiac arrest. Furthermore, even though AEDs are available in many public places, it is difficult for people to locate them in an emergency [GS18]. It is because of the first panic that arises when individuals have to deal with such conditions. Several people are also required to get familiar with AED in advance. In general, robotic technologies are rapidly being employed in a variety of methods to locate and save victims in a more timely and effective manner. The emergence of the smart world is briefly discussed in this work as well as physical-based coordination, socially inspired interaction, brain-abstracted cooperation, and cyber-enabled homogeneity since the future smart cities rely on these fundamentals.

2.1 AED and Existing System

Sudden cardiac arrest is a condition in which the heart stops beating suddenly due to a shortage of oxygen and quickly and unexpectedly ceases getting oxygen to the brain and other organs. This is one of the major causes of mortality in both men and women throughout the Globe. It can occur at work, at home, or anyplace else. Time is an essential issue when dealing with people who suffer from sudden cardiac arrest. AEDs are meant to assist people who are experiencing this terrible event. These devices can produce both single-phase and dual-phase waveforms. Single-phase waveforms produce a lot of energy. It has the potential to harm the heart and the skin. Double-phase waveforms, on the other hand, provide a low energy output. This output shocks the heart twice at the same moment, reducing defibrillator complications. Even before utilizing the AED, the person providing assistance should contact an ambulance, according to the AED guidelines. If there are two individuals who can aid, one should phone an ambulance while the other is working with the AED. Even though AEDs are considered medical instruments, ordinary persons may use them. However, it would be preferable if it was done by someone who has finished a first aid course [JAI+19]. These instruments must be administered to the sufferer as soon as possible to help reduce any major side effects while paramedics are on their way to the location. In the event of a medical emergency, after the emergency call, an ambulance is usually dispatched to the spot within ten minutes or more, often too much time to save a life [SZ16]. It can be clearly seen in figure 1. A variety of circumstances influence this issue, including traffic congestion, difficulties locating the location, lengthy distances, and so on. Any of these can result in a longer reaction time, increasing the patient's chances of death.

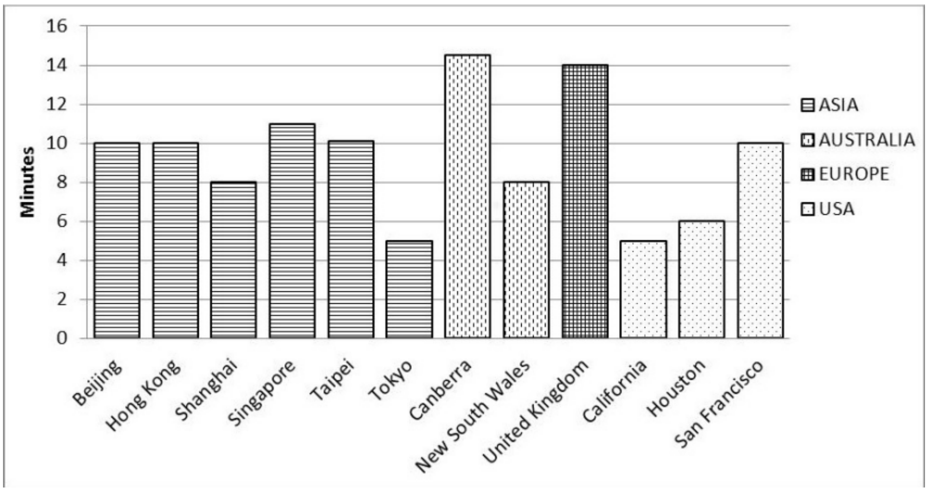

Figure 1: *Response times of the ambulances in various countries.*

3 Proposed System

The proposed ambulance robot for smart cities provides ambulance service with AED to aid someone experiencing a heart attack as well as disaster management and fire extinguisher. There is no need to wait for an ambulance to provide first aid treatments. An emergency message and the victim's current location will be created. A message on the victim's present conditions might be delivered to family members. The robot may be controlled in either automatic or manual mode [Roh+]. In figure 2 is represented the "AmbuBot" model.

