CONSIDERATION OF THE DIFFUSIVENESS OF ROBOT AND OBSTACLE MOVEMENT PARAMETERS IN THE CONTROL PROCEDURE

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Abstract. The article considers the methods of bypassing moving obstacles by the robot and assesses the risk of robot colliding with an obstacle, with an uncertain knowledge on the velocity of movement of the robot and obstacles. The uncertain knowledge on the velocity concerns the fluctuations of this quantity due to a slip, surface irregularity, etc. We will lay out the robot's route based on the prediction of the location of obstacles at the moment of being approached by the robot. The aim of the study is also an attempt to assess the risk of a collision of the robot and an obstacle, depending on the character and magnitude of diffusiveness of the moving objects. For the sake of simplicity, we assume that we will not take into account reactions resulting from mutual collisions of obstacles, thus assuming that the obstacles do not collide with each other. For the prediction of the position of an obstacle, we use the information of the directions of the robot and obstacle routes and the velocities of object movement. The term „diffusiveness of obstacle position prediction" appears in the article, which takes account of the uncertain information of object velocities.

1. Assumptions of the strategy of obstacle position prediction

The robot and obstacles move in any arbitrary directions, but they cannot perform rotary motions. Let us designate (Fig. 1) the robot's starting point by **B**, its velocity by *vr* and end point by **S**. The respective designations of obstacles are: *v*1, *v*2, ..., *vn*. The obstacles are distant by *d*1, *d*2, ..., *dn* from the most extended edges of the robot. The easiest method of determining the prediction of the position of an obstacle after being reached by the robot is displacing it along the direction defined by the velocity by a distance equal to

$$\overrightarrow{dt(i)} = di/vr \cdot \overrightarrow{vi} \tag{1}$$

Obviously, this is not a representation of the actual reciprocal position of the robot and the obstacle, but only a representation of a possible risk resulting from obstacle displacement that may lead to a collision. Therefore, the robot velocity is treated as a scalar and only serves for determining the time interval between the objects [3]. In this situation, the selection of the direction of robot displacement only takes account of the last obstacle position, which not necessarily may turn out to be the one that creates the greatest risk of robot colliding with the obstacle. This risk cannot occur before the time *di*/*vr* elapses.

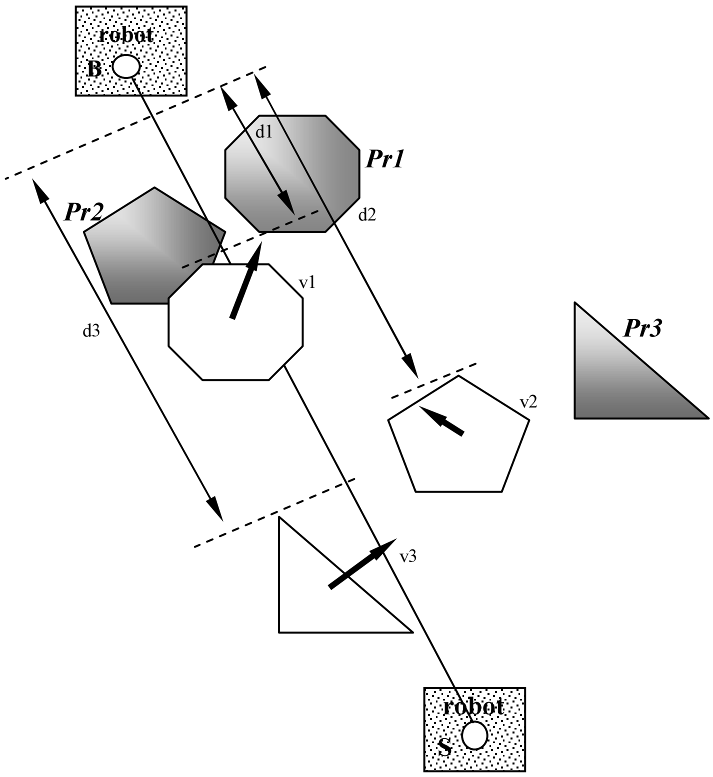

Fig. 1. Creating the prediction of the position the obstacle at the moment of being approached by the robot along the shortest path from the starting point to the end point (- obstacle position prediction)

A more penetrating analysis of object kinetics allows the correction of the method of treating the prediction, reducing it to the determination of the relationship of the distance between the robot and the obstacle when these objects move relative to each other, while treating the direction of robot movement in an universal manner, that is regarding the vector of velocity as a „rotating" vector. This vector will make it possible to determine the circles (range) of possible displacements as a function of time. At the same time, we can determine a „corridor" for the movement of obstacles, also as a function of time.

