EXPERIMENTS IN DISTRIBUTED CONTROL OF AUTONOMOUS MOBILE ROBOTS

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Abstract: Distributed control is known to produce simple and cost effective solutions for many control applications. This is particularily interesting for controlling autonomous mobile robots, where the designer faces severe constraints in what concerns energy consumption, and the overall cost of the mobile unit. This paper presents a couple of experiments aimed to illustrate two different approaches in the implementation of distributed control of autonomaous mobile robots. In the first experiment, the robot is integrated in a flexible assembly line, and the control tasks are shared between the on board electronics and a ground based PLC. In the second experiment, the robot communicates with a number of "neural beacons" deployed in the environment, and the resulting system acts as a distributed neural network capable to learn the control actions needed to guide the robot along predefined paths.

Keywords: Distributed control, Autonomous robots , PLC, Distributed ANN.

1. INTRODUCTION

One simple way to reduce the cost of many service robots is to give up the antropomorphic paradigm in designing these machines. Rather than viewing the robots as stand alone "organisms ", operating in an unknown and maybe hostile environment, we should notice that, in most practical situations, the environment is not only known/predictable, but also can be manipulated to include sensors, actuators, computing and communication equipment.

One good example of such situation is the industrial environment, where industrial robots (Nof (1999), Tomović, (1990)), having limited autonomy (see figure 1) are capable to execute a wide range of automation tasks.

Fig.1. Puma - a typical industrial robot – basically a robotic arm, located on a fixed platform, with some sensors, and strict programming rules

Martin Hägele et al. in Hägele (2002) introduced the concept of "robot assistant at manual workspace" – a sort of robotic apprentice, ideally capable to hand tools or components to a human operator. The actual implementation of this idea, called rob@work, (see figure 2), created by FRAUNHOFER consists in a robotic arm installed on a wheeled mobile platform. The resulting machine is so complex, and expensive that it remained in an experimental stage.

Fig.2. Rob@work from FRAUNHOFER IPA

Another type of service robots that operate in a known and easy to manipulate environment are the "nursing robots".

The first attempts to design such robots date back in 1985, when Borenstein and Koren (Borenstein, (1985)) described a mobile platform, equipped with a robotic arm, intended to support persons with disabilities in hospitals, or nursing homes.

The similarities in design with rob@work are obvious. And so is the obstination in ignoring the robot's environment.

Nearly two decades later, Pineau et al. (Pineau (2003)) conducted surveys about challenges and results in the research for creating nursing robots, and reported more challenges than results.

To conclude this very short analysis about the state of the art in the field of service robots, we will state that one major reason we don't have yet commercially available, and really useful service robots (other than autonomous vacuum cleaners, or mowers) despite the tremendous number of paper published every year on robotics is the persistence in ignoring the environment where robots operate.

In a totally different approach (Susnea (2008b)) we proposed a solution to create nursing robots, seen as intelligent wheelchairs, or walkers that operate in a manipulated environment holding most of the sensing and control equipment. This design approach, combined with simple, microcontroller based, on board electronics (Susnea (2008a), Susnea (2010)) lead to significant cost reduction of the entire nursing robot.

This paper presents two more examples of distributed control solutions for mobile robots. In section 2, we describe a simple means to integrate a mobile robot into a flexible assembly line. Section 3 contains the description of a navigation control system, wherein the robot and a number of neural beacons distributed in the environment implement a distributed ANN. Finally, Section 4 is reserved for conclusion.

2. INTEGRATING MOBILE ROBOTS IN FLEXIBLE ASSEMBLY LINES

Most of the automation problems in industry are now efficiently solved using PLCs, connected in control structures as shown in figure 3.

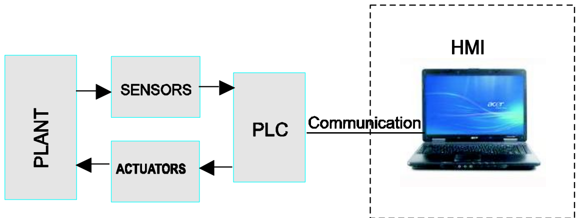

Fig.3. A typical control system in industrial automation

On the other hand, a typical solution for controlling mobile robots is presented in figure 4.

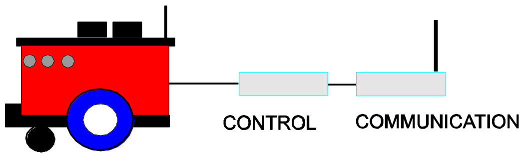

Fig.4. A typical control system for mobile robots

The block labeled "CONTROL" in figure 4 is normally a computer, or microcontroller, responsible with the kinematic control of the robot, while "COMMUNICATION" denotes the equipment dedicated to connecting the mobile platform to a remote computer that executes the supervision and decision tasks.