Figure 2: *The AmbuBot model.*

3.1 How it works

There are two methods for keeping cardiac arrest sufferers alive: a body-attached sensor or a mobile phone application. Whenever one of them is used, it will instantly send out a warning message and the AmbuBot center will receive Global Positioning System (GPS) data [SZ16]. The AmbuBot center will use a GPS and a GIS parser to transform the longitude and latitude coordinates into a street map position. After the AmbuBot center processes this data packet, it will generate two commands: one to dispatch AmbuBot from the station to the scene as a precaution to save the patient's life before the ambulance arrives, and another to deliver an emergency message to family members via Global System for Mobile Communication (GSM) so they can obtain relevant information about the falling person via mobile phone. In the event that a victim has been equipped with a body-attached sensor, family members will be notified via this message. It is important notifying the nearest hospital's ambulance when the situation is confirmed. In the case of monitored person information about blood type, height, weight, etc can be integrated to have better and more efficient first aid. In figure 3 is represented the general workflow of AmbuBot.

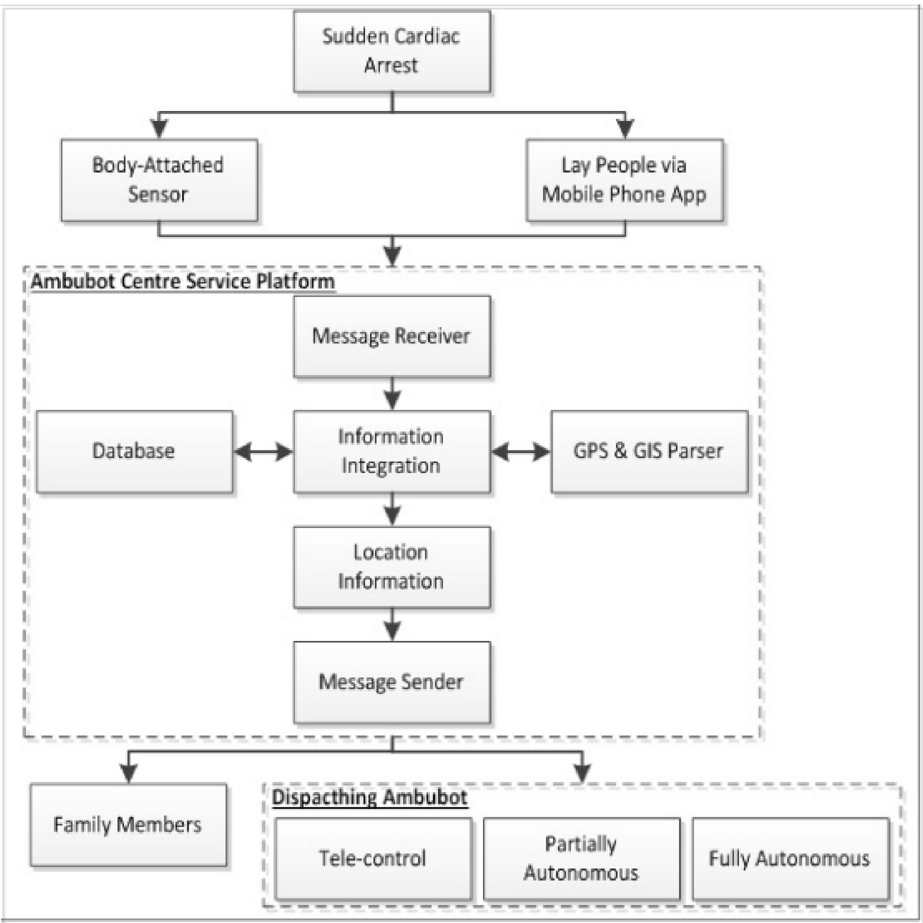

Figure 3: *General AmbuBot Workflow.*

4 Hardware Implementation

AmbuBot can travel at speeds of up to 10 km/h and climb slopes of up to 45 degrees. With quicker mobility, this robot can drive on rough terrain and climb up staircases to ease the ambulance's late-nests difficulties [AS14]. Following its hardware parts are presented to better understand how it is made AmbuBot. The microcontroller is connected to the motor relay and the robotic vehicle's wheels. This part also includes the IR sensors and the DC battery. The Zigbee RSSI is used for communication between the robot's many parts. AmbuBot consists of these sections [KP18], [GS18], [Gaj17] :

