University of Craiova
Faculty of Automation, Computers and Electronics

PhD Thesis

VIDEO BASED CONTROL SYSTEMS FOR MOBILE COOPERATIVE ROBOTS

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Objectives

The thesis deals with de-centralised control systems for mobile robots teams, with the design of a software operating system – RobOS – which solves the mobile robots cooperation problem at different levels: the sensory level (robots identification and relative localisation), the strategic level (trajectory planning) and communication level (message passing between robots).

The contents of the thesis focuses on four main directions:

- Path generation for mobile robots;
- Representation of mobile robots formations;
- Video camera based control of robot formations;
- Implementation of a wireless communication system which allows message passing between the robots.

Thesis Organisation

Chapter I is an introduction in the cooperative robots field, which shows existent applications and discusses representative work which shows important issues and characteristics of this domain.

Chapter II describes the matematical model of the differential actuated robots and the trajectory control system.

Personal contributions stand in the proposition of trajectory generation methods using Bezier trajectories. The methods differ in the way the control points are chosen. For testing these new methods, a Matlab based simulator has been developed which can generate Bezier curves between initial and end points.

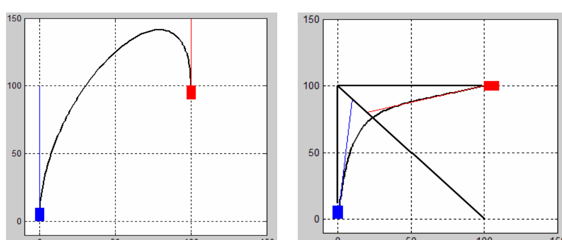

Fig.1 Bezier based trajectories.

Also, a control software has been implemented on the PcBot914, which allows Bezier trajectory generation and following. The control system is composed of two levels: RoboMotion – responsible with trajectory planning and control and Robot Abstraction Layer (RAL) which communicates with the motor control hardware in order to execute the generated trajectory. The structure of the two components is shown in the UML diagram below, along with the interaction between them.

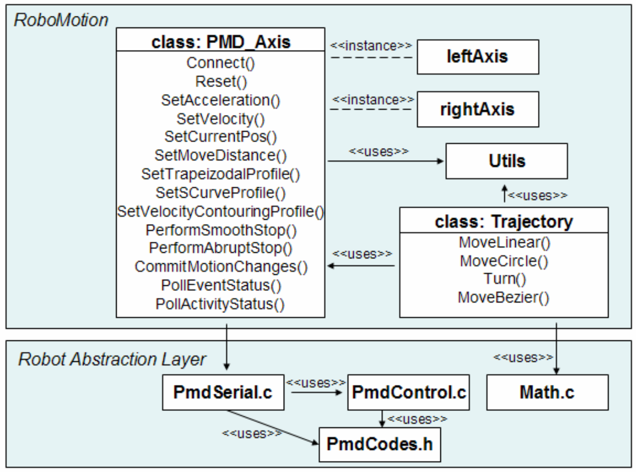

Fig.2 Software architecture of the control system.

Chapter III shows some control techniques for formations of cooperative mobile robots.

After presenting the graph based representation a new method is proposed which is based on the formation's center of gravity. The end of this chapter proposes an algoritm for establishing the formation graph, based on message passing between the robots.

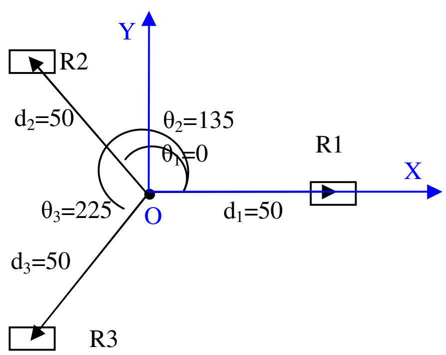

Fig.3 Formation representation based on its center of gravity.