If the communication between the robot and this remote computer obeys a standard industrial protocol, accepted by most HMI software, than it would be possible to create control structures like the one presented in figure 5.

To prove the feasibility of this idea, we have conducted a simple experiment with a simulated robot, and a low cost HMI application, namely

Winlog Lite, from SIELCO SISTEMI. (www.sielcosistemi.com).

The experimental setup is shown in figure 6. The robot simulator was MobileSim, a simple and efficient software simulator from MOBILEROBOTS. (www.mobilerobots.com)

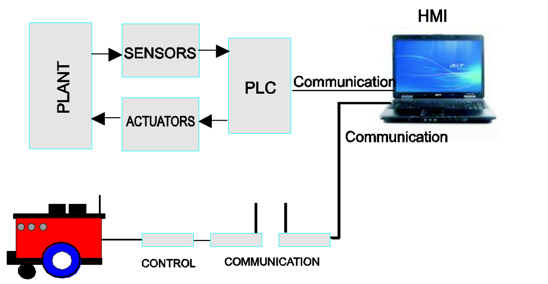

Fig.5. Distributed control structure that includes a mobile robot

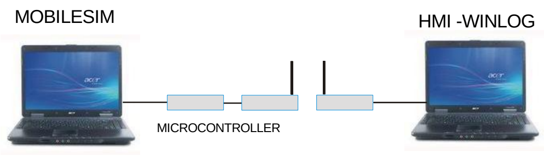

Fig.6. The experimental setup used in simulation

The microcontroller used was a low cost/low power chip, equipped with two serial communication interfaces. Its main tasks were:

- communicate with the robot, through a proprietary protocol,
- communicate with the HMI application according to the MODBUS RTU slave protocol,
- control the robot in real-time to the goal point specified by the HMI application, with obstacle avoidance.
- Report robot status information to the HMI.

Details on the actual implementation of the applications running on the microcontroller are presented in Susnea (2008a) and Susnea (2010).

In this approach, the robot itself is treated as an element of the environment, it is capable to react to/trigger events, and to interact with another sensors and actuators deployed in the environment. The real-time control task were distributed between the PLC, and the on board electronics of the robot, and the supervisory control was assigned to the HMI software.

It could easily execute tasks like transporting components between workstations, inspecting the assembly line and transmitting visual information in case of malfunction. Other functions could be performed through teleoperation.

Te proposed solution illustrates a simple means to integrate autonomous mobile robots in flexible assembly lines. A robotic arm, located on the mobile robot would increase the performance of the entire systems.

3. NEURAL BEACONS FOR ROBOT NAVIGATION

Another possible solution to create distributed control architectures for mobile robots was presented in extenso in Susnea (2012). In this paper, we will only outline the results of an experiment wherein a mobile robot, namely Pioneer3DX form MobileRobots, was guided along a predefined path using a distributed neural network comprising an on board microcontroller, and a number of "neural beacons" deployed in the environment.

The experimental setup is shown in figure 7. In the first stage of the experiment, a differential drive mobile robot R is manually guided along a path in an environment containing a number of "beacons"(1-8), each having processing and wireless communication means. Beacons are located at known positions in the environment.

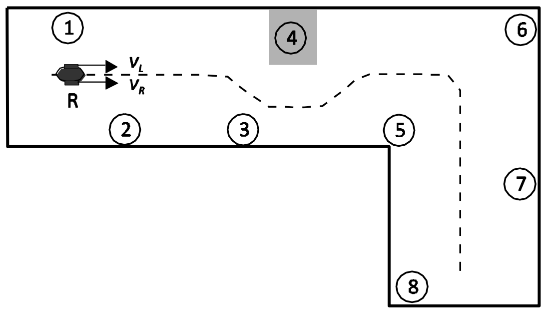

Fig.7. Mobile robot and beacons

The robot carries its own localization system (odometry), and periodically sends data packets containing information about the current position, and the values of the speeds of the driving wheels (v_L, v_R). This data is recorded by a computer connected to the robot through a wireless link.

The actual structure of the beacons, and the on board electronics is presented in figure 8.

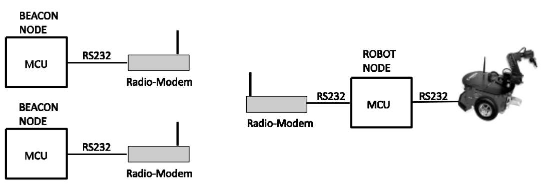

Fig.8. Robot and beacons in communication

In the second stage of the experiment, a dedicated software application implements the ANN in figure 9, which is trained using backpropagation to approximate the functions (1) using data recorded in the first stage.

