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Real-Time Coordination and Communication Process for the Issuance of Emergency Ambulance Alerts

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Abstract. The lack of attention to emergency alerts in road accidents in a timely manner may be due to the lack of management of resources or the lack of communication between hospital and patrol departments. The purpose of this research is to reduce the management time to provide attention to requests on highways. An alert and resource management process are proposed. This process will allow sending the optimized information in the shortest possible time. The experimentation was worked with a set of test instances and simulated in the laboratory using mechatronic devices to show the communication, coordination and attention in real time. The results obtained were acceptable, it was possible to identify the alert to be included in the algorithm which must comply with the restrictions and subsequently calculate the optimal route to be followed by the mechatronic device to reach the request node for the attention of the distress alert.

Keywords: Alert management, routing algorithm, smart cities, intersections, time.

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1 Introduction

The combination of advanced technologies, such as hybrid networks, RFID and mobile communication systems, together with community coordination approaches, can significantly improve the efficiency and effectiveness of emergency response. Technological progress through the use of artificial intelligence is making it possible to work with autonomous mechanisms that improve human comfort.

To contribute to this effort, this article addresses the problem of emergency alert attention in road accidents with the purpose of minimizing the time of attention received at the scene of the accident, since, if it is possible to establish a process of attention through a mechanism of real-time alerts to reduce the waiting time for attention to people alive in a car accident situation, then it will be possible to reduce the death rate due to this cause.

In this research it is proposed to optimize the arrival time of the assistance car to the place of the distress call. The routing algorithm allows identifying the best route taking into account the variables of time and distance, in the experimentation two stages were considered, one developed in the laboratory and the other one simulated. The laboratory stage used mechatronic devices simulating patrols and following the route to attend the distress alert; the simulation stage used instances whose distress alert was randomly generated.

The instances were considered of different sizes, for the laboratory platform experimentation, mechatronic devices and instances of 129 nodes representing a city were used, the alert emission at some point of the platform will be attended by the nearest mechatronic device, which will follow the optimal route issued by the algorithm to reach the place of the alert. Instances of 129 nodes with random alert requests are considered in the simulation.

The results of the experimentation reveal that the communication process is functional since in both experiments it was possible to capture the alert, establish the route and the communication with the vehicle closest to the point and reach it to give it attention.

2 State of the art

Real-time communication between ambulances and hospitals during medical emergencies is crucial to coordinate the transfer and care of patients. (Liu et al.,2021) Therefore, there are technologies that provide a necessary, fast and optimal connectivity that can be used in the protection and health sectors, providing an improvement in early attention to catastrophes, accidents and Emergency Medical Systems (EMS) of citizens, in addition to the application of routing algorithms to find the most optimal route for an ambulance to follow in real time.

Buzna and Czimmermann (2021) analyzed a unique dataset of GPS-based measurements collected from 17 ambulances over 3 years in the Zilina region of Slovakia. They developed a rule-based procedure to extract emergency ambulance trips from the GPS data. Trips were divided into training and test sets to develop statistical models capturing spatiotemporal characteristics. These models were used to generate synthetic ambulance trips and compared with the test set to decide which models are more suitable, finding very good fit between the probability distributions of the spatiotemporal properties of the synthetic and real trips.

Rolón and Cadavid (2021) propose an approach for efficient traffic management for smart ambulances based on technologies like IoT, cloud computing, GPS, etc. The proposed system uses an ambulance with GPS and IoT sensors that send its location to the cloud, where a SATMS application processes traffic data from cameras at intersections and determines the best route and alternative routes in case of congestion. Vehicles are assigned priorities based on the emergency where the ambulance has the highest priority. Traffic lights are managed in real time to provide fast passage and reduce ambulance transport time, and SATMS improves the deployment of portable and implantable medical devices.

Zhai et al. (2021) propose an architecture for a 5G network-enabled smart ambulance service, aiming to meet response times in emergency medical services. The 5G-enabled smart ambulance consists of three key components: 5G communication network, remote video, and telemedicine medical data exchange. The increased capacity of 5G enables the interconnection of these three layers to optimize the transfer and processing time of ambulance services. Patient data can be effectively processed to make timely rescue preparations and guide treatment while patients are at the accident scene or in transit. The proposed solution was also evaluated in an experimental environment, so that the performance and quality of the ambulance service can be guaranteed. This solution considers emergency scenarios to investigate medical data transmission capacity, network fluctuations between areas, and ambulance service network bandwidth.

In the work of Banshwar et al. (2021) an ambulance tracking system (ATS) based on GPS and GSM is presented. A low-cost Arduino microcontroller is used to control the GPS and GSM modules. The GPS provides the location coordinates of the ambulance, allowing communication with the base station monitoring the ambulance. The hospital can obtain information on the arrival of the ambulance in advance to prepare. The system can also be used in other emergency vehicles. Results show that the system is accurate and allows fast processing of location data, and can be implemented in pandemic situations to monitor patient vehicles and alert hospitals.