- **Arduino Mega**: The *Arduino Mega* microcontroller serves as the project's heart, controlling the whole system. It has 256KB of flash memory, 8KB of SRAM, 4KB of EEPROM and a fast speed. On-chip oscillation of 16MHz.
- **Liquid Crystal Display (LCD)**: An LCD is used to display all of the output data from the system as well as the process that is taking place inside the microcontroller. The LCD display

is shown all the information needed (temperature and heartbeat of the casualty), but also all the instructions needed for a first aid operation, since AmbuBot can also carry a first aid kit that comprises paracetamol, cleaning powder, or arrangement, cotton, micropore tape and so on.

- **Temperature Sensor**: The *Temperature Sensor* is to show the temperature output of the person.
- **Pulse Sensor**: The *Pulse Sensor* is to show the pulse rate of the person. The patient needs to place the tip of her fingertip across the sensor's face. The finger should be motionless and not pressed too tightly against the sensor. Within a few seconds, the circuit stabilizes, and the LED begins to blink in time with your heartbeat.
- **Power Supply**: A *Power Supply* is used to supply power to electrical devices, that need a DC source of power to operate.
- **GSM**: A *GSM* is used to send and receive the message, used to establish communication between a computer and a GSM-GPRS system.
- **Motor Driver**: A *Motor Driver* is a small current amplifier; its job is to convert a low-current control signal into a higher-current signal capable of driving a motor.
- **DC Motor**: A *DC Motor* is used to convert electrical energy into mechanical energy.
- **Voltage Regulator**: A *Voltage Regulator* is used to maintain a constant voltage level.
- **Global Positioning System (GPS)**: A *GPS* is a satellite-based navigation system that can determine locations everywhere on the planet.
- **Relay**: A *Relay* is a type of electrical switch. Many relays employ an electromagnet to mechanically activate a switching mechanism, although alternative working principles are sometimes used. Relays are employed when a low-power signal is required to control a circuit or when numerous circuits must be controlled by a single signal.
- **Zigbee RSSI**: A *Zigbee (cc2530)* is a true system on chip (SoC) solution for IEEE 802.15.4 applications. It combines the excellent performance of a leading RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8KB RAM, and many other powerful features.
- **Wireless Modem**: A *Wireless Modem* is a MODEM device that creates, transmits, or decodes data from a cellular network to establish a connection between the network and the computer.
- **Solar Panel**: A *Solar Panel* is designed to absorb the sun's rays and use them as a source of energy to generate electricity. AmbuBot, or ambulance robot, will be powered by a solar panel.

These are the main hardware parts of the Robot. In the figure 4 is shown the hardware architecture using the *RL 64pin Renesas* Micro-controller.

