

# BEHAVIOR ACTIVITY TRACE METHOD

## *Application to Dead Locks Detection in a Mobile Robot Navigation*

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Abstract: In the paper a novel approach to representation of a history in a mobile robot navigation is presented. The main assumptions and key definitions of the proposed approach are discussed in this paper. An application of the method to detection a dead end situations that may occur during the work of reactive navigation systems is presented. The potential field method is used to create an algorithm that gets the robot out of the dead-lock. Simulations that show the effectiveness of the proposed method are also presented.

## 1 INTRODUCTION

An autonomous mobile robot is a machine that can operate in an environment model of which is unknown a priori and can react dynamical changes of this environment (Cox and Wilfong, 1990). Inaccurate sensors, world unpredictability and imperfect control often cause the failure of traditional, planner based approaches to a mobile robot control system design (Cox and Wilfong, 1990). Therefore more efficient and faster methods of a mobile robot collision free movement control have been developed. One of them is a purely reactive architecture introduced in (Braitenberg, 1984, Brooks 1991) which implements a control strategy as a collection of stimulus-reaction pairs. The system consists of a collection of purely reactive rules that contain minimal internal state. These systems use no internal models, perform no search and merely lookup and take appropriate action for each set of sensor readings. A Braitenberg algorithm (Braitenberg, 1984) could be a good example of the reactive architecture. Behavior based control system architecture (Arkin, 1998, Brooks, 1991, Mataric, 1992, Michaud and Mataric, 1998) embody some of the properties of reactive systems and may contain reactive components. However the primary feature of behavior based systems is their distributed nature. They consist of a collection of parallel executing behaviors devoid of centralized reasoning module. The behaviors are more powerful than purely reactive rules because they may use

different forms of internal representation and perform computations on them in order to decide what action to take. One of the key issues that appears while designing behavior based systems is just a representation of the knowledge about an environment the robot is dedicated to work in (Michaud and Mataric, 1998). Since these systems are intended to work with the low cost, inaccurate sensors, the problem of building a model of a workspace is emerging. Here in this paper the method of knowledge representation based on so called behavior activity trace is presented. An idea of the proposed approach is to store in a time ordered way the knowledge of events that happened during the robot work. What is crucial for this method is the fact that these events are marked and recognized by behavior characteristic sequences. While collecting a knowledge of characteristic events a sort of event-map is built. The advantage of the proposed method is that this form of representation does not consume much memory resources. Another one is the computations using this sort of map can be performed in an efficient way. In the paper an example application of this method is presented. A module of behavior based system designed for detection of emergency situations during the work of the system is described. Simulation experiments proved the proposed approach to be effective.

## 2 THE CONTROL SYSTEM

A design of the control system used in this work is based on the behavior-based idea of control (Arkin, 1998, Brooks, 1991). The system is composed of behaviors that process the state and sensory information into proper set-points for motion controller - linear and angular velocity. The coordination of behavior activities is made by fixed priority arbiter. A general diagram of the controller is presented in fig.1. Its easy to distinguish five main modules of the controller:

- Behavior definition module;
- Arbitration module;
- Control computation module;
- Task execution watcher module;
- Dead lock detector module;

Each behavior can be perceived as a schema of reaction to a given stimulus that comes from an environment and it is represented by current sensory information and state of the robot itself. In our system there are eight behaviors implemented. First four of them (*avoid left, avoid right, avoid front, speed up*) are responsible for avoiding collisions with objects located correspondingly on the left, right, frontal and back side of the robot platform. Fifth behavior (*goal tracking*) minimizes the distance between the robot and the target. Behavior *stop* simply stops the robot in case a collision is detected or the target is reached. Sixth behavior called *stroll* makes the robot goes straight in case when no objects are detected.

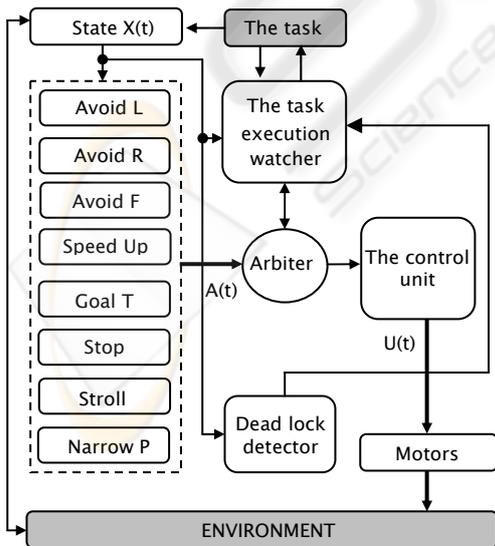


Figure 1: The control system architecture.

