ROUTING ALGORITHM AND KINEMATIC MODEL OF MOBILE ROBOTS IN WIRELESS SENSORS NETWORKS

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Abstract: Mobile wireless sensors networks are a fast changing branch of the wireless networks. The mobility of the nodes, the trajectory plan and the routing algorithm determine the implementation of a new strategy that take into account their interdependency with the scope of minimizing the energy consumption and increasing the coverage grade. The trajectory planning scheme consists of a routing algorithm to maintain the connectivity and decentralized receding horizon planners that reside on each vehicle to achieve coordination among agents. The advantage of the proposed algorithm is that each vehicle only requires local knowledge of its neighboring vehicles.

1 INTRODUCTION

This research concerns the development of mobiles wireless sensors network based on autonomous collaborative robots. A node in this network is an autonomous robot system, self-propelled, with enough capacity for processing information for decision-making and sufficient resources to ensure the implementation of a reduced number of specific tasks, in an unknown environment (Nicolae and Dobrescu, 2008).

Many application areas are naturally concerned by such research. Today, mobile wireless sensors are becoming increasingly complex, integrate capabilities of adaptation to various areas of operation and target ever-increasing demands of robustness, ergonomics and safety. In addition, several robots have the opportunity to solve more efficiently and rapidly a mission.

Most coordinated tasks performed by teams of mobile wireless nodes, require reliable communications between the members. Therefore, task accomplishment requires that nodes navigate their environment with their collective movement restricted to coverage area to guarantee integrity of the communication network.

Maintaining this communication capability induces physical constraints on trajectories but also requires calculation of communication variables like routes and transmitted powers.

2 ROBOT MODEL

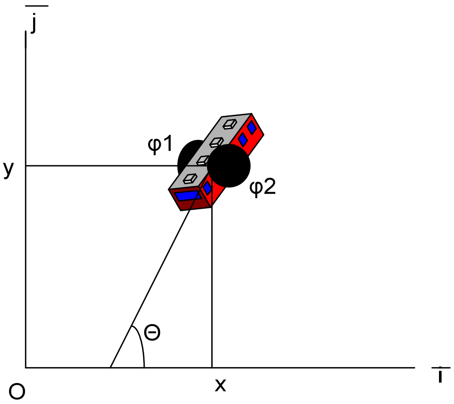

Figure1: The model.

$$\begin{cases} \dot{x}_i = v_i \cos\theta_i \\ \dot{y}_i = v_i \sin\theta_i \\ \dot{\theta}_i = w_i \end{cases} \quad (1)$$

- The system is subjected to kinematic constraints (Guo and Parker, 2002), and also to communication constraints;

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-The scope of communication is to gather all information from sensors to a central station, to have a better coverage and a minimum energy consume;

-Every node has a start point and a finish point in the same geographical area.

Decentralized strategies have recently been introduced. They generally require a communications flow fairly high in order to transmit information request to other individuals.

The protocol can include notions of intent and commitment from which each robot elaborated its own path, taking into consideration the activities of other robots.

However, this approach does not fulfill the constraint on the maintenance communication links. Other strategies based decentralized fields of potential (Gazi and Passino, 2004), navigation functions (potential field without local minimum, (Gennaro and Jadbabaie, 2006) on the decomposition cell (Lindhe et al., 2005) have been developed. However, they are not applicable to the non-holonomic systems.

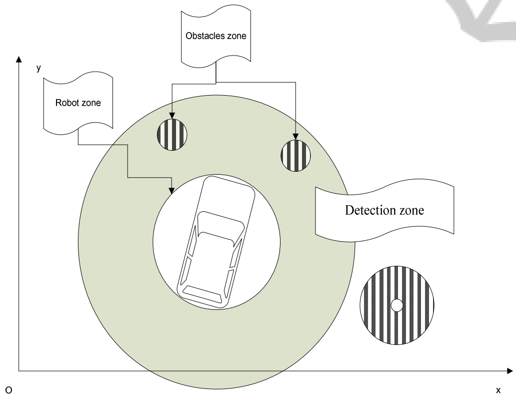

Figure 2: Obstacle detection.

Each disc O_{mi} is defined by the coordinates of its center (X_{Mi}, Y_{mi}) and its radius rmi ($1 \leq mi_d \leq Mi$).

For the avoidance of collisions, the distance between the robot and obstacles detected Omi time t, ie

$$d_{i,O_{mi}}(t) = \sqrt{(x_i(t) - X_{mi})^2 + (y_i(t) - Y_{mi})^2} \qquad (2)$$

has to satisfy the inequality :

$$d_{i,O_{mi}}(t) \geq \rho_i + r_{mi}, \forall t \in [t_k, t_{k+1}], \forall O_{mi} \qquad (3)$$

The planning problem is to compute, in a cooperative manner, for N robots, allowable trajectory and collision-free, joining the initial configuration q_i ($t_{initial}$), the final configuration $q_i(T_{final})$ (with initial velocity u_i ($t_{initial}$), and final $u_i(T_{final})$ assumed to be zero), which optimize the critter function.