SaiKumar et al. (2022) show a method to automatically identify the position of crashed vehicles and transmit this information to emergency services. GPS and GSM modules are used to obtain vehicle location coordinates and send them by SMS message when an accident occurs. Collision sensors are used to detect accidents and trigger the sending of the alert. The system was implemented in an ambulance to control traffic lights and clear traffic on its way to a hospital. An RF transmitter is installed in the ambulance to communicate with the traffic lights and activate the clearance sequence. The driver can select the direction to clear with coded buttons that are transmitted to the traffic lights. The traffic lights have additional lights to indicate emergency clearance. The system operates within a range of 60 meters between the ambulance and the intersection. Results show that the system can reduce response times and increase survival of critically ill patients.

Darwassh Hanawy Hussein et al. (2022) present a smart city ambulance vehicle routing approach based on the bat algorithm (BAT) and convolutional neural networks (CNN). They use a residual convolutional neural network (ResNet) to identify the safest relay nodes. The BAT method generates offline data for combinations of different source and destination coordinates. This data is trained on the neural network to find the shortest routes between origin and destination. The performance was evaluated in terms of end-to-end delays, throughput and packet delivery fraction and the results show that with 10 malicious nodes the proposed method achieves a packet delivery fraction of 0.90, outperforming other methods.

Abdeen et al. (2022) propose a novel smart ambulance system to minimize response time and hospital arrival time. It uses real-time information on traffic conditions and hospital load to make 'optimal decisions, including choosing hospital and ambulance with the shortest patient response time, 'optimal route to and from the hospital. It minimizes the time between request and start of hospital treatment and develops a queuing model to analytically analyze the performance of the proposed algorithm. Simulation results agree with the analytical results, verifying the correctness of the model. Compared with a previous algorithm and traditional ambulances, the proposed algorithm significantly improves the performance metrics.

Nadar et al. (2022) address in their paper the problem of ambulance placement in emergency medical services (EMS), taking into account temporal variation in demand. The authors propose a mixed integer programming model that considers heterogeneous performance measures based on survival function and coverage for different types of patients. They also develop an approach based on memetic algorithms to solve the problem. Computational results show that neglecting temporal variation in demand may underestimate the number of ambulances required during peak demand. It is shown that the proposed solution approach provides good quality solutions in a reasonable time.

In the review by Ashwini et al. (2023) on research related to the development of an intelligent ambulance management system, the main problem sought to be solved is the loss of human lives due to delays in the arrival of ambulances to hospitals due to traffic congestion. Affected areas such as emergency medical services that are impaired by traffic are analyzed, software solutions and hardware devices connected through wireless or wired networks are proposed, using technologies such as IoT to connect and control the components through the internet, in addition it is proposed to monitor the vital signs of patients in the ambulance and transfer them to the hospital, while controlling the traffic lights to give free passage to the ambulance. They also consider the traffic density in the traffic light control algorithm and the integration of health monitoring and traffic control can help save lives.

In the study by Priliana and Rosyida (2023) they focus on addressing the problem of finding the optimal route for ambulance transportation from public health centers to referral hospitals, taking into account distance and traffic density. The Floyd-Warshall algorithm is used, which is a widely used technique in solving routing problems in weighted networks. Employing traffic information provided by Google to model the ambulance route in a weighted graph, where the weights represent the difficulty or congestion of traffic on each segment of the route. To determine the optimal route, the simple additive weighting (SAW) method is used, which allows assigning weights to different factors that influence route choice, such as distance and traffic density. This method allows multiple criteria to be considered and assigned relative importance, resulting in a route that optimizes the different objectives set. The results are more efficient than the initial routes determined by the health centers. This implies an improvement in the efficiency of ambulance transport and a reduction in response time in emergency situations.

Subrata et al. (2023) presents a comparative study of the implementation of all-pair shortest path algorithms, specifically Floyd-Warshall, Johnson, and Dijkstra, in a real-world scenario using the Google Maps API. The goal of the research is to understand the strengths and weaknesses of these algorithms in different types of applications. The study also compares the use of adjacency and list matrix representations, and modifies the algorithms to return additional values about the path taken. The performance of the Floyd-Warshall and Johnson algorithms in finding the shortest path between multiple locations is also compared. It was found that the Johnson algorithm is faster and requires less memory than the Floyd-Warshall algorithm, especially when the network is sparse. However, Floyd-Warshall is easier to implement and may be more suitable for small networks. The paper recommends using these algorithms to optimize routes in transportation and logistics. It is mentioned that these algorithms can be used to find efficient routes for emergency vehicles, such as ambulances or fire trucks, by considering the shortest total travel time or sequences of roads that form a loop with a shorter total travel time. This can be especially useful in situations of traffic congestion or to find alternative routes in case of road blockages.

In the review of the literature on real-time alert systems, we have found works that address each process in isolation, for example, there are works that only address the identification of the alert and the location to feed their system and allow finding the route to give attention to the request. Others combine systems such as GPS and congested route systems to calculate an optimal route to respond to the request; other authors present analyses of shortest route algorithms; others present research carried out directly in ambulances to determine the route to respond to emergency requests. So far, no process has been found to speed up and reduce the response time to road accident emergency alerts.