Establishing the current formation graph is done using the following algorithm:

- Each of the robots rotates against its own axis, until it finds its neighbours, using its local sensors;
- For each robot that it finds:
  - Calculates the relative distance and orientation;
  - Adds the information to the local copy of the adjacency matrix;
  - Sends the localisation information to all of the robots in the team. Each of the receiving robots will update their local adjacency matrix.
- When all of the neighbours have been found, the current robot will brodcast a synchronization message to the network.

- For each of the received synchronization messages the robot will increment a local counter;
- When the counter reaches value N, it means that the graph has been established and the team can go to the next step of the operation.

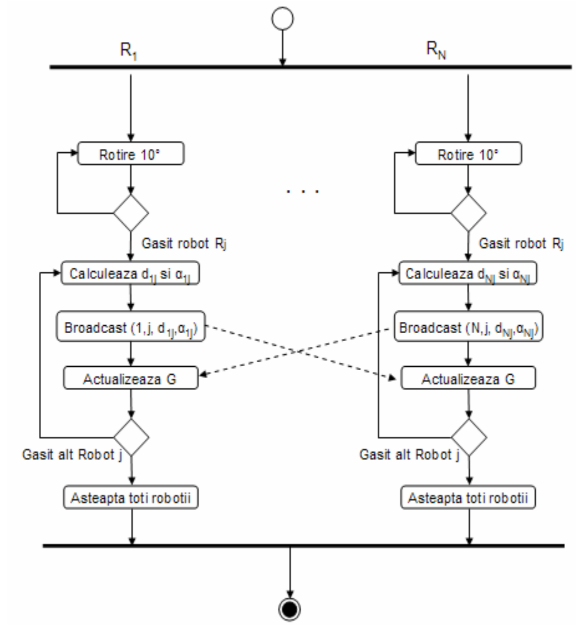

Fig.4 Current graph construction protocol.

Chapter IV deals with the analisys of formation control using the local video system, mounted on each of the robots.

First part of the chapter describes image preprocessing techniques that have been used in practical experiments. Then, a hibrid control system is proposed, which combines an image based controller and a position based controller. This system solves the situation in which the leader robot gets off the image plane so the image-based controller will not be able to calculate the image error.

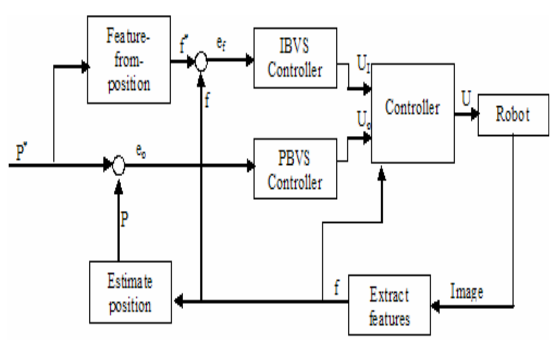

Fig.5 Hybrid control system.

A method for image processing time reduction is proposed, based on the estimation of a region of interest. The goal of the proposed solution is to process only the region of the image where the landmark is expected.

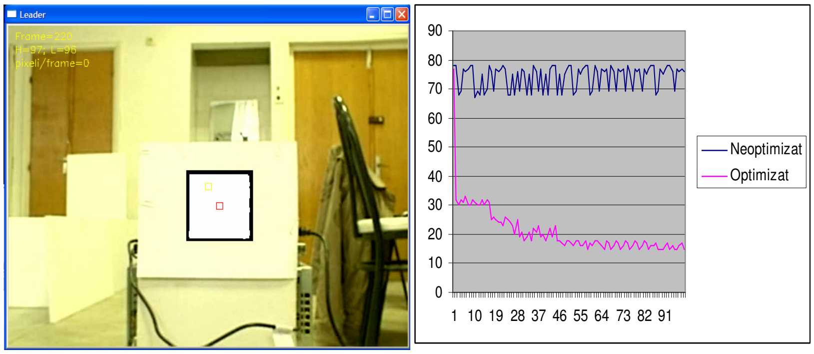

Fig.6 Using the region of interest method to reduce processing time.