And the last behavior – *narrow passage* stabilizes robot movement preventing oscillations during going through narrow passages. Each behavior is designed as a function which maps a part of input data  $X$  into activation level of the given behavior  $a_i$ , and it is defined by the s-class function.

Describing details of implementation of particular behaviors is out the scope of the paper. But for understanding concepts that are presented in the next sections it is reasonable to show more details of an implementation of the behavior *goal tracking*. This behavior will be used further to generate action of escape from the dead lock situation. The work of this behavior consist in monitoring the error  $\Delta\Theta$  between the current heading of the robot  $\Theta_r$  and the desired heading  $\Theta_d$ . The way of calculating the value of the last one is presented in the section 5. In each moment of time this behavior is checking the error  $\Delta\Theta$ . A value of the error is determined from:

$$\Delta\Theta = \begin{cases} |\Theta_d - \Theta_r| & \text{for } |\Theta_d - \Theta_r| \leq \pi \\ 2\pi - |\Theta_d - \Theta_r| & \text{for } |\Theta_d - \Theta_r| > \pi \end{cases} \quad (1)$$

The heading  $\Delta\Theta_d$  is a set point generated by the control system. If  $\Delta\Theta$  it is greater than some threshold value  $\varepsilon$  then the output signal of the behavior is rising rapidly according to:

$$f_{gt}(\Delta\Theta) = \frac{1}{1 + e^{-\alpha_{gt}(\Delta\Theta - \varepsilon)}} \quad (2)$$

Given behavior generates a control optimal from the perspective of its own "point of view". Therefore the method of coordination has to be used to obtain final control of the robot optimal from the perspective of the task executed. In our case we use the method of priority arbitration, which select this  $k$ -th behavior which satisfy the following:

$$k = \max_{i=1,2,\dots,B=7} (a_i q_i) \quad (3)$$

where  $q_i$  denotes the priority fixed to the  $i$ -th behavior. The activation of the selected  $k$ -th behavior constitute the basis for computation of robot control. Both angular and linear velocities are defined by heuristic functions of the activation level of the selected behavior:

$$u = [\omega, v] = f_k(a_k) \quad (4)$$

The next module called task execution watcher, is designed as a finite state automaton the role of which is to supervise the process of the task execution. The automaton is determined by four states presented in fig.2:

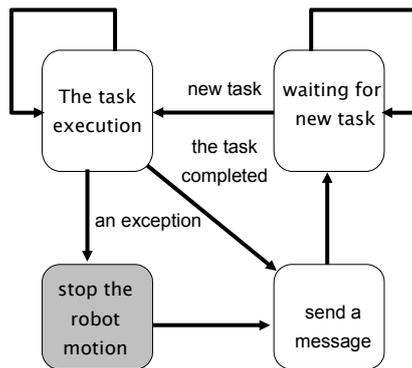


Figure 2: The finite state automaton of the task execution watcher module.

The module starts its work in a state of waiting for a new task to do. If the new task is sent to the module it will switch itself to the state of execution of the task - the robot moves in collision free way toward the target. If task is completed the module will send a message to the global coordinator and switch to the first state. If any exception happens during task execution (collision detection for instance) the robot will stop, send appropriate message to the global coordinator, and switch to the first state.

The aim of the above is only to sketch the main principles and ideas of construction of the behavior based motion controller module. Detailed description exceeds the scope of the work and is not its main subject. For more details please refer to (Skrzypczyk, 2005).

### 3 BEHAVIOR ACTIVITY TRACE

The problem of local minima as well as dead lock situations are the weak points of reactive systems. Moreover, the fact that in a given moment the robot is provided only with current information from sensors makes the problem of detection of dead locks hard to solve. There are many reasons of dead end situations occurrence. One of them (and probably the most common one) is a structure of a workspace the robot operates inside of which. Reactive systems are usually designed to work with an inaccurate sensory systems. The information provided by this kind of sensor is not sufficient for construction of precise maps that would be useful in environmental structure analysis. Therefore another methods of data representation and processing should be applied. Here in this paper we propose to use a method of behavior activity trace. The key issue of the proposed approach is that the system does not store and analyze the information about the

shape of the environment but it utilizes information about events. Since the events are caused by a configuration of the environmental objects information about the structure of the workspace is obtained in an indirect way. The discussion of the proposed method we start with defining the notion of the activity trace itself. While the control system is working, in each discrete moment of time behaviors are activated. Next in the arbitration process the most appropriate one is selected. Since the activity of behavior is strictly related to the configuration of the workspace, the place the robot was located when given behavior was activated can be perceived as a part of a symbolic map. These places are called further characteristic points.