Perez et al. (2022) discuss a global emergency system based on hybrid WPAN and LPWAN networks, highlighting that the alarm transmission time to reach the emergency service is less than 5 seconds on average. This finding is crucial for the development of real-time ambulance alerting systems, as the speed of information transmission can be vital in emergency situations (Perez et al., 2022).

Fan et al. (2011) present an autonomous community coordination technology in wireless sensor networks, comparing different approaches for emergency information transmission. This study is relevant to understand how communication networks can be optimised in emergency situations, ensuring that critical information efficiently reaches monitoring centres (Fan et al., 2011).

Morimura et al. (2012) discuss emergency medical support in the context of the Fukushima nuclear power plant accident. The study emphasises the importance of clear communication about exposure levels and corresponding risks, which is essential for effective coordination of emergency medical services in disaster situations (Morimura et al., 2012).

Lindskou et al. (2019) review the pre-hospital emergency medical care system in Denmark, highlighting the implementation of Emergency Medical Coordination Centres (EMCCs) and their impact on improving emergency care. This approach can serve as a model for the coordination of ambulance services in other contexts (Lindskou et al., 2019).

Lowthian et al. (2011) address the increasing demand for ambulance services by older patients, suggesting that there is a need to develop a coordinated approach that includes innovative models of patient-centred care. This is relevant for resource planning and management in emergency services (Lowthian et al., 2011).

Chen (2013) proposes an RFID-based smart hospital environment, which improves service quality by delivering emergency messages and assigning health workers. This technological approach can be useful for real-time coordination of emergency medical care (Chen, 2013).

Chun and Park (2014) describe a policy-based approach to emergency biomedical data management in mobile care, enabling rapid and accurate response in emergency situations. This system can be instrumental in improving communication in emergency medical care (Chun & Park, 2014).

Zhang et al. (2016) discuss the need to introduce new techniques to deploy emergency communication networks quickly and effectively. This approach is essential to ensure that emergency services can respond in a timely manner to crises (Zhang et al., 2016).

Campana et al. (2014) present the E-SPONDER system, a new communication infrastructure for emergency networks, which is characterised by its reconfigurability and high performance. This system can be instrumental in supporting first responders during disaster events (Campana et al., 2014).

Abdellah et al. (2018) develop a real-time pre-hospital communication system using mobile technology, which enables multidimensional monitoring and data sharing prior to ambulance arrival. This approach can significantly improve the quality of emergency medical care (Abdellah et al., 2018).

This research presents a coordinated and communicated process in real time to respond to emergency alerts in road accidents

3 Process coordinated and communicated in real time

3.1 Description of the problem

Currently, the percentage of deaths in Mexico due to road accidents is increasing due to different causes: lack of infrastructure on highways, lack of road education of the inhabitants, lack of maintenance of vehicles, lack of coordination between patrols and ambulances, among others. With this background, the need arises for a system that coordinates the elements or parties involved in providing care and timely assistance in road accidents.

The construction of the communication solution was done with a communication plane between different devices and an algorithm for the construction of the best route.

3.2 Description of the communication system

The communication system considered for the solution to the problem is shown in Figure 1, which describes the real-time communication process to respond to the emergency alert.

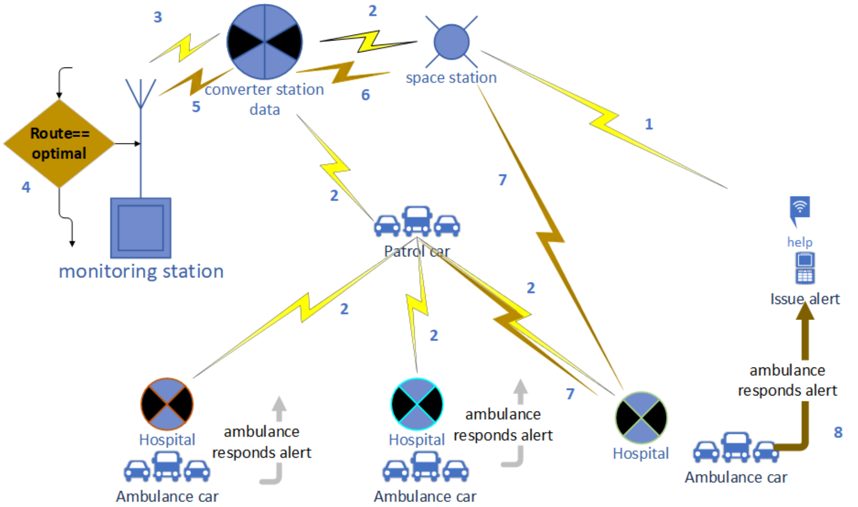

Fig. 1 Real-time communication process.