In addition to the individual constraints which involve only the node itself (ie. constraints non-holonomy, constraints $u_i \in U$ on the qualifying speeds and constraints (1) of avoidance robots), the planned trajectory must respect the constraints defined here (Desai et al., 1998), (Dunbar and Murray, 1998), (Defoort et al., 2007d).

On the other hand, it is necessary to maintain some communication links (eg. for an exchange of strategies for the use of sensors decentralized, maintain connectedness of training).

To describe the coupling constraints, we can define the communication graph that will model the topological structure of the network of com-communication between vehicles. (Defoort et al., 2007d).

In general, the performance function is defined as:

$$J = \int_{t_{init}}^{t_{final}} L_i(\varphi_1(z_i, \dot{z}_i, \dots, z_i^{(l_i-1)}), \varphi_2\left(z_i, \dot{z}_i, \dots, z_i^{(l_i-1)}\right), t) \qquad (4)$$

where the constraints are:

$$\begin{cases} \varphi_1\left(z_i(t_{init}), \dots, z_i^{(l_i-1)}(t_{init})\right) = q_{i,init} \\ \varphi_1\left(z_i(t_{final}), \dots, z_i^{(l_i-1)}(t_{final})\right) = q_{i,final} \\ \varphi_2\left(z_i(t_{init}), \dots, z_i^{(l_i-1)}(t_{init})\right) = q_{i,init} \\ \varphi_2\left(z_i(t_{final}), \dots, z_i^{(l_i-1)}(t_{final})\right) = q_{i,final} \\ \varphi_2\left(z_i(t), \dots, z_i^{(l_i)}(t)\right) \in U_i \\ d_{i,O_{mi}}(t) \geq \rho_i + r_{mi}, \forall t \in [t_k, t_{k+1}], \forall O_{mi} \end{cases} \qquad (5)$$

The trajectory will be projected from q_i and u_i in the flat coordinate z. (Defoort et al., 2007d)

In an unknown environment the planned trajectory will be available only for a short interval until the sensors detect obstacles or others robots.

Also for avoiding robots the trajectory planning can be use, but this approach implies a lot of communications between nodes. The strategy for planning the trajectory in such environment is to use a sliding horizon of time to calculate the new trajectory. The principle of planning the trajectory is to divide it in two parts:

- The planning horizon T_p – represents the interval for which the performance is evaluated:
- The calculus horizon T_c – the trajectory is calculated.

The critter of performance is then defined as:

$$J_{\tau_k} = \left\| q_i(\tau_k + T_p, \tau_k) - q_{i,final} \right\|^2 + c \int_{\tau_k}^{\tau_k + T_p} L_i(q_i(t,\tau_k), u_i(t,\tau_k), t)\,dt \qquad (6)$$

where L_i is the cost function and it represents the energy consumed on every calculated step τ_k to reach the goal of minimizing the performance function.

The kinematic of robots influences the messages passing through the network.

In actual research the topology of the network is fixed. This introduced a fixed constrain in the kinematic equation of robots:

$$d_{ip}(t,\tau_k) \leq \min(d_{i,com}, d_{p,com}) - \varepsilon \qquad (7)$$

where $d_{i,com}$ and $d_{p.com}$ are the radio distance covered by the radio signals at the step τ_k.

The disadvantage of this approach is the inflexibility of the topology of the network. The robot sensors cannot cover a large and dynamic area of interest.

A new approach is needed to have an authentic influence between the constraints, the energy consummation, the geographical coverage and the network coverage.

3 THE ROUTING ALGORITHM

The proposed routing algorithm will use the information of the planned trajectory of the nodes. Our network will respect some principles:

- The messages will be from the principal node to the specific node and back,
- The main goal of the network is to gather data from mobile sensors to the principal node,
- The role of principal node is to be the network gateway,
- This node will not have kinematic constraints with respect to the radio links,
- The network will be defined in layers, every layer will represents the number of hops the message pass from source to destination:
  layer (i) - represents the layer on which the node *i* is placed in the network, and represents the number of nodes that a message will pass from *i* to node *0*.

The new approach will introduce dynamic constraints. We will consider T_s as the period these constraints will be updated.

- $T_s < T_c$, we will be in the situation of fixed constraint,
- $T_s \geq T_c$, the routing algorithm will influence the trajectory planning.