**Definition 1:** The characteristic point  $CP_k$  we call a point in a cartesian space of coordinates  $(x_{kCP}, y_{kCP})$  defined by a location of the center of a mass of the robot  $(x_r, y_r)$  recorded in a moment when the  $k$ -th characteristic event occurred.

For the purpose of this work three characteristic events were defined.

#### Event 1

This event is determined by a moment of beginning of the process of navigation. The result of detection of this event distinguishes the characteristic point CP1.

#### Event 2

This event is set up when the behavior *goal tracking* was selected to control the robot. It is related to the situation when robot is far from any obstacle and starts the tracking of the goal. The characteristic point CP2 is related to this event.

#### Event 3

Third event is defined by an occurrence of a situation when the behavior *avoid front* was selected to control the robot and the condition  $\Delta\Theta < \varepsilon$  is satisfied at the same time. Such a condition denotes that the behavior *goal tracking* is slightly activated or is not activated at all. The conditions above can be interpreted as a detection of the obstacle on the course of the vehicle straight toward the target. Occurrence of such an event defines the characteristic point  $CP_3$ .

Now the notion of the activity trace can be introduced.

**Definition 2:** The activity trace is the time ordered sequence of characteristic points:

$$T = \{CP_k^0, CP_k^1, \dots, CP_k^{n-1}, CP_k^n\} \quad k = 1, 2, 3 \quad (5)$$

As can be seen the activity trace is the record of the past activity of the robot by means of characteristic events. The events have been recorded since a moment of the beginning of the navigation process  $t=0$  till the present time  $t = n\Delta t$ .

## 4 DEAD LOCK DETECTION

The activity trace concept discussed in the previous section was applied as a base of dead lock detection module. On the base of multiple experiments with the controller a few observations have been made. It was stated that a situation when the robot is not able to reach the target is mainly caused by a configuration of environmental objects that form u-shaped lay-by located on the course of the vehicle. The undesirable behavior of the robot manifest in repeating a sequence of actions what push the robot into the dead end. Such a situation can be easily detected using behavior activity trace concept. It was observed that dead end situation described above corresponds to an occurrence of three element chunk of the activity trace  $CP_2, CP_3, CP_2$ . The illustration of this fact is presented in fig.3.

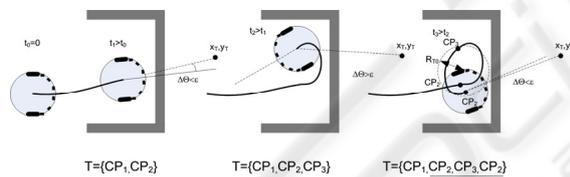


Figure 3: Dead lock detection based on the activity trace concept.

Detection of this three element sequence in the activity trace may show that the system got stuck in a dead lock. Additionally a mutual location of the characteristic points is checked. If all of them are inside of a circle of a radius  $r_T$  and a center in the gravity center of these points that means the navigation algorithm failed. Detected dead-lock location is recorded in a buffer and denoted by coordinates  $(x_{d,i}, y_{d,i}) \quad i = 1, 2, \dots, N_d$ , where  $N_d$  denotes the number of all detected dead locks. In such a case the recovery algorithm should be turned on. Although the method is very simple multiple experiments proved its efficiency.