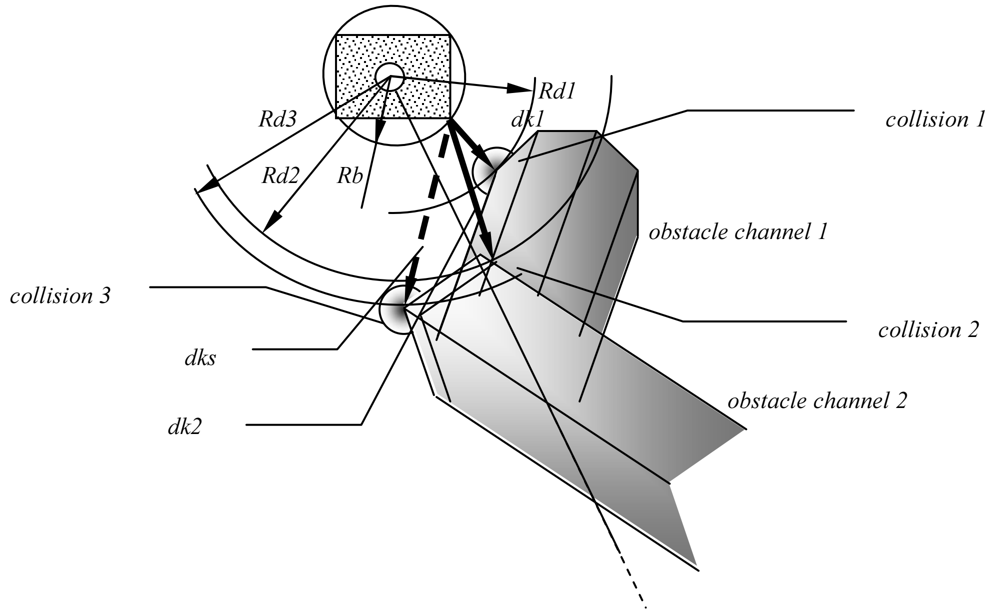

Fig. 2. Determination of the moments of possible collisions of the robot and obstacles, *Collison1* and *Collision 2*

In Figure 2, two obstacles from Figure 1 are considered. The movement of the obstacles is represented in the form of channels, *Obstacle channel 1* and *Obstacle channel 2*, as a function of time. The movement of points forming the vertices of the robot contours are initially described in the form of circles, as the direction of the displacement is unknown. From the point selected as the least distant from the obstacles and regarded as sensitive (in terms of a possible collision), distances to the location of a potential collision, $dk1$ and $dk2$, have been determined. The lines defining these distances are also sensitive directions and certainly cannot be chosen as robot displacement directions. The aim of the analysis is to find a robot displacement direction that will enable the robot to bypass the obstacles and maximally approach the target (end point). The coordinates of the vertex of the i-th obstacle can be written as follows:

$$Ws(i) = (xi,yi;xi2,yi2;...;xik,yik) = (xi,yi;xi + \delta x2,yi + \delta y2;...;xi + \delta xk,yi + \delta yk) \quad (2)$$

The displacement of the robot and the obstacle is represented by the correction of the coordinates x and y by the increments Δx and Δy. The coordinates of the vertices will undergo the following correction:

$$Ws(i, \Delta d) = (xi + \Delta x,yi + \Delta y;\ xi + \delta x2 + \Delta x,yi + \delta y2 + \Delta y;...;xi + \delta xk + \Delta x,yi + \delta yk + \Delta y)$$
$$(\Delta d)^2 = (\Delta x)^2 + (\Delta y)^2 \quad (3)$$

where: k - number of robot vertices, xi, yi - base robot vertix, δxi, δyi - increments indicating the reciprocal location of the vertices (exclusion of rotary motion makes the quantities δxi, δyi constant).

The movement of the robot along the selected direction can be represented by the following matrix:

$$\begin{bmatrix} xi+\Delta x, yi+\Delta y \;;\; xi+\delta x2+\Delta x, yi+\delta y2+\Delta y \;;\ldots;\; xi+\delta xk+\Delta x, yi+\delta yk+\Delta y \\ xi+2\Delta x, yi+2\Delta y \;;\; xi+\delta x2+2\Delta x, yi+\delta y2+2\Delta y \;;\ldots;\; xi+\delta xk+2\Delta x, yi+\delta yk+2\Delta y \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ xi+q\Delta x, yi+q\Delta y \;;\; xi+\delta x2+q\Delta x, yi+\delta y2+q\Delta y \;;\ldots;\; xi+\delta xk+q\Delta x, yi+\delta yk+q\Delta y \end{bmatrix} \tag{4}$$

