SOLVING THE BOX-PUSHING PROBLEM BY MASTER-SLAVE ROBOTS

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Abstract:

This paper presents a design of the solution box-pushing problem by two robots working in the master-slave style cooperation. The configuration of the solution consists of two robots Khepera (the Master and the Slave) with similar implemented functions. The proposed methods and algorithms are experimented.

Keywords: *mobile robot, robotics, Box-pushing, pushing, experiment, Khepera.*

1. Introduction

As it was pointed out in [1],[2] starting with the moment of opening the market to commercial hardware robotic platforms, robotics provides new challenges for programming. Despite of the research groups that include professionals from mechanical and electro engineering, as well as from the fields of computer programming, this relatively new field is now open. These tasks are specific in robotics, because of very limited possibilities of programmers to influence the existing robotic hardware. The new situation in the market of robotic platforms seems to be suitable for programming these platforms. From the programming point of view, the situation is new, because instead of programming more or less closed systems like common computers, we are faced with programming of extremely open systems, like robotic platforms. This difference implies many new problems and generates many new challenges to modify generally accepted methodologies of traditional computer programming. The project of multi-robotic solution of the well-known problem of collective robotics, the box-pushing problem [3], described in this paper, provides an illustration of this kind of robot programming, as sketched above.

The goal in the case of the so-called box-pushing problem consists of pushing a selected object (the box) to a pre-specified place (the target-place) in robot environment. In order to perform this task it is necessary to design and implement number of subtasks and their composition to achieve the requested behaviour and solution. Various approaches and techniques in solving this task can produce many results and experiences that can be used for solving similar tasks in the real world.

We have seen that the box-pushing task can be described very simply, but there can be a lot of modifications of this task. These modifications can differ in the number of cooperative robots, goal specifications, box's sizes or shapes, approaches (centralized x decentralized)…

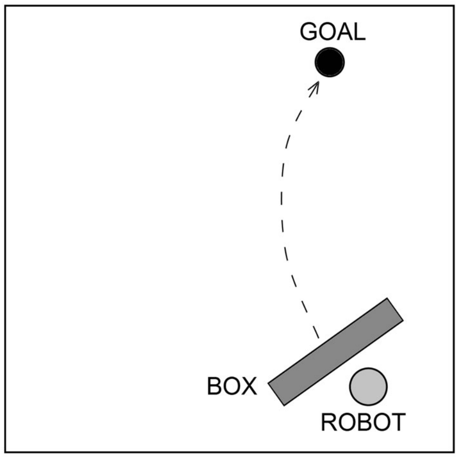


Fig. 1.Simple Box-pushing task.

The simplest specified task is to push the box by only one robot to the target position in the environment. In [4] we can see an interesting solution of box-pushing task between two walls using neural controller.

In the case of solving the task by multiple robots cooperation, there can be different number of robots, different communication techniques or levels of centralization/decentralization. The goal can be, for example, specified by illuminated area, by different colour of the goal and the environment or, in the case of implemented global positioning systems, by given coordinates.

We can find a good example of distributed approach with central control of tasks execution in [5]. An example of the decentralized solution of box-pushing task without any explicit communication in dynamic environment is described in [6]. In this behaviour-based solution is for the robots' actions selection used a set of behaviours applied on situations in the process of solving this task.Finally, the example of approach to robots communication, but with decentralized control, can be found in [3].Two robots use a communication channel to share information about the world with each other, but each robot uses its own control for its actions.

In our work, we found inspiration for the design of our solution in these examples, but we tried to combine them - we designed centralized solution with the need of communication.

2. Hardware

First of all, we describe the robotic platform we used – Khepera. We have used miniature mobile robots Khepera by the Swiss producer K-Team. These robots are ideal, due to their small size and various extensions, for a number of experiments in mobile robotics. They are equipped with two independent wheels – each wheel is powered by a DC motor - and eight IR sensors. With these sensors, Khepera can measure both light intensity and distance to obstacles and walls. More detailed description of Khepera robots can be found in [7].

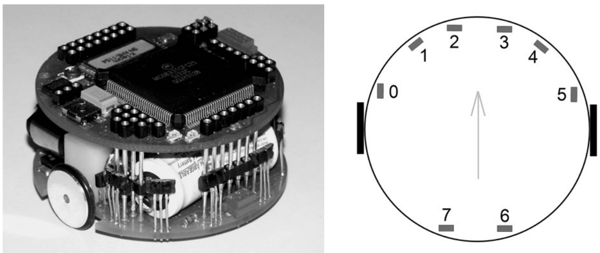


Fig. 2. The basic module of Khepera robots and the position of wheels and IR sensors in it.