The real-time communication process indicates the following sequence:

1. Distress signal is emitted, which is replicated by the data station to the patrols and ambulances.
2. The distress signal is channeled to the information and data conversion station.
3. Location and distress data are sent to the monitoring station.
4. The monitoring station processes the road data, ambulance locations and distress signal information, generates the optimal route and identifies the nearest ambulance unit to respond to the distress alert.
5. The optimal route information and care assignment is sent to the nearest ambulance unit.
6. The information is replicated directly to the hospital containing the ambulance unit for their knowledge.
7. The hospital manages and processes the information.
8. The ambulance with the optimized routing and assignment information in step 6 is directed to provide care to the alert location.

For the real-time communication simulation, a fleet of 9 differential mobile robots and a fictitious city of 129 nodes represented on the LANAVEX laboratory platform were used. The differential mobile robots will represent each of the ambulance units available in the hospitals.

A mobile robot is characterized as an electromechanical system with the ability to move autonomously, without being physically linked to a single point. This device incorporates sensors that enable constant monitoring of its position relative to its origin and destination. Generally, its control is performed in a closed loop, and its displacement is achieved through various locomotion devices, such as wheels, legs, tracks, among others (Sotelo et al. 2007).

A differential mobile robot is a type of robot capable of moving in a straight line, turning on itself and tracing curves due to its configuration (Sánchez et al. 2017), with two wheels fixed on its axis and with one or two contacts (see Figure 2). This type of robot is characterized by its mobility capacity on hard and obstacle-free terrain, which allows it to reach relatively high speeds, making them ideal for the experimentation to be carried out in the LANAVEX laboratory.

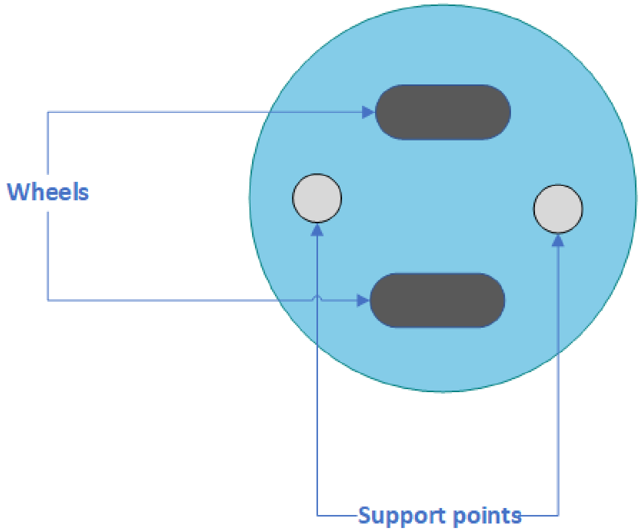

Fig. 2. Differential mobile robot.

Specifically, the design, modeling and control that these robots will have been carried out by Hernández-Huerta (2020) and used for the construction of the prototypes of the present work.

Description of the fictitious city. Considering the available work space, an area was adapted for experimentation in the LANAVEX laboratory with dimensions of approximately 408x612 centimeters, dividing it into squares of 34x34 centimeters. In this way, we began to trace the routes forming a virtual city, taking into account different shapes and sections of the streets and blocks that could be found in a city. Each edge or 'corner' is defined as a node or point reachable by the vehicle.
Figure 3 shows the layout of the fictitious city created with 129 nodes.

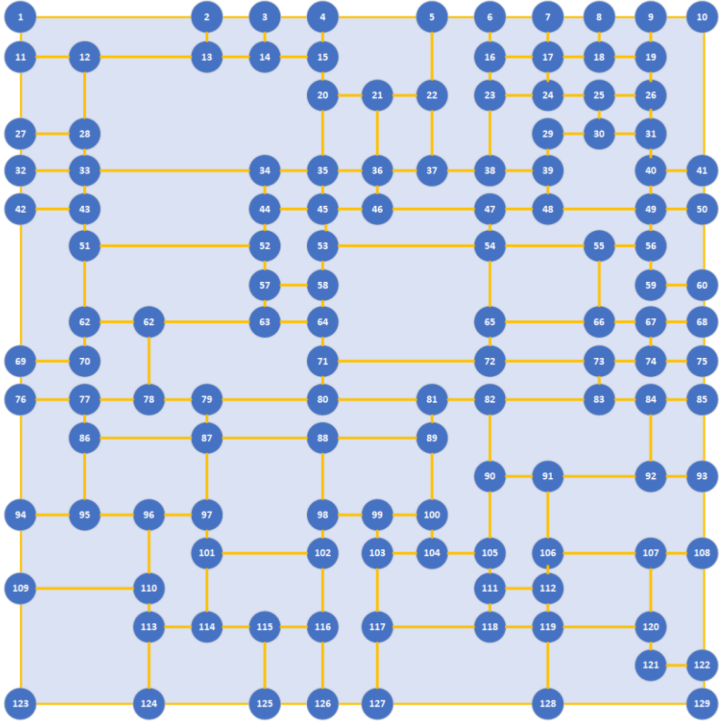

Fig. 3. Fictitious City instance with 129 nodes.

Taking into consideration the above, every 34 centimeters on the platform will be considered as a unit in the algorithm, making a coordinate transformation at the beginning and at the end of the algorithm in order to facilitate the construction of the adjacency matrix and the coordinate matrix of each of the nodes in the network.