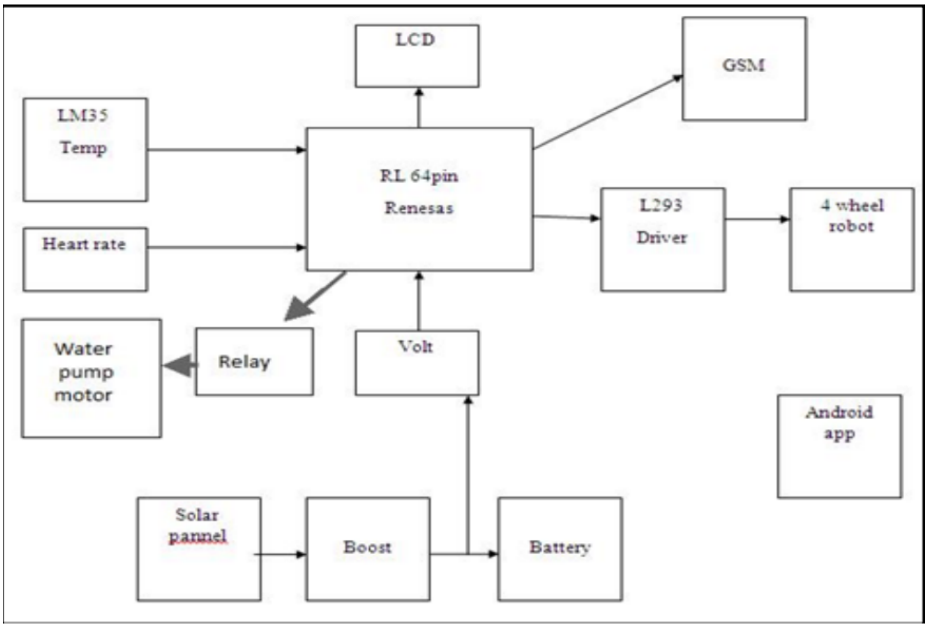

Figure 4: *Hardware Architecture of AmbuBot.*

5 Software Implementation

The Software part of AmbuBot was developed through *Embedded C*. The C Standards committee developed Embedded C as a collection of language extensions for the C programming language to address commonality concerns with C extensions for different embedded devices [Roh+].

6 Dispatching AmbuBot

AmbuBot can be dispatched in a variety of modes, including partially autonomous, fully autonomous and tele-control [AS14]. It is an ambulance robot that is stationed at various points along the road. If a user or patient is experiencing health problems, he should launch an Android application on his smartphone, if the person is not equipped with a **Fall sensor** detecting a possible health issue. Launch the AmbuBot app on your smartphone. This may be done by any user, patient, or nearby neighbor. After opening the app, the user must click the AmbuBot Button. An SMS containing the patient's GPS position is sent to the nearest Ambulance (Robot, i.e. AmbuBot). AmbuBot will be dispatched from the AmbuBot station and will arrive at the patient's location with a first-aid kit. AmbuBot will notify the hospital of the patient's condition.

6.1 Partially Autonomous

Flexibility and human intelligence become critical components in partially autonomous robot control. It is related to the robot's inability to establish comprehensive work plans and to do relevant jobs in the actual world for lengthy periods. As a result, human operators should assist in adapting task processes to the actual world, and they will respond independently to dynamic changes in

AmbuBot's surroundings to complete the mission reliably. AmbuBot will carry an AED and follow the victim's pathway until the destination is reached. In contrast to the tele-control mode in which human operators need to assume complete control of AmbuBot during movement, AmbuBot is now in autonomous navigation and obstacle avoidance mode, reducing the suffered stress of the operators.

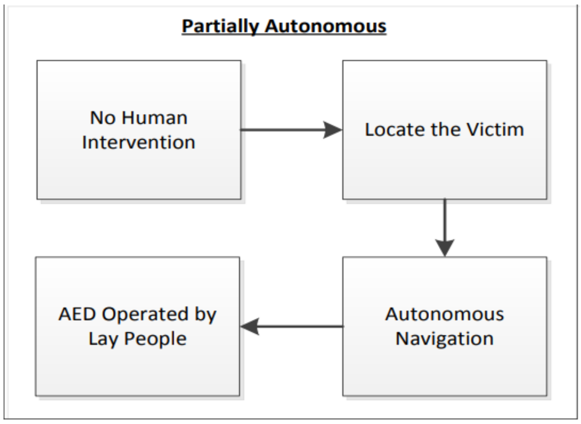

Figure 5: *Workflow of the search assistance for partially autonomous.*

6.2 Fully Autonomous

AmbuBot can travel and accomplish required activities in rapidly changing situations without constant human guidance in this mode. The key distinction is in the application of AED. In the preceding sections, lay rescuers put AED pads to patients' chests on their own. However, in this mode, Ambu-bot performs AED on its own without constant human supervision. In the future, AmbuBot will do CPR as first aid to save the victim's life in the event of a cardiac arrest.