The functionality of robots Khepera can be extended by several extension modules. For our work and experiments, we used extension modules K213 Vision Turret and Radio Turret. K213 Vision Turret extends the Khepera's functionality with the linear vision. It can be used for landmark recognition and in our experiment for the goal detection. The view angle is 36 degrees and the image resolution is 64 pixels (each 256 grey-levels) [8].

To make robots communication possible, we equipped our robots with Radio Turrets. This Radio Turret makes it possible to send and receive messages between the robots in the environment [9].

3. The Experimental Environment

We have optimised the task specification for our robotics lab equipment. The experimental environment for the task was a square area (120 x 120 cm). This area was bound by wooden cuboids and, above them, with walls made of white paper carton. The black paper cylinder defined the goal position for the pushing. This cylinder was well recognized by the K213 Vision Turret in front of the white walls. This cylinder (the goal) must be positioned in the environment to the maximum distance from the box, in which the goal could be reliably detected and recognized by the K213 Vision.

In the environment, any non-white (black) object is could be a goal, so we equipped both robots with white paper strip to eliminate incorrect detection of any robot as the goal. Robots equipped and modified this way (Fig. 3) were placed in the experimental environment.

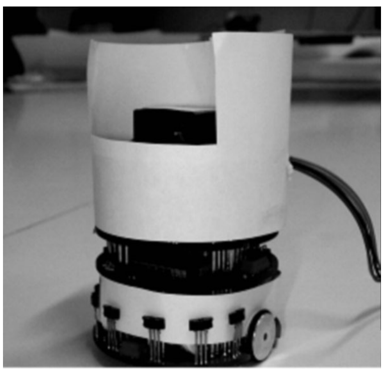


Fig. 3. Khepera equipped for the experiment.

The box to be pushed to the goal was a paper cuboid (20.5 x 4.5 x 4.0 cm). This box was modified to be identifiable and localizable in the area only by the eight IR sensors of Khepera. The modification consisted of two IR diodes (IR light emitting diodes) placed on one side of the box. These diodes were controlled by an electrical circuit, which emitted the IR signal in the specified intervals. This IR signal can be sensed and measured by the Khepera's IR sensors and thus the box can be located and identified. During the period, when the IR signal was not emitted, the distance to the box could be measured, and if the IR light was emitted it was possible to detect and localize the box. The intensity of the light emitted from the box was high enough that the box could be detected from approximate distance of 10 to 15 cm.

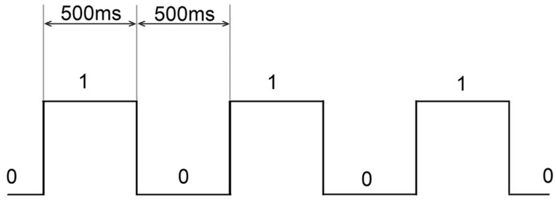


Fig. 4. IR light emission in the time.

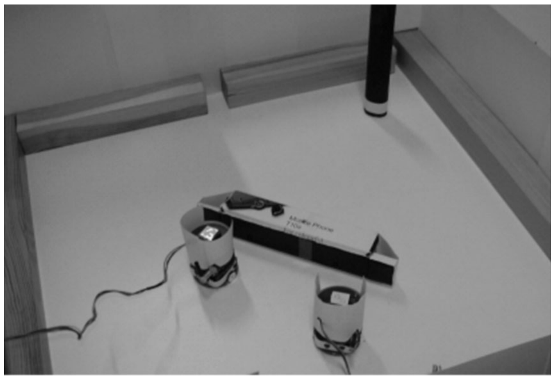


Fig. 5. Robots, box and goal in the experimental environment.

Two fluorescent tubes provided the lab lighting. Proper lighting is important for the success of the experiment. We used a limit value for the evaluation values of the image from K213 – any value greater than this limit was evaluated as black and any value less this value as white. This information is used for the image evaluation and recognition of the goal in the environment. Shadows or sunshine can cause an inaccuracy of the image recognition and affect the sensed values.

4. Solution Design

For the experiment we chose the centralized solution of the box-pushing task. As mentioned above we used two robots Khepera in the “Master-slave“ relation. This approach is based on sending/receiving messages between robots and evaluation of the solution situation by one central robot. Master robot decides in every step of the solution the next best step based on the information sensed by sensors and received from the second (the Slave) robot.

In our solution we allowed almost unlimited number of box positions in the environment. The only requirement for the box position was to place the box to the sufficient distance from the wall, so that it was possible to manipulate and push the box. This sufficient distance was about 10 cm from a wall.