3.3 Mathematical Model

The purpose of the objective function is to minimize the time to respond to the alert request, by means of a best route. The mathematical model is defined as shown in equations 1 to 5

$$Min\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}t_{ij} \qquad i\in\{1,2,3,4,5,\ldots n\} \quad j\in\{1,2,3,4,5,\ldots m\} \tag{1}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} t_{ij} < t_a \tag{2}$$

$$t_a = \frac{x_{ij}}{90} \tag{3}$$

$$u_{v_q} \rightarrow u_s \qquad q\in\{v_1, v_2, v_3, \ldots, v_{qq}\} \tag{4}$$

$$r = \{u_{v_q}, node2, node3, node4, \ldots nodek, u_s\} \tag{5}$$

Where:

x_{ij}	Represents the distance traveled by vehicles from node i to node j
t_{ij}	It represents the time taken to travel each distance between nodes considered from node i to node j on a route.
t_a	Represents the time it takes for the ambulance to reach the alert location along a route r.
r	Represents the optimal route
u_s	Represents the location of the Alert request or end node of the route.
u_{v_q}	Represents the location of the ambulance vehicle that will respond to the alert..
ij	They represent the initial node i and final node j in each section of the route that is being traversed.
$nodek$	It represents each node of the optimal route.
q	Represents the number of ambulance vehicles
v_q	Represents the ambulance vehicle that will provide care to the request.

Equation (1) shows the objective function whose purpose is to minimize the response time to requests by taking the best route.

Equation (2) shows that the response time should be less than the time allotted in minutes ta after receiving the distress alert. For this experimentation, ta is considered at a maximum speed of 90 km/h, depending on the type of emergency.

Equation (3) shows the calculation of the attention time. In this research, the maximum speed of the ambulance will be 90 km/h. So that the time of attention given these conditions must oscillate between a radius of 80km giving as a result thatta=53.33 minutes.

Equation (4) shows that the location of the vehicles available for attention should be as close as possible to the location of the alert request.

Equation (5) shows the optimized route to be followed by the vehicle that will give attention to the request. To calculate the optimized route, the start node (location of the nearest unit) and end node (location of the request) must be available.

3.4 Algorithm

Next, the algorithm considered in generating the optimal route is described. For its implementation, a hybridization between a routing algorithm and a genetic algorithm has been used.

```
00 Start
01 Initialize distances between graph nodes and alert node
02 Find nearest node index using minimum distance
03 Print nearest node index
04 Set initial variables:
      -Get the total number of nodes in the graph (n)
      -Set the first term to start the search
      -Set the second term as the closest node
      -Define the number of repetitions to find the best path
05 Initialize variables for storing results:
      -Current path size
      -Previous path as an array of zeros
      -Size of previous path as infinite
      -Best route found initially empty
06 Main simulation loop:
      -Repeat process up to defined number of repetitions:
      a)Generate random permutation of nodes from 1 to n
      b)Find index of first term in the permutation and adjust it to start with the
      first term
      c)Iterate over each node in the adjusted permutation
      c-i)Determine the part of the vector that will maintain its original position
      c-ii) Check if there is a direct path between consecutive nodes in the
      permutation; if it does not exist, try to readjust the order until a viable
      path is found or discard the permutation if it is not possible
      c-iii) Calculate the size of the path as the permutation progresses
      c-iv) If the second term is found, record the path to that point and exit the
      loop
      d)Evaluate whether the found route is better than the previous one in terms of
      length and size and, if so, update the best route and its size
      07 If the condition of the number of repetitions of the main loop meets, show
      the best route found and its size otherwise return to step a).
```

4 Experimental procedures

In the experiment, the tests carried out on communication between devices in the LANAVEX laboratory are presented to test the operation of information transfers between devices using the ESP32 series, which has the ability to run its own applications in real time, in addition to offering connectivity to those microcontrollers that They lack it, thus being an intermediary and an attractive alternative to be used in IoT projects or that need communication with the network. Mobile robots, equipped with ESP32 microcontrollers, receive these instructions through wireless communication based on the ESP-NOW protocol. The communication between MATLAB and the mobile robots goes through an intermediary which is the Arduino IDE software, which sends the data from the microcontroller connected to a serial in the computer, allowing it to send a chain of the necessary data so that Each mobile robot complies with the instructions sent to it by the coordination algorithm. Figure 4 describes the communication process between the robots and the devices used in this experiment.