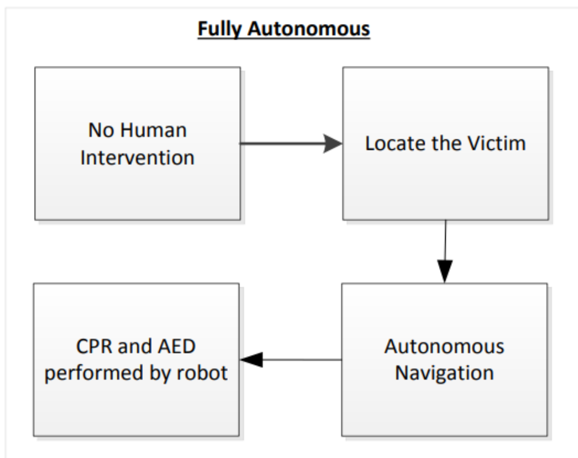

Figure 6: *Workflow of the search assistance for fully autonomous.*

6.3 Tele-Control

Tele-Control uses a visual display and a control pad to help the human operator in navigating the AmbuBot. AmbuBot requires a human-like driver to direct the robot using a remote control device that resembles a controller panel and to monitor the real-time video feed from two security cameras aboard AmbuBot to navigate, find, and approach the victim. When AmbuBot reaches the victim in this situation, human operators, from the control center, give precise instructions to people.

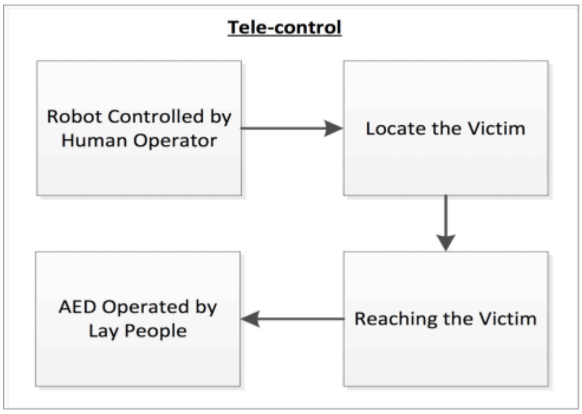

Figure 7: *Workflow of the search assistance for tele-control.*

7 Utilization of the Robot and System Architecture

Tele-Control is the main modality to control AmbuBot because of the difficulties of implementing additional modes in a practical health care context, mostly due to safety concerns. The human operator gives two commands: the *motion command* used to operate the robot so that it may deliver the AED and the *vocal commands* used to instruct persons in the victim's surroundings on how to use the AED device. The interaction between the operators, that uses a pad and a PC to control the robot, and AmbuBot is fundamental since the human operator receives information about the situation and the surroundings through the various sensors equipped on the robot. The robot located in the station and the control server equipped with a computer is included in the tele-control mode. AmbuBot center service platform consists of three servers, each of which is implemented on a separate server system: *database server*, *message controller server*, and *GIS server*. To improve system security, all servers are kept behind a firewall [SZ16].

- The **database server** is designed for the storing and administration of data.
- The **message controller server** is linked to the telecoms short message server to improve message process speed.
- The **GIS server** (Geographic Information Server) is used to convert GPS longitude/latitude coordinates to location information in terms of the street address and important landmarks, allowing family members and AmbuBot to more efficiently acquire geographical spatial information about the falling patient and dispatch AmbuBot. Furthermore, this server is entirely responsible for assisting AmbuBot in determining the quickest path between AmbuBot and the victim.

AmbuBot system architecture incorporates ICT technologies to assist survivors and victims' family members in saving the victims' lives before they arrive at the hospital. Because our service center is linked to the GSM network, the system is able to overcome the GPS problem of an invalid signal. To locate the victim, the system uses a GSM-locating service offered by a local GSM network provider. Though it did not pinpoint the victim's position, it does eliminate the problem of being unable to locate the victim in adverse weather. As was mentioned, there are two methods for keeping cardiac arrest sufferers alive: a body-attached sensor or a mobile phone application. Both the body-connected sensor and the mobile phone application will create an emergency message and the victim's current location. Following a sudden cardiac arrest, these data will be reviewed and automatically transmitted to the AmbuBot center. AmbuBot employed GPS and a GIS parser to convert the victim's longitude and latitude coordinates to a street map location [JAI+19]. AmbuBot can carry out simple commands automatically, but human supervision is still required to take over additional control of AmbuBot in the event of a communication failure. In figure 8 is shown the system architecture of AmbuBot center.