We chose sequential approach of box pushing to the goal - we could not use real-time parallel pushing because of limited view angle of Khepera (only 36 degrees). The vision capability of Khepera is like a vision capability of human with a short or no peripheral vision.

In every step of pushing, robot had to look round and search for the goal. This was done by sequential rotation about the robot's centre in small steps and by image evaluation in every step. Therefore it was necessary to synchronize each robot's functions by this sequential approach.

We decomposed the task into following steps:
- Localization of the box in the environment;
- Goal detection;
- Preparing box for pushing;
- Box-pushing to the goal.

Tasks for each robot:

The master robot:	**The slave robot:**
· Move in the environment; · Find the box; · Move to the box; · Prepare box; · Localize the goal; · Evaluate situation; · Push box.	· Move in the environment; · Find the box; · Move to the box; · Localize the goal; · Push box.

These subtasks were implemented for both robots. Some of them had to be run sequentially; some of them need parallel execution.

The master robot controls the solution. The whole solution is based on the messages sent between the two robots. Whenever master robot needs information from the second robot or needs the second robot to begin any action, it sends a message. Both robots have implemented process for sending and receiving messages. This message parser runs concurrently with other processes. Suitable action is implemented for each of allowed messages. Whenever a message is received, global variables are set and other processes are stop or start.

4.1. Localization of the box in the environment

Master robot moves through the environment and avoids obstacles and walls. In every moment it senses the environment by IR sensors and evaluate these sensor's values. Whenever any sensor senses IR light emitted by IR diode on the box, the robot stops movement. In this situation – the box has been identified – the robot starts moving closer to the box. This movement to the box is controlled only by IR sensor's values. The goal of this movement is to navigate the robot to the box and stop in front of IR diode.

The measurement of both IR light intensity and distance from objects is done in these steps: at first we need to check if the light is emitting at the moment. If the light is emitting, robot uses sensed values to navigate and to get closer to the box. Comparing values in the left and right group of IR diodes does this movement. In the period when IR light is not emitting, robot uses the values of distance from an object to stop in front of the box. It is very important to stop and set the robot in the position, in which the robot is close to the box and is set straight at the box. This position is the basic position for the goal location.

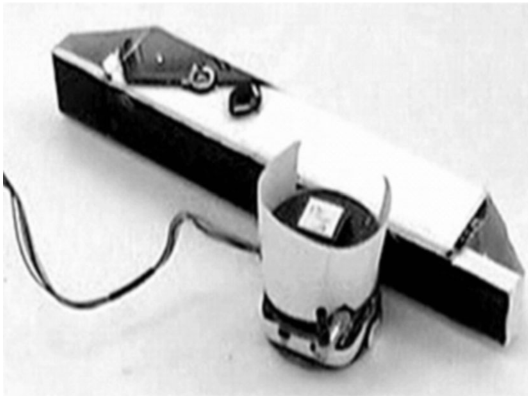


Fig. 6. Robot's basic position by the box.

4.2. Preparing the box

As mentioned above we allow unlimited box position in the environment. In this phase of solution it is necessary to prepare the box for pushing. The box can be pushed only at one side the side with IR diodes. Therefore it is necessary to rotate the box to such position from which the robot can sense the goal in the range of -70 to 70 degree rotation from his position by the IR diode in the box.

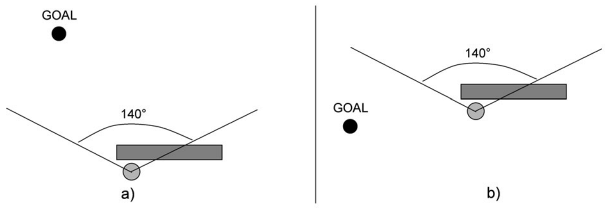


Fig. 7. a) Example of good position of box b) Example of bad position of box.

In the situation, when the box is in the bad position, the box has to be rotated to a better position. This can be done by one robot and with information about the position of the goal and with information if the robot is standing on the left or the right end of the box. The location of the goal means, that the robot needs to identify the goal and determine the angle to the goal. The angle to the goal means the value of robot's rotation, which the robot must accomplish to see the goal. This process of location and getting the angle to the goal is implemented in this procedure: the robot rotates in small steps (10 degrees) around its centre and evaluates an image from K213. If the goal is recognized, the value of the rotation angle is saved and the robot returns back to its basic position.

Fig. 8. Robot's step-by-step rotation to locate the goal.

To set the box to the proper position it is necessary to push one of the box's edges. The selection of which edge to push depends on the angle and the information whether the robot stands in front of left or right diode.