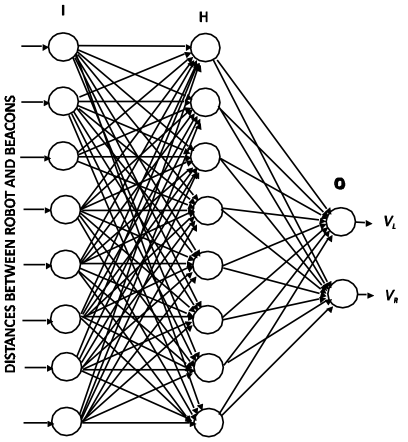

Fig.9. The ANN used to approximate v_L, v_R

(1) $$v_L = f(t, d_1, d_2, d_3, ..d_8)$$
$$v_R = f(t, d_1, d_2, d_3, ..d_8)$$

where d_1,..,d_8 are the distances between the robot and the beacons 1,...8, at the moment *t.*

Finally, the microcontroller units (MCU) located on the beacons, and another MCU carried by the robot are programmed to implement a distributed ANN. The weights of the synapses obtained by training in the second stage were transferred in a nonvolatile EEPROM memory of the MCUs. The communication network is shown in figure 8.

The microcontroller unit on the robot implements the two neurons of the output layer (see figure 9), and sends the values of v_L, v_R to the robot via a second RS232 communication line (see figure 8).

To do this, the microcontrollers located on the beacons and the on board microcontroller hold data structures of the following type:

struct neuron
{
double $\bar{x}$ *[LAYER_SIZE];*
double $\bar{w}$ *[LAYER_SIZE];*
double A;
double y;
}

where $\bar{x}$ is the vector containing the input values, $\bar{w}$ is a vector containing the weights of the incoming synapses (stored locally), A is computed locally according to (2), and y is the output value, computed locally with sigmoid functions.

(2) $$A_i = \sum_{j=1}^{N} w_{ij} x_j$$

In a feedforward topology, the vector $\bar{x}$ contains the output values of the neurons of the previous layer. Obviously, these values can be transmitted by means of messages, broadcasted over a communication network.

For simplicity reasons, we have used a specially designed MASTER-SLAVE protocol. The general structure of the messages is shown in figure 10.

Fig.10. Structure of the messages over the communication network

Assuming that:

- each neuron has an unique ID on the network,
- each neuron holds a list containing the IDs of the neurons with whom it makes synapses,
- each neuron stores the weights $\bar{w}$ of the incoming synapses,
- each neuron is capable to compute the values *A* and *y*
- each neuron broadcasts messages containing the current computed value of its output *y*,

then, for any three-layer perceptron it is possible to design an equivalent distributed ANN running on a communication network made of simple microcontroller based nodes.

With this setup, the trajectory of the robot, under the control of the distributed ANN, recorded with the simulator MobileSim is shown in figure 11.

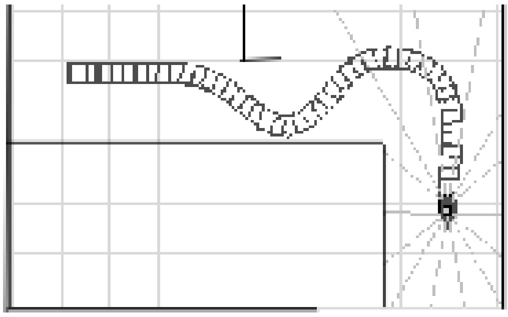

Fig.11. The trajectory of the robot recorded with MobileSim

A MATLAB simulation based on the same data set produced the trajectory depicted in figure 12.

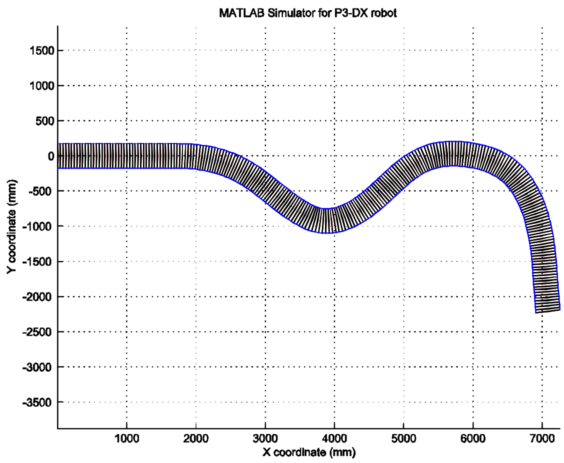

Fig.12. MATLAB simulation of the robot motion under the control of the ANN

4. CONCLUSIONS

The experiments outlined here demonstrate that simple distributed control structures may be used to perform complex navigation tasks with autonomous mobile robots.

In both situations presented, we have used low cost/low power microcontrollers, and the overall cost of the system can be significantly reduced.

The key element of the distributed control approach is to reduce the equipment located on the robot, which is expensive, and replace it with conventional ground based equipment, and thus move the design focus on communication, rather than creating expensive, and difficult to reproduce antropomorphic robots.

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