At the same time, that is during performing q robot displacements, the obstacle with the number j will perform displacements along another direction at the velocity vj. It can be written by another matrix, as below:

$$\begin{bmatrix} xj+\Delta xj, yj+\Delta yj \;;\; xj+\delta xj2+\Delta xj, yj+\delta yj2+\Delta yj \;;\ldots;\; xj+\delta xjk+\Delta xj, yj+\delta yjk+\Delta yj \\ xj+2\Delta xj, yj+2\Delta yj \;;\; xj+\delta xj2+2\Delta xj, yj+\delta yj2+2\Delta yj \;;\ldots;\; xj+\delta xjk+2\Delta xj, yj+\delta yjk+2\Delta yj \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ xj+q\Delta xj, yj+q\Delta yj \;;\; xj+\delta xj2+q\Delta xj, yj+\delta yj2+q\Delta yj \;;\ldots;\; xj+\delta xjk+q\Delta xj, yj+\delta yjk+q\Delta yj \end{bmatrix} \tag{5}$$

where: $\Delta xj = \Delta d \cdot vj/vr \cdot \cos(\alpha j)$ and $\Delta yj = \Delta d \cdot vj/vr \cdot \sin(\alpha j)$: increments of the displacement of the obstacle with the number j along the coordinate x and y performed during the robot displacement Δx, Δy.

The angle α_j is shown in Figure 3.

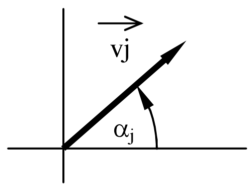

Fig. 3. Angle of displacement of the obstacle with the number - j

2. The concept of bypassing obstacles by the minimization of the collision risk

To describe the situation being the risk of a possible collision, a protective zone can be initially defined, being, for example, a circumscribed circle lying on all the most extended and possible to be considered vertices of the robot and obstacle contour (Fig. 4).

Obviously, if a situation arises in the simulation analysis process, where the distance between the objects (the robot or an obstacle) is smaller than the sum of protective zone diameters for the both objects, dis(*r,j*) ≤ (*rr* + *rj*), then it is assumed that a collision has occurred. This is a „safe" assumption, which will not always be necessarily true in reality. It is worth mentioning here that there are many other methods of identification of collision risks, but they are, however, a little more complex.

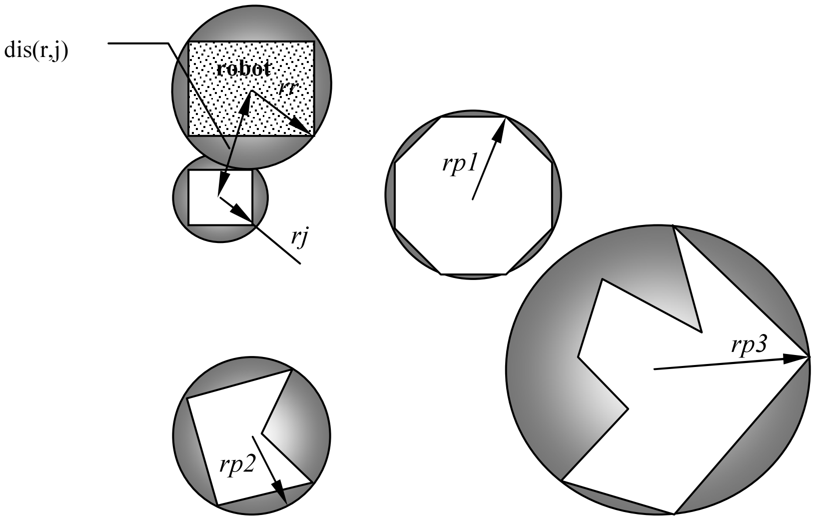

Fig. 4. Protective zones describing the contours of the robot and the obstacles:

The next step of the analysis of the reciprocal position of the robot and obstacles is the creation of a matrix of the distances of protective zone centres in successive phases of displacement. One of the matrix dimensions can correspond to the numbers of successive displacement phases, while the other - to the numbers of obstacles. For the creation of this matrix, it is convenient to construct a vector defining the phases of displacement of the centre of the robot's protective zone circle and the vectors of displacements of particular obstacles:

$$[xo + \Delta x, yo + \Delta y; xo + 2\Delta x, yo + 2\Delta y ; \dots ; xo + q\Delta x, yo + q\Delta y],$$
$$[xoj + \Delta xj, yoj + \Delta yj; xoj + 2\Delta xj, yoj + 2\Delta yj ; \dots ; xoj + q\Delta xj, yoj + q\Delta yj], 1 \le j \le n \quad (6)$$

where: *xo*, *xoj* - centres of the protective zones, respectively, of the robot and obstacles; *n* - number of obstacles.