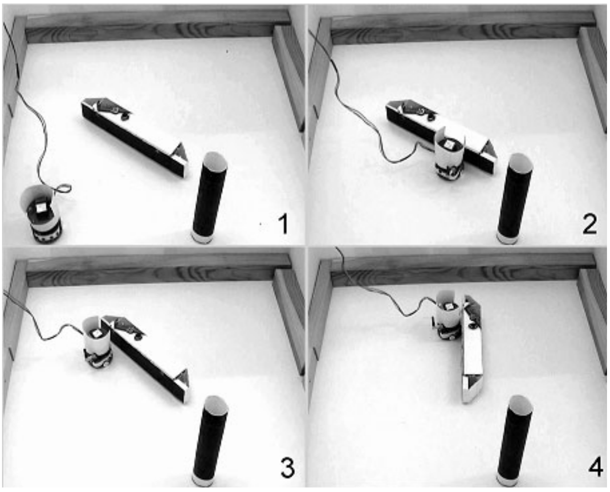


Fig. 9. Example of the box rotation by master robot.

After completing this step, the master robot sends the message to the slave robot. The slave robot starts movement in the environment, locates the box and moves to the box.

4.3. The box-pushing

When the slave robot has localized the box, moved close the box and stopped in front of second diode, the main phase of the solution can begin. The pushing process is based on sequential measurement of the angle to the goal and evaluation of these values by the master robot. The master robot makes a decision which robot will push the box the box can be pushed by one of the robots or by both robots simultaneously.

Box-pushing phase of the solution is based on this algorithm:
1) Master robot localizes the goal gets the angle to the goal;
2) Master robot sends message to the slave robot to start slave robot's action;
3) Slave robot localizes the goal gets the angle to the goal;
4) Slave robot sends value of the angle to master robot;
5) Master robot evaluates these values of both angles and determines next step;
6) Pushing of the box by one of the robots or by both robots simultaneously;
7) Go to the step 1).

The box localization in this phase is analogical to the method of box localization used in the phase *Preparing the box*. The only difference is in the search range. In this phase we suppose the right position of the box, so the search range can be only about 160 degrees.

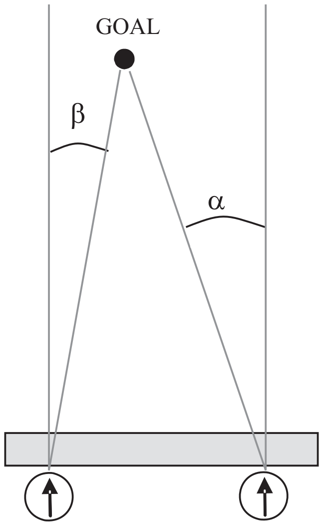


Fig. 10. The angles measured by the robots.

These three situations can occur, depending on the angle values:

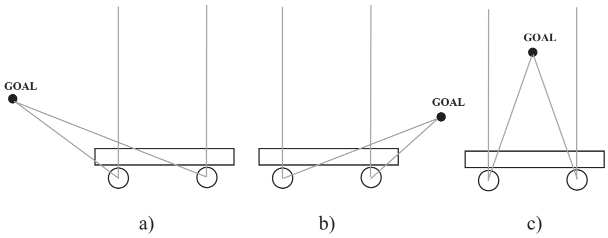


Fig. 11. Possibilities of the position of the goal and box.

According to these three situations the master robot evaluates the next best step:
- $\alpha<0°$ AND $\beta<0°$
  - both robots localize the goal on the left pushing is done by the robot standing on the right edge of the box (Figure 11a.);
- $\alpha>0°$ AND $\beta>0°$
  - both robots localize the goal on the right pushing is done by the robot standing on the left edge of the box (Figure 11b.);
- $\alpha>0°$ AND $\beta<0°$
  - goal is located in front of the box pushing is done by both robots simultaneously (Figure 11c.).

The pushing distance in each step is about 5 to 7 cm. When the box is pushed only by one of the robots, the distance should not be very long, because of “over-rotation” of the box. In the case of box pushing by both robots simultaneously, the pushing distance can be longer.

We have also implemented a procedure to solve a situation, when one of the robots does not localize the goal. In this case, the decision which robot will push the box depends only on the robot's knowledge of one angle value and information about the position (on the left or right edge of the box), which successfully localized the box. This situation can occur due to an error or inaccuracy in the image evaluation or due to an inaccuracy in the robot basic position.

This box-pushing procedure is repeated until the box is pushed to the goal.

