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A MOBILE WIRELESS SENSOR NETWORK FOR
COLLABORATIVE TASKS ACHIEVEMENT BY MEANS
AUTONOMOUS ROBOT ROBOT SWARM

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A Mobile Wireless Sensor Network Architecture for Collaborative Tasks Achievement by means of Autonomous Robot Swarm

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Introduction

In the last years, the detection of spatial and temporal variability of heterogeneous parameters is real-time performed [1] thanks to the development of innovative and integrated monitoring system such as Wireless Sensor Network (WSN). Such a technological solution provides an adequate level of pervasiveness mandatory for the observation of complex environmental phenomena in both civilian [2] and military applications as for example dangerous areas surveillance, target tracking , and intrusion detection [3]. Nevertheless, the efficiency and flexibility of a WSN architecture can be further enhanced if suitably integrated to gain other features (e.g., mobility) extend current functionalities. For example, WSNs can be “extended” thanks to the use of dedicated robotic devices in order to achieve the so-called mobile swarm sensing. State-of-the-art researches have explored different synergies among WSN and robots leading to different kinds of cooperation and applications. Considerable efforts have been devoted to develop collaborative-task solutions through swarm intelligence [4,5] and the arising Mobile Sensor Network architecture merges the advantages of the distributed sensing with the pervasiveness of the mobile robotics. As a matter of fact, wireless robot swarms can explore unreachable areas to rescue human victims or simply improve the sensing capabilities of the whole system focusing on selected “regions-of-interest” within the environment under test.

In this work, an experimental study of an intelligent distributed network where sensors and robots interact to solve collaborative tasks is presented. Thanks to the wireless connections among fixed and mobile (robot) nodes, a distributed sensing is realized as well as the achievement of a user-defined control task. In order to assess the feasibility of the proposed distributed control strategy as well as the reliability of the WSN-based mixed (fixed and mobile) robotic system, some preliminary experimental results concerned with the location of the most illuminated point in a room are shown.

Problem Statement

Let us consider a WSN-based infrastructure composed by $N = N_S + N_M$ nodes, N_S and N_M being the number of static and mobile (robot) nodes, respectively,

deployed in a two-dimensional domain $D = \{0 \leq x \leq X_D, 0 \leq y \leq Y_D\}$ as shown in Fig. 1(a).

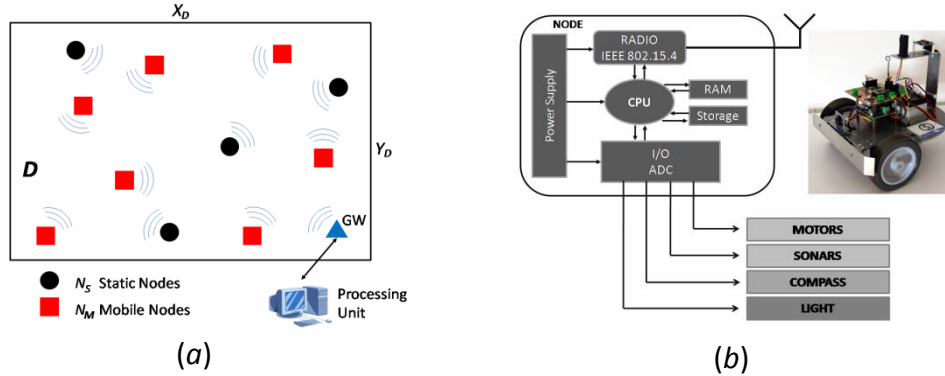


Fig. 1 – Logical representation of network infrastructure (a) and of the mobile nodes (b).

Each node controls a set of sensors that differ according to the node typology. The mobile robot nodes constitute the particles of the swarm. They manage the mobility as well as sensing and network communication issues [Fig.1(b)]. The static nodes act as a support for data gathering and processing and, eventually, for additional tasks (e.g., robot localization by means of standard triangulation strategies). Such a functional differentiation “moves” the complexity of the control strategy from the mobile robots, still simple, to the static infrastructure. Each mobile particle conceptually belongs to a higher-level entity that assures the system robustness even in the presence of a single particle failure. The collaborative task at hand is modeled as that of determining the position \underline{r}_{opt} where a physical quantity, $\Delta(\underline{r}, t)$, measured at the time instant t by the mobile nodes is maximized. Towards this end, the following iterative procedure is repeated:

Step 1 – Sensing. Let us consider the set of positions $\underline{r}_n = (x_n, y_n); n = 0, \dots, N_M - 1$ of the mobile nodes at the time instant t . Each robot measures the value of $\Delta(\underline{r}_n, t)$ by means of its on-board integrated sensors. The quality of the wireless links among the network nodes is also monitored to allow a distributed control of the swarm and the environment knowledge sharing. When $RSSI_m < \tau$ ($RSSI_m$ and τ being the Received Signal Strength Indicator of the link between the m -th mobile node and the nearest node of the network and a user-defined threshold, respectively), the m -th node is considered out of the network coverage and a warning message is generated for the successive *Decision Making* phase;