The matrix of the distances of the robot and obstacles will help determine tendencies to change in the mutual position of the objects, such as approaching, colliding and moving away. This matrix can be presented in the following manner:

$$MD = \begin{bmatrix} dis^{t1}(r,1) & dis^{t2}(r,1) & \dots & dis^{ts}(r,1) \\ dis^{t1}(r,2) & dis^{t2}(r,2) & \dots & dis^{ts}(r,2) \\ \dots & \dots & \dots & \dots \\ dis^{t1}(r,n) & dis^{t2}(r,n) & \dots & dis^{ts}(r,n) \end{bmatrix} \tag{7}$$

where: $dis^{tk}(r,j) = \sqrt{((xo + k\Delta x) - (xj + k\Delta xj))^2 - ((yo + k\Delta y) - (yj + k\Delta yj))^2}$

tk - phase of the displacement of the robot and obstacles with the number k, s - number of the phases of displacement of the robot and obstacles.

The criterion of the avoidance of a collision of the robot and obstacles moving in the selected directions (Δx, Δy and Δxj, Δyj) relies on verifying whether or not the distances between the objects (the robot and the obstacle) are greater than the sum of protective zone radii: $dis^{tk}(r,j) \geq (rr + rj)$; $1 \leq k \leq s$; $1 \leq j \leq n$.
The criterion of bypassing the i-th obstacle can thus be presented as the satisfaction of the criterion of the avoidance of a collision with the objects approaching each other, with subsequent objects growing apart.

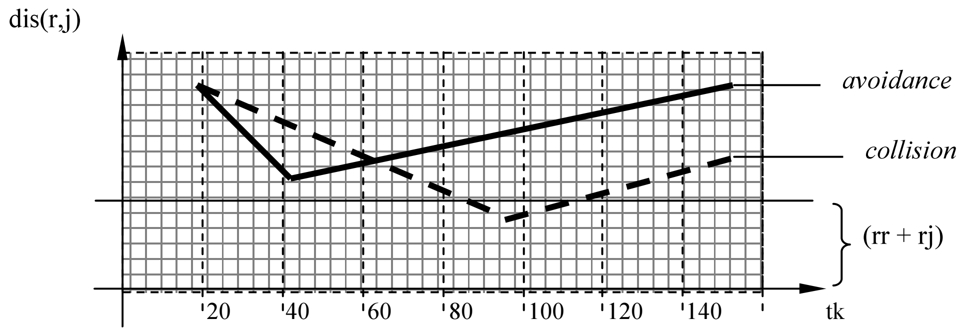

Fig. 5. Change in the distance between the objects during bypassing the obstacle

Figure 5 suggests that by selecting the direction of robot movement, represented by the solid line, we approach the obstacle faster and then pass it by, for instance, in front of it, avoiding a collision. The direction represented by the broken line is characterized by slower approaching the obstacle, but resulting in a collision with it. The direction of robot displacement, connecting the robot's current position with the end point, is the most effective direction. However, it is only a matter of chance that by choosing this particular direction all obstacles will actually be bypassed. Establishing this favourable direction is a trivial task ($dir = \Delta y/\Delta x = $ $= \mathrm{tg}(\alpha r) = (ys - yb)/(xs - xb)$). In practice, to choose a direction that will delay

the moment of the fist possible collision and allow the bypassing of the largest possible number of obstacles, we correct the selected direction, for instance, in the following manner: $\alpha r = \alpha r \pm \xi$.
The selection of the optimal direction by the method of a simple search will make it possible to chose a solution providing a trade off between:
– the closest approach to the target ($kdir = /\alpha r\text{-}\alpha dir\ /\ 2\pi$)
– the minimal number of potential collisions (*mcol*),
– the maximal number of obstacles bypassed until the moment of risk of the nearest collision (*mom*), and
– the maximal delay of the moment of risk of the first collision (*tfcol*).
The parameters of the criteria detailed above are illustrated in Figure 6.