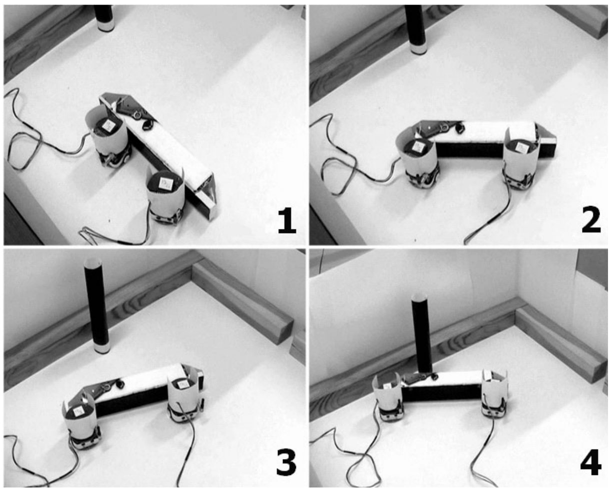


Fig. 12. Example of box-pushing in real environment.

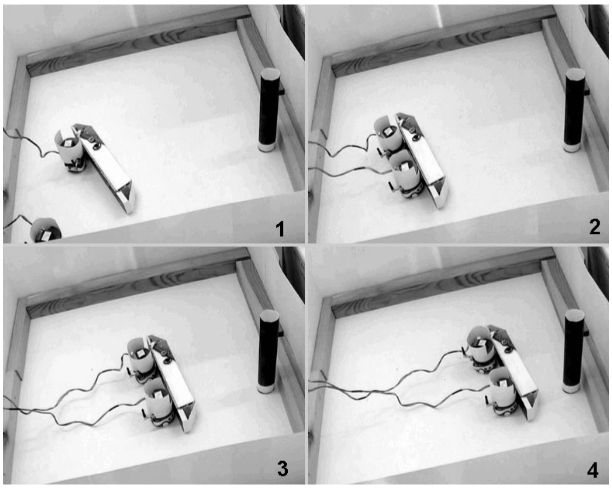
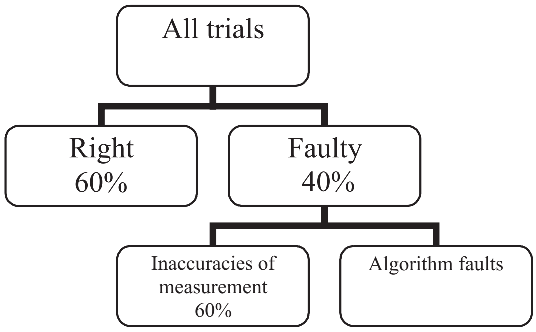


Fig. 13. Example of box pushing in real environment.

5. Conclusion

We have designed, implemented and tested the solution of box-pushing task for two robots Khepera. The task was formulated to be solvable in our robotic laboratory. We used two robots Khepera and modified the environment for this experiment. We have also designed and constructed the box with two IR diodes to be identified in the environment by robot's IR sensors.

We have made several final experimental trials. The ratio of the number of successful experiments to the number of experiment in which correct solution of the task was not achieved was about 3:2. The failure of the solution was in most cases (about 60%) caused by the inaccuracy of the measurement by sensors and the camera.



The accuracy of sensed values and thereby the accuracy of solving of the task can be affected by the lighting of the environment – for a precise solution it is important to have ideal environment. The shadows and darkness in the environment causes inaccuracy of target's localization. More robust solution could be implemented, for example, by the use of any neural controller.

The correctness of the solution depends on the accuracy of robot's motion and precision of movement commands. The success of the solution can depend on the number of steps needed, on starting position and localization of the box and robots in the environment.

Adding more check and control mechanisms to minimize failures and errors of each sub-step of solution - these mechanisms can raise the time complexity of the solution - can optimise the inaccuracies.

There are certain prerequisites important for the success of each run of the experiment. The success of the experiment depends on the successes of the subtasks and on accuracy of each step of the solution. The quality of box-pushing depends also on the number of the steps and on the length of the pushing distance in each step.

We have shown that Khepera is suitable for the solution in our lab and that our design was right.

Both, the videos and the time-lapse photographs from trials are available at:

Video:

- http://robotika.fpf.slu.cz/files/download/projekty/Box_Pushing/BoxPushingTrial1.avi
- http://robotika.fpf.slu.cz/files/download/projekty/Box_Pushing/BoxPushingTrial2.avi

Photographs:

- http://robotika.fpf.slu.cz/files/download/projekty/Box_Pushing/TimeLapsefromTrial1.rar
- http://robotika.fpf.slu.cz/files/download/projekty/Box_Pushing/TimeLapsefromTrial2.rar

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