## 5 RECOVERY ALGORITHM

The method described in the previous section allows to detect the dead end situation the navigation algorithm stuck in. Next step of the control system synthesis is to design a recovery algorithm that is able to get the primary algorithm out of the dead lock. In order to construct the recovery algorithm we utilize the concept of potential field method (Khatib, 1986). According to this concept the workspace of the robot is filled with artificial potential field inside of which the robot is attracted to its target position and repulsed away from the obstacles. The robot navigates in direction of the resulting virtual force vector. In order to apply this idea to get the robot out of the trap each detected dead-lock is considered as a source of repulsive force that has an effect on the robot. So the value of the repulsive force that  $k$ -th dead lock acts on the robot is determined from

$$\begin{cases} |\mathbf{F}_{r,k}| = k_r \left( \frac{1}{L_k} - \frac{1}{L_0} \right)^2 & \text{for } L_k < L_0 \\ |\mathbf{F}_{r,k}| = 0 & \text{otherwise} \end{cases} \quad (6)$$

where  $L_0$  is a limit distance of influence of virtual forces. The  $L_k$  in (6) denotes a distance between  $k$ -th dead lock and the robot:

$$L_k = \sqrt{(x_{d,k} - x_r)^2 + (y_{d,k} - y_r)^2} \quad (7)$$

The repulsive force is a vector sum of forces generated by all dead locks:

$$\mathbf{F}_r = \sum_{k=1}^{N_d} \mathbf{F}_{r,k} \quad (8)$$

The value of the attractive force is determined from the following formula:

$$|\mathbf{F}_{a,i}| = k_a \frac{1}{L_T^2} \quad (9)$$

Where  $L_T$  in (9) is a distance between the robot and the target. Coefficients  $k_r, k_a$  determine share of each force-component in the resultant force  $F$  and they are adjusted experimentally. Finally the resulting force that acts on the robot is determined as a vector sum:

$$\mathbf{F} = \mathbf{F}_r + \mathbf{F}_a \quad (10)$$

the argument of the vector  $\mathbf{F}$  determines a direction the robot is demanded to go. Therefore the value of the  $\Delta\Theta_d$  from (1) is calculated as:

$$\Delta\Theta_d = \arg(\mathbf{F}) \quad (11)$$

## 6 SIMULATION

In order to verify the presented method it was implemented in the M.A.S.S. simulation environment. The workspace structure as well as the navigation target was set in the way that create dead lock situations. Figure 4 present the result of the simulation of the system without the dead lock detector and recovery algorithm. It is easy to see that the robot suck in the dead lock inside of an u-shaped obstacle.

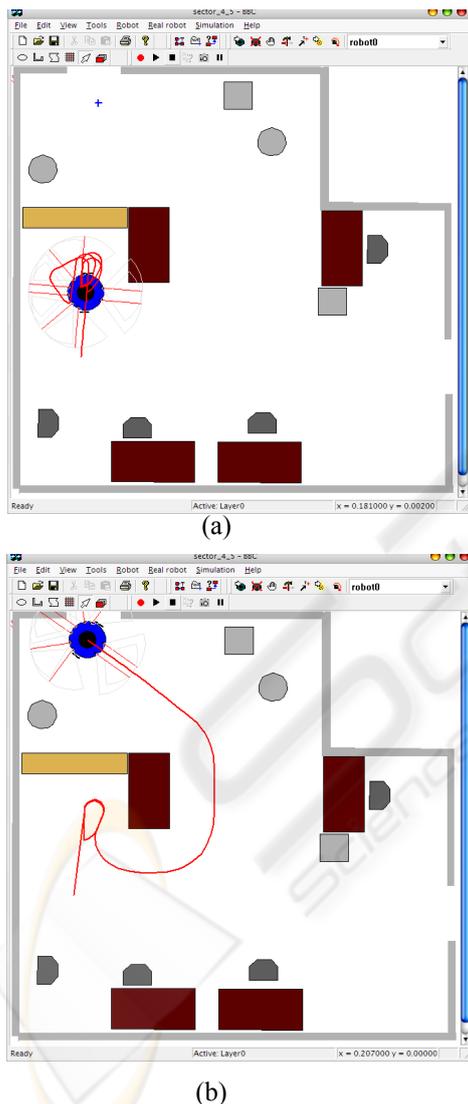


Figure 4: The result of the simulation with dead lock (a) and the recovery algorithm action (b).

In figure 4a the situation when the robot stuck in a dead lock is presented. In figure 4b the result of a

work of the dead lock detector and recovery algorithm is shown. The algorithm got the robot out of the dead lock.

## 7 CONCLUSION

In the paper a novel approach to representing a history in a mobile robot navigation was presented. The method was applied to detect a dead lock situations that may occur during the work of reactive navigation systems. The potential field method was used to create an algorithm that gets the robot out of the dead-lock. Multiple simulations proved an efficiency of this method. There are ongoing works focused on implementation of the method and application to a real robot control.

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