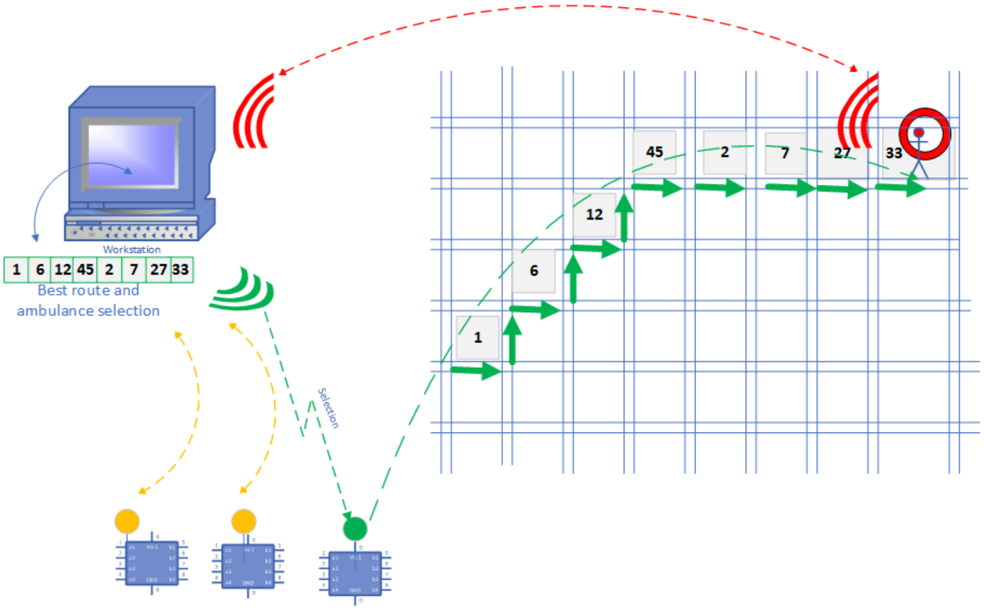

Fig. 4. Components for communication between differential mobile Robot.

To construct the optimized route, the algorithm is described using a flow chart which was programmed in Matlab r2021a, with a machine with an AMD Ryzen 5 4500U processor with Radeon Graphics 2.38 GHz, 16 GB RAM, 64-bit operating system and Windows 10. Home. With connectivity: Wi-Fi: 802.11 b/g/n, speed up to 150 Mbps, supports access point and station mode.

4.1 Process flow diagram

In the context of coordination in medical emergencies, the optimization of emergency response routes is a critical aspect to ensure rapid and effective medical care. The efficient movement of emergency vehicles, such as ambulances, can make the difference between life and death in emergency situations. Figure 5 describes the information flow diagram of the proposed algorithm.

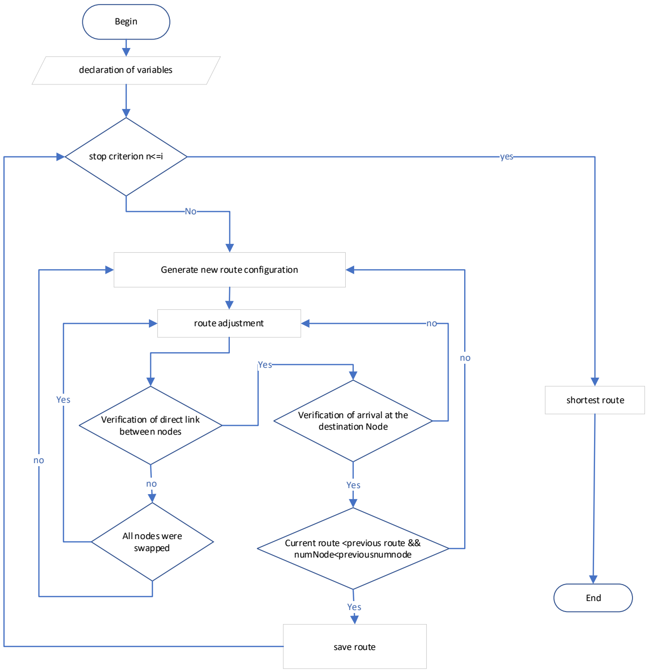

Fig. 5. Flowchart.

Test instances are classified into two groups. The first group is an instance of 129 nodes representing the fictitious city in Figure 3. This instance was generated for experimentation in the LANAVEX laboratory to test the communication and validation of sending information in real time with nine mechatronic devices. The second group was generated for experimentation in the simulation using randomly generated instances with a size of 129 nodes and varying the number of runs. Table 1 describes the test instance.

Table 1. Description instances

Description of variables	Set	Location/ Distance	starting node/ end node
Fleet ambulances	9	Location	
Number of nodes	129	Location/Distance	Starting node
Information Alert		Location/Distance	End node

5 Results

100 instances of 129 nodes were built. The number of repetitions that were executed was 500, 1000, 1500, 2000 and 2500 with a stopping criterion of 25 generations each, in which the data shown below were obtained: where Ng = Number of generations, Route size represents the units traveled. TE(s) = Execution time.

Table 2 shows the results obtained from 500 repetitions, obtaining a best route of 30 travel units with a frequency of 2 in an execution time of 0.87 seconds.