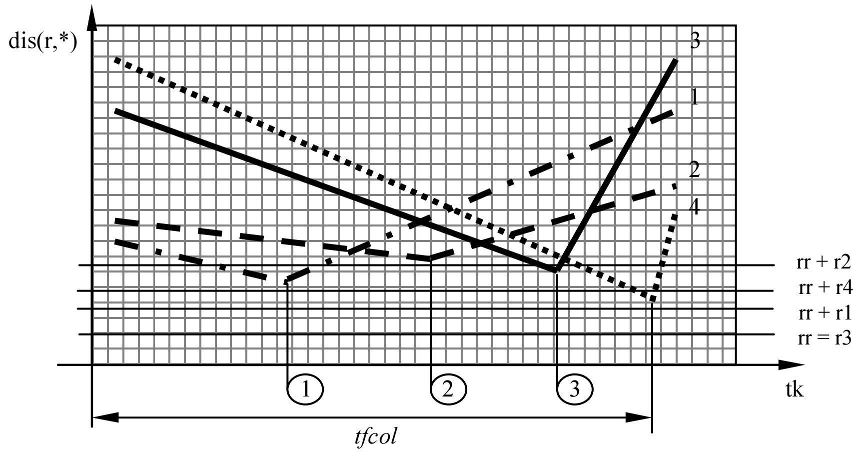

Fig. 6. Diagram of the robot distance from four obstacles, illustrating the method of determining the parameters of robot control criteria. The numbers of bypassed obstacles are shown in circles

The selected direction of robot movement, characterized by the diagram in Figure 6 will allow the obstacles with the numbers 1, 2, 3 to be bypassed. As soon as these obstacles have been bypassed (*tk* > *tfcol*), this direction will have to be corrected, since, as can be seen from the diagram, there is a risk of collision.
The algorithm of robot control includes situation analysis mechanisms and inference mechanism. In the inference mechanisms, the compromise between the criteria is provided by the selection of the weights ($k1, k2, k3, k4$) for particular control parameters. This can be written as follows:

$$Gcrit = \mathrm{k1} \cdot mom + \mathrm{k2} \cdot tfcol - \mathrm{k3} \cdot kdir - \mathrm{k4} \cdot \overrightarrow{mcol} \longrightarrow max \qquad (8)$$

The basic information concerning the control of robot movement (αr) is, of course, the argument of the parameter *kdir*.

3. The diffusiveness of robot and obstacle movement velocities and its effect on the control process

Variations in the velocities of the objects may result from either intended or unintended causes. Control algorithms usually do not have mechanisms correcting velocity depending on the results of analysis of the relative position of the robot and obstacles.

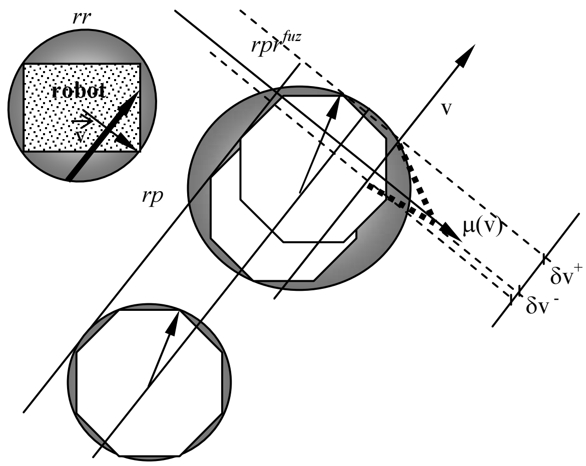

Fig. 7. The effect of obstacle velocity diffusiveness on the shape of prediction of obstacle position and dimensions (rpr^{fuz}) - the radius of the protective zone of obstacle location prediction), $\mu(v)$ - function of inclusion of the velocity in the interval $\{\delta v^+ \cup \delta v^-\}$ [6]

Therefore, uncertain (diffuse) information on velocity may only increase the risk of collision. Obviously, this is connected with the diffuse prediction of the objects' positions, whose dimensions are usually larger than the dimensions of the object itself (Fig. 7). The radius of the protective zone of the prediction of moving object location increases in the following manner: $rpr^{fuz} = rp + \delta v^+$.

4. Conclusions

1. The effect of an uncontrolled diffusiveness is always negative, as it causes an increase in the diameter of the protective zone, thus increasing the risk of collision, whereas a controlled diffusiveness provides chances for bypassing the obstacles.
2. Developing heuristics assisting the control of a robot is based on selecting the empirical weights $k1$, $k2$, $k3$, $k4$ in the generalized criterion $Gcrit$ (8).

3. The fact of bypassing an obstacle and correcting the direction of robot movement does not relieve us from the necessity of tracking the positions of obstacles.
4. The analysis using moving object contours instead of protective zones ((4), (5)) increases the time complexity of the algorithm and the risk of collision, but makes it possible to find the shortest way to the chosen target.

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