Next a modified version of the Census transformation is proposed for the detection of the leader robot. The Census transform ([Zabih R et al., 1994], [Froba et al, 2004]) is a local transformation, which is based on the intensity of the neighbour pixels, relative to the value of the central pixel. The k-th bit of the central pixel value is obtained after the comparing between the internsity of the k-th neighbour and the central pixel. The proposed modification considers an 8x8 square region, splited in 4 subregions. For each of the four regions, we calculate the sum of the pixels. In the end, four values V_1, V_2, V_3, V_4 that are obtained, will be compared by a threshold and a 4 bit stream is obtained ($b_1b_2b_3b_4$), which represents the Modified Census Transformation (MCT) for the central pixel.

The proposed method not only detects the corners of the landmark, but, based on its binary value, it also helps identify which corner is it (top-left, left-bottom, top-right, right-bottom).

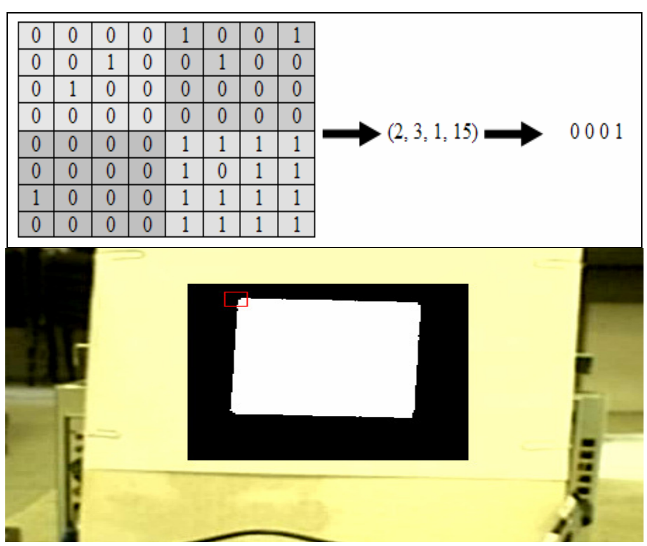

Fig.7 Transformata Census modificată.

Because the Modified Census Transformation requires a slightly more computation power by going through all the vicintiy of the current pixel, the processing time is a bit higher than using the state-machine method. In order to reduce the processing time, an efficient solution is to scan the image with an adaptive step. In order to avoid missing any corners in case of a big scanning step, the step value is chosen based on the Modified Census transformation value of the previous pixel, following some rules. If the neigbourhood of the current pixel contains a large 0 value area, then the scanning step is increased, then the step will be half of the previous step and will have negative sign. This will determine the scanner go halfway back and verify if a corner has been missed. If 1-3 bits are 1, then the scanning step will be 1, for a fine search of the corners.

The graph below shows comparative execution times obtained with constant step and adaptive scanning step,respectively. The graph shows substantial increase in processing speed for the second solution.

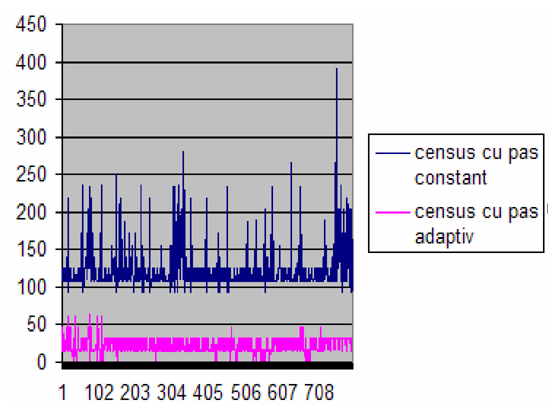

Fig. 8 Image processing time in case of constant and adaptive scanning step.