Table 2. Results of executions on 129 node instances with 500 repetitions

Ng	Route size	TE (s)	$t_{a(min)}$
1	32	0.805	+0,007253
2	39	0.849	0,00884
3	44	0.837	0,009973
4	32	0.854	0,007253
5	38	0.845	0,008613
6	32	0.855	0,007253
7	36	0.798	0,00816
8	30	0.865	0,0068
9	34	0.891	0,007707
10	32	0.852	0,007253
11	38	0.856	0,008613
12	34	0.812	0,007707
13	36	0.871	0,00816
14	30	0.876	0,0068
15	32	0.897	0,007253
16	34	0.863	0,007707
17	38	0.871	0,008613
18	36	0.875	0,00816
19	32	0.961	0,007253
20	32	0.869	0,007253
21	34	0.907	0,007707
22	32	0.854	0,007253
23	34	0.869	0,007707
24	36	0.878	0,00816
25	38	0.923	0,008613

Table 3 shows the results of the 1000 repetitions identifying the best route of 30 units with a frequency of 9 in an average execution time of 1.706 seconds and a service time of 0.0068 minutes.

Table 3. Results of executions on 129 node instances with 1000 repetitions

Ng	Route size	TE (s)	t_a (min)
1	32	1.584	0,007253
2	32	1.712	0,007253
3	30	1.705	0,0068
4	36	1.687	0,00816
5	30	1.672	0,0068
6	30	1.735	0,0068
7	34	1.740	0,007707
8	30	1.686	0,0068
9	36	1.694	0,00816
10	30	1.689	0,0068
11	34	1.721	0,007707
12	32	1.716	0,007253
13	37	1.665	0,008387
14	34	1.669	0,007707
15	32	1.674	0,007253
16	30	1.749	0,0068
17	36	1.670	0,00816
18	34	1.636	0,007707
19	30	1.680	0,0068
20	34	1.686	0,007707
21	34	1.700	0,007707
22	30	1.707	0,0068
23	30	1.727	0,0068
24	32	1.720	0,007253
25	32	1.703	0,007253

Table 4 shows the results of 1500 repetitions with a frequency of the best route of 30 units of 14 with an average execution time of 2.530 seconds and attention time of 0.0068 minutes.

Table 4. Results of executions on 129 node instances with 1500 repetitions

Ng	Route size	TE (s)	t_a (min)
1	30	2.462	0,0068
2	31	2.561	0,007027
3	34	2.520	0,007707
4	30	2.537	0,0068
5	32	2.471	0,007253
6	30	2.516	0,0068
7	30	2.537	0,0068
8	30	2.530	0,0068
9	32	2.534	0,007253
10	30	2.553	0,0068
11	34	2.508	0,007707
12	32	2.513	0,007253
13	30	2.587	0,0068
14	32	2.492	0,007253
15	30	2.525	0,0068
16	30	2.483	0,0068
17	32	2.592	0,007253

18	30	2.511	0,0068
19	32	2.487	0,007253
20	32	2.600	0,007253
21	30	2.524	0,0068
22	30	2.493	0,0068
23	30	2.561	0,0068
24	32	2.538	0,007253
25	30	2.595	0,0068

Table 5 shows the results of 2000 iterations with a best path frequency of 18 and an average execution time of 3.347 seconds, with an attention time of 0.0068 minutes.

Table 5. Results of executions on 129 node instances with 2000 repetitions

Ng	Route size	TE (s)	t_a (min)
1	30	3.236	0,0068
2	30	3.539	0,0068
3	30	3.316	0,0068
4	30	3.303	0,0068
5	32	3.390	0,007253
]6	30	3.387	0,0068
7	32	3.342	0,007253
8	30	3.392	0,0068
9	30	3.319	0,0068
10	32	3.321	0,007253
11	30	3.351	0,0068
12	32	3.259	0,007253
13	30	3.377	0,0068
14	30	3.305	0,0068
15	30	3.435	0,0068
16	30	3.316	0,0068
17	30	3.402	0,0068
18	30	3.257	0,0068
19	32	3.305	0,007253
20	30	3.274	0,0068
21	30	3.328	0,0068
22	32	3.276	0,007253
23	32	3.322	0,007253
24	30	3.352	0,0068
25	30	3.364	0,0068

Table 6 shows the results of executions of 2500 repetitions with a frequency of 13 and an average execution time of 4.196 seconds with an attention time of 0.0068 minutes.

Table 6. Results of executions on 129 node instances with 2500 repetitions

Ng	Route size	TE (s)	t_a (min)
1	30	4.091	0,0068
2	30	4.190	0,0068
3	30	4.153	0,0068
4	32	4.134	0,007253
5	32	3.990	0,007253
6	32	4.074	0,007253
7	32	4.087	0,007253
8	30	4.133	0,0068
9	30	4.445	0,0068
10	30	4.276	0,0068
11	30	4.182	0,0068
12	30	4.209	0,0068
13	32	4.238	0,007253
14	30	4.116	0,0068
15	30	4.209	0,0068
16	30	4.241	0,0068
17	30	4.131	0,0068
18	30	4.167	0,0068
19	32	4.282	0,007253
20	32	4.104	0,007253
21	34	4.330	0,007707
22	32	4.196	0,007253
23	32	4.129	0,007253
24	32	4.182	0,007253
25	32	4.148	0,007253

Table 7 shows the summary of the convergence of the algorithm with the best route and the execution time and the attention time..