Step 2 - Decision Making. Once the sensing phase has been completed and the data gathered by the mobile nodes, $\Delta(\underline{r}_n, t)$, $\underline{r}_n = (x_n, y_n); n = 0, \dots, N_M - 1$, have been transmitted and collected, the algorithm updates the network state by

changing the positions of the robots according to a Particle Swarm (PS) strategy aimed at fitting the problem objective through the solution of an optimization problem. More specifically, each mobile robot of the swarm is modeled as a particle that acts individually under the same governing principle: “*accelerate toward the best personal and best overall location while constantly checking the value of its current location.*” Mathematically, such a statement is recast as the minimization of a suitable cost function

$$\varphi(\underline{r}_n, t) = \max \left\{ 0, \frac{\Delta^{th} - \Delta(\underline{r}_n, t)}{\Delta^{th}} \right\} \quad (1)$$

quantifying the “quality”/“fitness” of the current solution [i.e., the location of the robot (\underline{r}_n, t)], Δ^{th} being the threshold value of the on-board sensor.

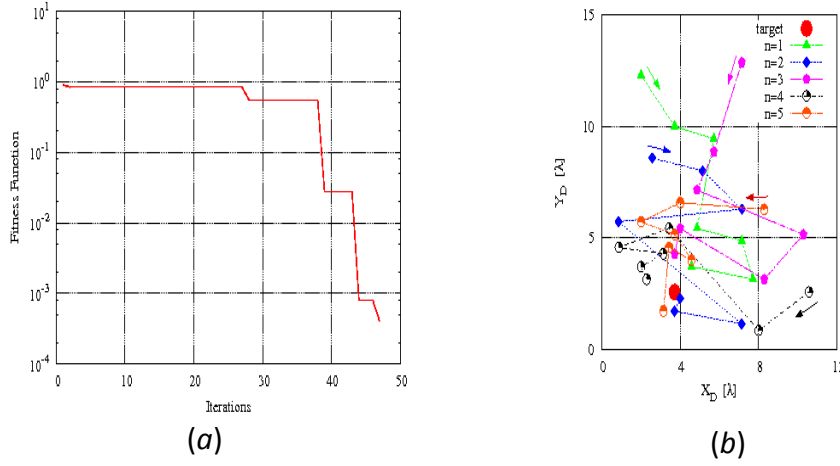


Fig. 2 – Behavior of the cost function (a) and evolution of the personal best positions of mobile robots (b).

At time instant $t' = t + \Delta t$, the robot positions are updated $\underline{r}'_n = \underline{r}_n + v_n \Delta t$, $n = 0, \dots, N_M - 1$ according to the PS procedure,

$$v_n = w \hat{v}_n + k_1 c_1 (\underline{r}_n^{pb} - \underline{r}_n) + k_2 c_2 (\underline{r}_n^{gb} - \underline{r}_n) \quad (2)$$

being the velocity of the n -th particle evaluated starting from \underline{r}_n^{pb} and \underline{r}_n^{gb} , namely the *personal best* and *global best* particle positions, respectively. When warnings about “weak wireless links” verify, the involved nodes move closer to the *best overall location* \underline{r}_n^{gb} by neglecting the indications from the swarm updating equation (2);

Step 3 – Execution. The motor units move the robots to reach the new positions $\underline{r}'_n, n = 0, \dots, N_M - 1$ computed at the Step 2. During its movement, each robot

activates additional ultrasonic sensors to avoid collisions with unknown obstacles or other mobile nodes;

The iterative procedure stops when the user-defined convergence threshold γ is reached or after a fixed amount of time.

Experimental Validation

The effectiveness and the reliability of the proposed robot swarm control strategy have been assessed by means of a preliminary experimental validation concerned with the unsupervised localization of a light source in an indoor scenario. A WSN composed by $N = 9$ nodes ($N_S = 4$, $N_M = 5$) has been deployed in a rectangular room of size $X_D = 12\lambda$ and $Y_D = 15\lambda$, λ being the wavelength at the working frequency $f = 870\text{MHz}$. Each mobile node has been equipped with a battery-powered motor unit, ultrasonic sensors for collision avoidance, and a light sensor. The static nodes have been positioned on the corner of the domain, while the mobile nodes have been randomly distributed. The light source has been centered at $\underline{r}^{target} = (3.7\lambda, 2.5\lambda)$. After $I = 46$ iterations, the cost function [Fig. 2(a)] reaches Δ^{th} and the optimization process ends with a global best position $\underline{r}_{gb} = (3.9\lambda, 2.4\lambda)$. For completeness, Figure 2(b) shows the evolution of the personal best positions \underline{r}_n^{pb} of the robots during the iterative optimization. As it can be observed, the whole swarm goes towards the target position.

Conclusions

In this paper, a WSN-based mixed infrastructure for cooperative monitoring/control has been described. Preliminary experimental results have been presented to assess the feasibility of such a solution as well as the effectiveness of the wireless integration between fixed and mobile robotic nodes.

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