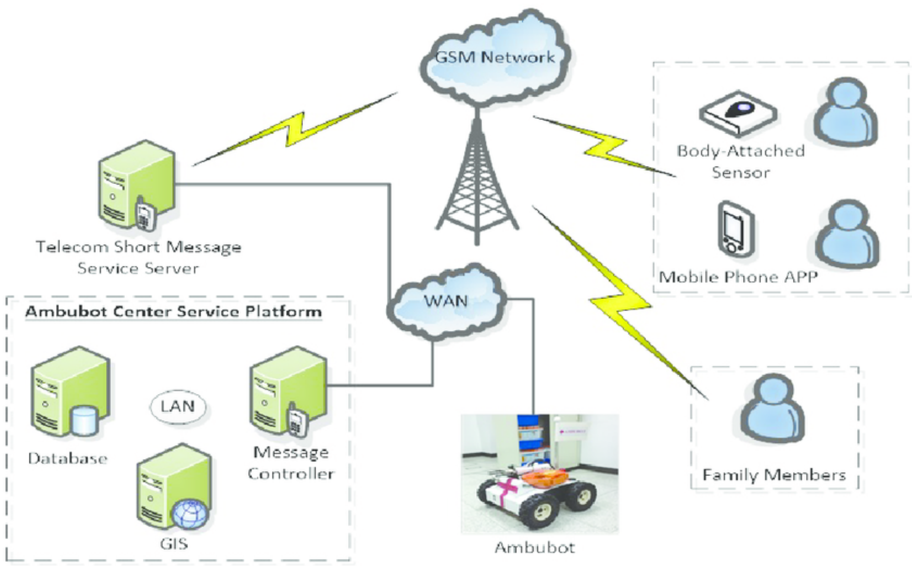

Figure 8: *System Architecture of AmbuBot center.*

8 Structure of the Robot

AmbuBot is a mobile robot with a basic design that is reliable in both indoor and outdoor environments and has good agility. For autonomous navigation, this combines with a 9 DOF IMU (Gyro/Accelerometer/Compass) and an outside GPS. AmbuBot has a light gripper that can pick up things weighing less than 10 kg [SZ16]. Furthermore, the gripper may be employed for activities like the handling and item inspection, as well as an articulated sensor platform. This robot is powered by four powerful motors, one for each wheel, allowing AmbuBot to travel quickly. These motors are built for rough terrain and can go vertical and climb up low-rise stairs. Furthermore, AmbuBot is equipped with 2 video cameras through which the human operator can have information about the surroundings. AmbuBot is in the form of a Skid Steering Mobile Robot (SSMR). Similar to differential drive-wheeled vehicles, steering an SSMR is dependent on managing the relative velocities of the left and right side drives. However, because all wheels are aligned with the vehicle's longitudinal axis, turning necessitates wheel slippage. Assume the robot moves on a plane with a linear velocity

$$v = \begin{bmatrix} v_x & v_y & 0 \end{bmatrix}^T \tag{1}$$

in the local frame and rotates with an angular velocity vector

$$\omega = \begin{bmatrix} \omega_x & \omega_y & 0 \end{bmatrix}^T \tag{2}$$

The vector

$$q = \begin{bmatrix} X & Y & \theta \end{bmatrix}^T \tag{3}$$

is the state vector, which describes the robot's generalized coordinates. The robot's kinematic model may be expressed as

$$\dot{q} = S(q)\eta \tag{4}$$

where

$$S^T(q)A^T(q) = 0 \tag{5}$$

and

$$S(q) = \begin{bmatrix} cos(\theta) & x_{ICR}sin(\theta) \\ sin(\theta) & x_{ICR}cos(\theta) \\ 0 & 1 \end{bmatrix} \tag{6}$$

where ICR is *Instant Center of Rotation*, $\dot{q}$ is generalized velocity in null space of A and

$$\eta = \begin{bmatrix} v_x \\ \omega \end{bmatrix} \tag{7}$$

is the internal velocity vector. The dynamic model of the robot can be presented as:

$$\vec{M}\dot{\eta} + \vec{C}\eta + \vec{R} = \vec{B}\tau \tag{8}$$

in which

$$\vec{C} = S^T M\dot{S} = mx_{ICR} \begin{bmatrix} 0 & \dot{\theta} \\ -\dot{\theta} & x_{1CR}\dot{c}os(\theta) \end{bmatrix} \tag{9}$$