Table 7. Frequency of best route with respect to number of repetitions

Repeat	Frequency	Average TE	t_a (min)
500	2	0,87	0.0068
1000	9	1,706	0.0068
1500	14	2,53	0.0068
2000	**18**	**3,347**	0.0068
2500	13	4,196	0.0068

Figure 6 shows the graphical behavior of the frequency of the optimal route with respect to the number of repetitions of the experimentation of the proposed algorithm.

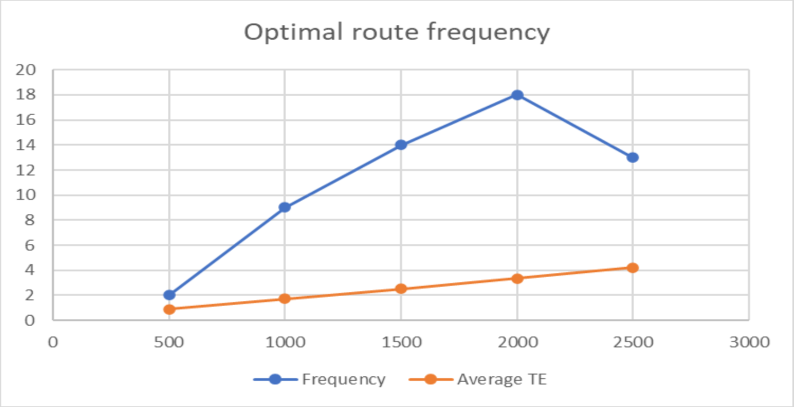

Fig. 6. Optimal route frequency

The experimentation for the assignment of the ambulance car that will attend to the request was carried out with 30 randomly generated instances with 2000 repetitions, in order to establish the closest route to the alert in a specific coordinate and its closest node. Table 8 shows the results obtained for the ambulance assignment. Where: NC = Closest node. No. NPP = Number of nodes to pass. From the generated alert coordinates, the node closest to that coordinate is represented with NC with a number of nodes to travel the size of the route.

Table 8. Results of 30 instances for ambulance assignment with fixed location in node1

No.	Alert coordinate	NC	No. NPP	Route size	TE (s)
1	(6,18)	127	14	24	3.159
2	(2,12)	96	10	15	3.220
3	(11,12)	92	17	23	3.247
4	(1,9)	70	7	10	3.003
5	(4,7)	57	9	11	2.812
6	(7,14)	104	15	21	3.263
7	(5,7)	58	10	12	2.853
8	(4,4)	34	6	8	2.536
9	(5,10)	80	11	15	3.014
10	(11,1)	19	10	12	3.098
11	(5,15)	102	13	19	3.228
12	(8,8)	65	11	16	3.042
13	(0,17)	123	10	18	3.423
14	(3,9)	79	10	13	3.073
15	(0,14)	94	8	13	2.969
16	(4,8)	63	10	12	2.890
17	(2,10)	78	9	12	2.905
18	(8,7)	54	10	14	2.887
19	(4,5)	44	7	9	2.702
20	(7,15)	104	15	21	3.256
21	(4,0)	3	3	4	2.003
22	(7,13)	100	13	20	3.171
23	(4,9)	63	10	12	2.866
24	(11,8)	67	13	19	3.140
25	(6,10)	80	11	15	3.086
26	(8,9)	72	12	17	3.135
27	(3,13)	97	11	16	3.221
28	(3,5)	44	7	9	2.657
29	(10,0)	8	8	10	3.119
30	(12,15)	108	20	26	3.263

Table 8 shows the alert request coordinates, the route represented by the nearest node and nodes to be traversed, as well as the route size and route generation time. The results represent the requests that will be handled by the ambulance located at node 1.

The experimentation to generate the routes for a set of 9 ambulances is shown in Table 9.

Table 9. Set of 9 ambulance instances with 129 nodes

Ambulance	Alert Distance	Disponibility
1	10	2
2	3	2
3	5	1
4	7	2
5	13	3
6	8	1
7	2	1
8	5	2
9	6	2

Each ambulance will respond to an alert with an available route represented in the table as distance to the alert with an availability of patient quota in the ambulances. Thanks to the National Council of Humanities, Science and Technology, for the scholarship support. Thanks to the LANAVEX laboratory for the assigned space and the tools for the experimentation of this project.

6 Conclusions

Based on the experiments carried out in the laboratory and the instances generated, as well as the use of differential robots and communication devices, it can be concluded that the process of communication and coordination in real time for assistance to road accidents is possible. Based on the results obtained in the tests carried out in the laboratory, it is shown that the coordination of the different devices and units for assistance to the injured in road accidents, as well as the execution of routing algorithms hybridized with heuristics gave good results, which is expected to be implemented in the future with real instances in real time. The calculation of the optimal route in execution time for the algorithm is considerable in instances of 129 nodes and it is expected that the execution time can be obtained in a considerable time for larger instances. The attention times in the laboratory were in the order of minutes because the distances considered in the instances were very small, but it is expected that in instances with routes in kilometers it can be within the range of attention less than 55 minutes. It was also found that in 2000 repetitions the algorithm converges to the optimal solution.

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