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INDIVIDUAL SCANS FUSION IN VIRTUAL KNOWLEDGE BASE FOR NAVIGATION OF MOBILE ROBOTIC GROUP WITH 3D TVS

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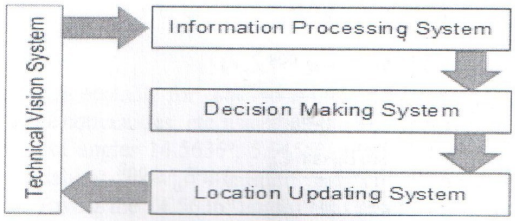
Abstract — Robotic group communication in a densely cluttered terrain is the main objective to optimize group navigation and efficient trespassing of the sector on terrain. This paper describes the basic set of tasks need to be solved for distributed robotic group behavior. The model of transferring of data obtained from technical vision system (TVS) that uses the principles of dynamic triangulation is given.

I. Introduction

Robotic group systems are widespread and specialized for the multi objective tasks. The robots in the group are usually distributed, on large areas during their missions. Individual robot in group can cover part of the area while patrolling and detect different types of dynamic events and static obstacles in surroundings in real time, searching for objects of interest (goal) etc. The robotic group can perform such tasks in a better way, because they can perform monitoring of an environment with less amount of devises than, for example, a static sensor network. During the monitoring each robot is obtaining data only by own vision system. To avoid the rescanning of the same part of terrain by another robot in the group, the propagation of information within the group (data exchange) should be implemented. Robots must operate with the predefined rules of collective behavior [1] in order to organize the communication process. Paper consider to use a homogeneous group of robots [2, 3] that are able to perform different simple tasks independently. In addition, robots must be able to move to their goal in the environment without losing contact with the group members along the way.

II. Obstacle detection by individual technical vision system

Each mathematical / computing unit in the conventional algorithm of autonomous robot (Fig. 1) during its work is basing on data obtained from the set of sensors, in general case the vision system.

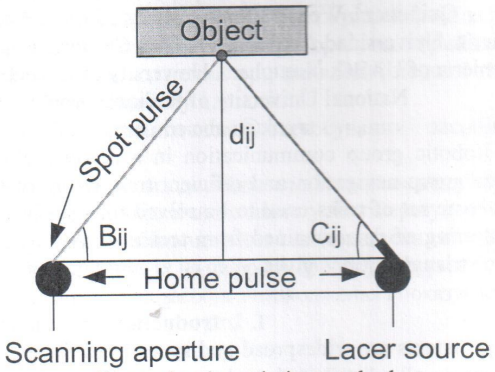


Autonomous robot system

The amount of data to process and transfer can be estimated basing on the type of visual system. Many robots and drones are equipped with cameras or more expensive equipment like ToF (Time-of-Flight) cameras which assume the presence of data storage devices with large storage capacity. Since a group of robots can be moved in low light conditions with a large number of obstacles, the aforementioned systems may not always give the correct result during post processing. Therefore, there is a need a system with satisfactory accuracy in hard conditions.

Article [7] presents the most appropriate technical vision system (TVS) for such conditions. It is able to work in complete darkness, and can obtain the real, 3D coordinates of

any point highlighted by laser ray on real, not imaginable, surface. Its idea based on a dynamic triangulation method. The main components of the TVS are positioning laser (PL) and the scanning aperture (SA) (Fig. 2).



Dynamic triangulation method

Dynamic triangulation [4] consists of detection of laser instantly highlighted point coordinates based on two detected angles Bij and Cij (here ij means the number of horizontal and vertical scanning steps consequently) and fixed distance a between a projector and a receptor. Such triangle's lifetime is about 0.039×0.5/2000≈0.00000975s (where 0.039 s is minimal time of semi-sphere scanning at 7-13 rev/s motor speed; 0.5 cm is averaged laser spot size on experimental striking distance, and 2000 cm is the selected frame width). In such triangle (Fig. 3) if 3 parameters are known, it makes possible to calculate all others. Angle Bij is calculated as simple ratio of two counters codes: number of clock pulses between two home pulses and in interval 'home pulse – spot pulse' (Fig. 3) (Eq. 1).

$$B_{ij} = \frac{2\pi N_A}{N_{2\pi}}, \tag{1}$$

where NA is the number of reference pulses when laser rays are detected by the stop sensor and N2π is the number of reference pulses when the 45° mirror completes a 360° turn detected by the zero sensor. To calculate x, y and z coordinates the next equations are used (Eq. 2-5):