The image processing system presented in this chapter has been implemented on a PcBot914 robot. An algorithm performance measurement system has also been developed for measuring the processing speed.

The next part of the chapter proposes the usage of potential field method for choosing the trajectory of each robot. In this proposal, each of the robots R_i calculates its own potential field at each step t. The minimum potential value is assigned to the position occupied by the leader robot $R_{\{Leader(i)\}}$. The maximum potential is assigned to the positions of the obstacles and of the other robots in the team.

The final part of the chapter proposes a behavioural based control system that is inspired from fish schooling behaviour.

Chapter V proposes the implementation of a wireless communication protocol for mobile robots, based on the IEEE 802.15.4 standard – a radio protocol with low energy consumption, designed for sensor networks. The implemented communication system allows message passing between each pair robots by using intermediate robots for message routing.

At the network layer, an improved version of C-Skip routing algorithm is proposed for tree routing. This modified protocol solves the problem of localisation of re-connected nodes. The proposed solution consists in assigning each of the robots an address composed of two fields.:

- The A_{CS} field that contains the C-Skip generated address;

- The A_{ID} field which contains a randomly generated address which uniquely identifies the robots in the network.

When the A_{cs} address changes due to reconection to a different router, the node can still be localized using the A_{ID} adress. This allows the relocalisation of the destination by the packet sender, after the destination has reconnected to a different router. After the relocalisation step, the communication continues based on the A_{CS} address assiged by the C-Skip protocol.

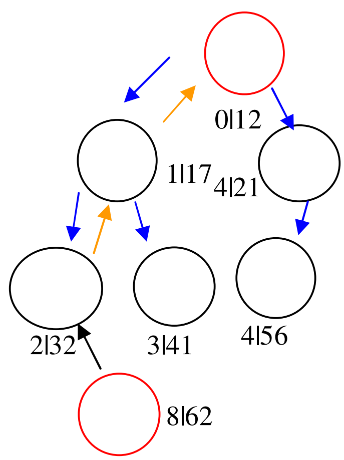

Fig. 10 Assigning adresses using Modified C-Skip algorithm.

Contributions

New Bezier based methods are proposed for trajectory generation. For testing these methods, a Matlab based simulator has been developed, which allows Bezier path generation between an initial and an endpoint.

A method of robot formation formation has been proposed, using the distances and orientations relative to the center of gravity of the formation.

This can be extended by considering any point in the operation space as a reference for the formation.

A simulator has been developed for the movement of a robot formation and for it dynamic configuration change.

An algorithm for initiating a formation has been developed based on message exchange between robots.

The PcBot914 control software has been developed, which allows dynamic change of wheels angular velocities during the movement, allowing for following complex trajectories.

An image processing simulator has been developed for image preprocessing and feature extraction. This software allows the simulation of each phase of image processing and measurement of the execution time for each of the implemented algorithms. Its flexible architecture allows easy adding new algorithms.

A hybrid control system has been designed for a Leader-Follower type formation. For testing this system, a MatLab simulator has been developed.

A modified Census transformation has been proposed for detection of the leader robot.

The software for the PcBot914 robot has been written, which allows the robot to track a moving target. The software implements some methods of reducing the image processing time, including a region of interest estimation technique and the usage of a variable scanning step.

A behavior based control system has been designed, which allows a robot to attach to an existing formation and keep the formation sticked. This control system has been inspired from fish schooling behaviour.

The potential field method has been considered for analysis of cooperative formations of robots. For simulation of this method a MatLab software has been proposed.

A wireless communication system has been designed, based on the new IEEE 802.15.4 technology – a radio protocol designed for low power sensor networks.

The proposed communication system allows message passing between each pair of the robots, by routing messages through intermediate robots.

An improved version of C-Skip algorithm is proposed for tree routing, which solves the problem of robot re-localisation after they have been reconnected to a different router.