$$\vec{M} = S^T MS = mx_{ICR} \begin{bmatrix} m & 0 \\ 0 & m{x_{ICR}}^2 \end{bmatrix} \tag{10}$$

$$\vec{R} = S^T R = \begin{bmatrix} F_{rx}(\dot{q}) \\ x_{ICR}F_{ry}(\dot{q}) + M_r \end{bmatrix} \tag{11}$$

$$\vec{B} = S^T B = \frac{1}{r} \begin{bmatrix} 1 & 1 \\ -c & c \end{bmatrix} \tag{12}$$

9 Navigation of the Robot

AmbuBot can traverse difficult situations both indoors and outdoors to find the sufferer. This robot is teleoperated, allowing it to communicate with human rescuers and obtain critical information. Because the robot does not know its beginning position and must locate itself from scratch, it must decide its locomotion before going to new positions. The robot performs optimal localization in outdoor environments, thanks to the GPS, whereas it finds difficulties operating in indoor environments, such as shopping centers. In this regard, has been used the *Extended Kalman Filter* for indoor localization to assist AmbuBot to achieve its objectives. This mechanism allows the robot to determine and estimate its position in an unfamiliar environment at all times. Furthermore, it has been used AmbuBot's Inertial Measurement Unit (IMU), which has 9 degrees of freedom, improve the performance of the Extended Kalman Filter [SZ16].

9.1 AmbuBot Loop System

The AmbuBot loop may be divided into three modules: the *AmbuBot path* or control module, the *observation module* given by the IMU sensor, and the *estimating module* utilizing EKF. Because AmbuBot's IMU has 9 degrees of freedom, this sensor can estimate roll, pitch, and yaw. The accelerometer and gyroscope create pitch and roll estimations, respectively, while the compass generates yaw estimation. An Extended Kalman Filter has been created as a sensor fusion method and a quaternion, since quaternions are more flexible than Euler angles, to represent angular position data throughout system modeling and design. The EKF's two correction stages have been employed: the first used data from the accelerometers to correct the system state, and the second user data from the magnetic compass to adjust the angular position. to compare the performance of AmbuBot, have been utilized two distinct algorithms: a *moving average method* and the *EKF*. The performance was evaluated in terms of the angular displacement between the measured and estimated positions from different algorithms The angular displacement between measured and predicted positions from different methods was used to evaluate performance. The angular displacement error was computed from 1 second to 10 seconds for the simulation using the moving average and the EKF [SZ16]. Subtracting the value of measured angular position from the value of estimated position derived the error and the absolute value was used to plot in figure 9. The AmbuBot Loop system is shown in figure 10.

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 9: *Comparison of angular displacement errors in various approaches*