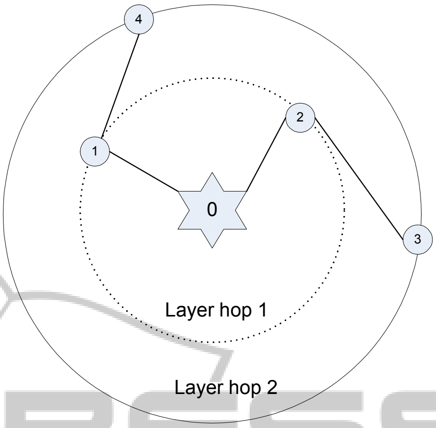

Figure 3: Logical view of the network layers.

At each T_s, in the network, a SYNC message will be send in the network with information regarding the current layer of the transmitter.

And second, there will not be enough time to calculate the planned trajectory for every possibility we have to.

Finally the routing algorithm is defined:

- The message from node k will be sent to the node 0 through the node that minimize the performance critter;
- This node is on the next layer close to first layer;
- Every node, from every layer will take the same decision based on the critter of performance;
- Node 0 will always be on layer 0.

At every interval T_s the constraints will be dynamically changed based on the information broadcasted through the network.

The performance critter will be calculated locally on each node after the update of the network layers finish. The second equation (2) becomes:

$$d_{ip(t)}(t,\tau_k) \leq \min(d_{i,com}, d_{p(t),com}) - \varepsilon \qquad (8)$$

where $p(t) \in \mathcal{M}_i(\tau_k)$ represents the constraint node, with it the critter is evaluated and $\mathcal{M}_i(\tau_k)$ represents the union of the radio linked nodes at τ_k moment:

$$\mathcal{M}_i(\tau_k) = \{ j \mid j \neq 0, (i,j) \in radio\ neighbor_i, layer(j) = layer(i) - 1 \} \qquad (9)$$

4 SIMULATION

For solving the equations we will utilize the function CFSQP ("Constrained Feasible Sequential Quadratic Programming") developed at Maryland University. This routine utilizes an optimization algorithm based on sequential quadratic programming (SQP).(Lawrance et al.,1997)

The SQP is a method iterative where the critter is changed in an approximated quadratic equation and the constraints in equations linear. This will permit to calculate very fast a solution verifying the constraints.

The robot radius is 0.3 meters and the radio link is up to 3 meters. The robots will have a maximum speed of 1 m/s and the orientation will be 0 degree.

In the fixed configuration the existing approaches are simulated (the network topology will not influence the planning), in the Fig.2 the new algorithm is simulated, it will take in consideration the topology of the network.

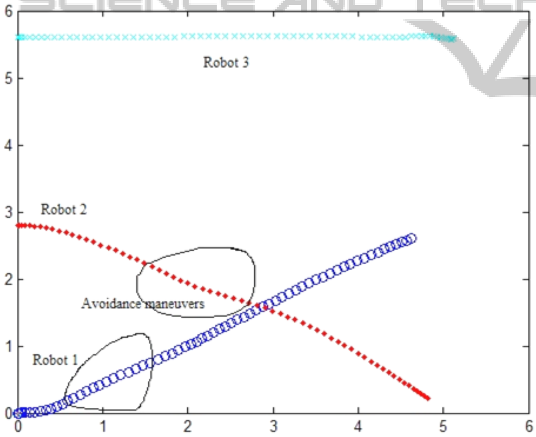

Figure 4: Fixed configuration.

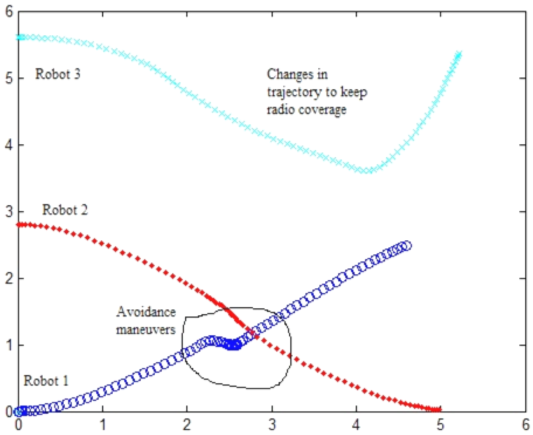

Figure 5: Dynamic configuration.

Table 1: Simulation results.

Nodes	3	6	10
Time (s)			
Fix	9.16	9.61	9.77
Dynamic	9.24	12.53	11.92
Radio Coverage (%)			
Fix	70	68	55
Dynamic	100	98	94

5 CONCLUSIONS

In the Table 1, the results of the simulation show the good potential of this algorithm with dynamic constraints the radio coverage is substantially improved from 55-70% of radio communications to over 94% but with some penalties in the average time to get to finish.

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