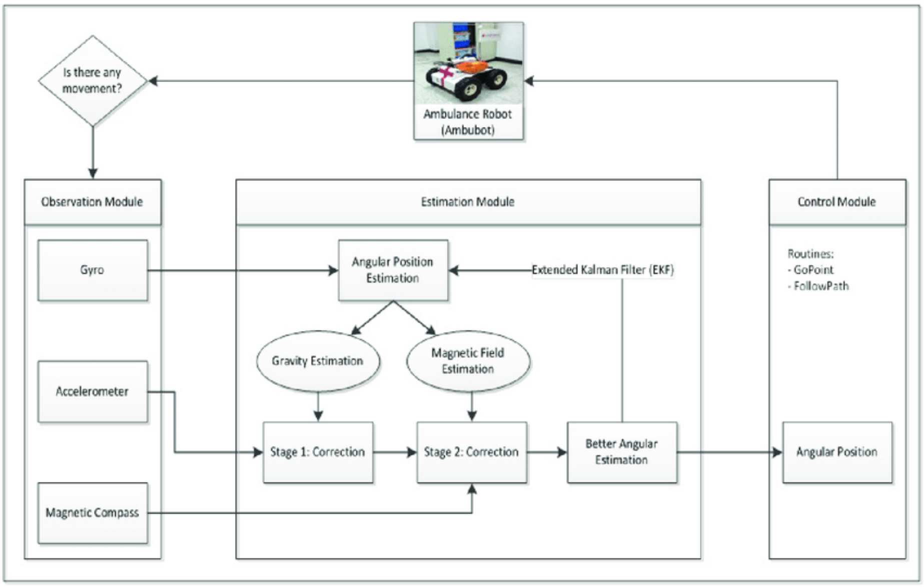

Figure 10: *AmbuBot Loop System.*

9.2 Probabilistic Roadmap Method

Because of the high computing cost of the distance transform and skeletonization approaches, they are impractical for large maps, prompting the development of probabilistic alternatives. The **Probabilistic Roadmap**, or RPM technique, is the most well-known of these strategies since it samples the world map sparsely. The probabilistic roadmap planner includes two phases: building and query. During the building phase, a roadmap is created to approximate the motions that can be performed in the environment. To begin, a random configuration is generated. It is then linked to some neighbors (typically either the k nearest neighbors or all neighbors less than some predetermined distance). The graph is filled with configurations and connections until the roadmap is thick enough. The start and goal settings are joined to the graph during the query phase, and the path is determined using Dijkstra's shortest path query. Using imported binary data, the map is displayed as an occupancy grid map. PRM employs this binary occupancy grid representation to derive free space when sampling nodes in a map's free space. Furthermore, when computing an obstacle-free path on a map, PRM does not take the robot dimension into account. As a result, the map should be enlarged by the robot's size [SZ16].

10 AmbuBot Advantages and Applications

This research covered the topic of a robot (AmbuBot) capable of giving first aid to the victims, carrying an AED and a first aid kit, but this module can be used also for multiple purposes like a fire extinguisher and disaster management. The main advantages of AmbuBot are [GS18], [JAI+19]:

1. The robot would be able to pass through all road junctions without stopping so that the victim does not have to wait a lot.
2. It can be used in a variety of methods to locate and save victims in a more timely and effective manner.
3. It is also intended to do rescue tasks in conditions that are too risky for humans to manage, such as rainstorms, fallen structures, blockages, and harmful chemicals.
4. It is a simple system to use.

11 Conclusion

Because science is discovering or generating big breakthroughs in numerous disciplines, technology is always evolving. Smart cities with smart technologies can bring a new era in which people are considerably helped by innovations. Also in the medical field, lots of technological improvements can be done, such as AmbuBot. Sudden cardiac death is still a serious public health concern. Data from animals and humans show that early defibrillation increases survival and that reducing the time to defibrillation can enhance survival after a cardiac arrest [Gaj17]. However, the ability of EMSs to respond rapidly in many places, particularly in rural and urban areas, is limited. The AED represents a major advance in the effort to achieve early defibrillation and further improve survival following out-of-hospital sudden cardiac arrest. AmbuBot represents a light in the dark regarding the AED utilization and prompt first aid. It helps to overcome the obstacles that people can face during cardiac arrests, such as not finding the AED due to panic, the scarcity of AEDs in the surroundings, and so on. With few modifications, it also can be effectively implemented as a real-time system.

11.1 Future Ideas

AmbuBot can be improved on multiple points so that an optimal way of operation can be obtained, collaborating with human rescuers in saving lives.

- Future research should thus on enhancing the capability of the robot so that AmbuBot can make its own decisions based on external conditions while being guided by the user [SZ16].
- The main modality through which the Robot operates is the *Tele-Control* modality. An operator takes the control of AmbuBot and let's lay rescuers apply the AED pads to the victim, under his/her guidance. One of the main objectives for the future is to have the unit "AmbuBot" completely autonomous, capable of facing every obstacle and of applying the AED alone, without problems.
- The system can be expanded from a single robot to many robots for collaborative performance. The present mobile robot can be outfitted with a drone robot companion that can fly in collaboration with the current ground robot for quicker performance and operation at greater heights [AS14].

Of course, other improvements can be done, such as hardware and software improvements. This research will lead to a better approach to saving someone's life during a cardiac arrest and minimize the pressure on lay rescuers to locate an AED on the premises, bringing greater practical and economic value to our society and, ideally, future smart cities.

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