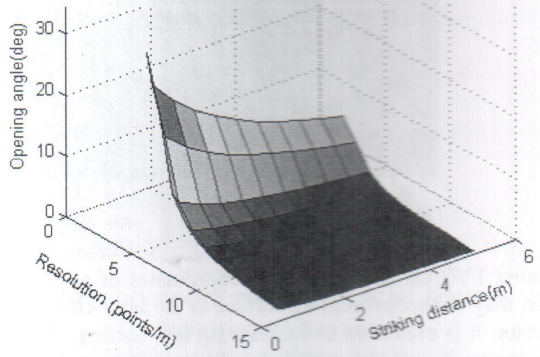
$$x_{ij} = a\frac{\sin B_{ij}\cdot\sin C_{ij}\cdot\cos\sum_{j=1}^{j}\beta_j}{\sin[180^o-(B_{ij}+C_{ij})]}, \tag{2}$$

$$y_{ij} = a\left(\frac{1}{2}-\frac{\sin B_{ij}\cdot\sin C_{ij}}{\sin[180^o-(B_{ij}+C_{ij})]}\right) \text{ at } B_{ij}\le 90^o, \tag{3}$$

$$y_{ij} = -a\left(\frac{1}{2}+\frac{\sin B_{ij}\cdot\sin C_{ij}}{\sin[180^o-(B_{ij}+C_{ij})]}\right) \text{ at } B_{ij}\ge 90^o, \tag{4}$$

$$z_{ij} = a\frac{\sin B_{ij}\cdot\sin C_{ij}\cdot\cos\sum_{j=1}^{j}\beta_j}{\sin[180^o-(B_{ij}+C_{ij})]}, \tag{5}$$

obstacles for its classification and better motion, decreasing robot's speed; **the zone of critical scanning range** – being at a given distance from an obstacle agent is already necessary to stop to avoid a collision. The speed control implementing linguistic variable "striking_distance" (Fig. 6). To determine the variable three membership functions (z-shaped for the "critical" distance, trapeze-like for "optimal" and s-shape – "effective") are used.



Dependencies of opening angle, resolution and striking distance

Using the striking distances zones and opening angles the data for fuzzy logic [5] rules can be represented in Tab. 1

TABLE 1. COMPARISON OF SCANNING ANGLES

Striking distance(SD) (m)	**Radius type (linguistic variable)**	**Opening angles (deg)**	**Resolution (linguistic variable)**
SD ≤1	Critical	5.209	Low
1<SD≤3	Optimal	3.011	Medium
3<SD≤5	Effective	1.34	High

Calculation is based on the general opening angle (step) of stepper motor (0.9°) comparing to low resolution angles of 5.209°. Suggesting that each point has X, Y and Z coordinates. They are described using floating data type. The amount of data needed to store each equal to 4 bytes. Results are in Tab. 2.

TABLE 2. COMPARISON OF SCANNING ANGLES

Opening angles (deg)	**Points/metre**	**Points/metre^2**	**Amount of data (Bytes)**	**Data reduction (Number of times)**
0.9	178	31622	379464	-----
14.5636	11	121	1452	261.34
5.209	31	961	11532	32.9

Using the extended algebra of algorithms for describing the passes of speed control determination will be:

SPEED=<INPUT(striking_distance)*[zone_state](d^{s}nvd^{o}nvd^{e}n)*RULES>

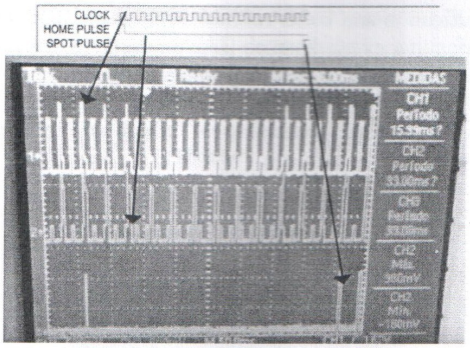
RULES={[critical](RESOLUTION_LOW) *

* [optimal](RESOLUTION_MEDIUM) *

* [effective](RESOLUTION_HIGH)}

where "*striking_distance*" – receive the value "*c*" (critical) if obstacle in critical scanning range, "*o*" (optimal) if obstacle in optimal scanning range and "*e*" if in effective scanning range; n – fixing statement.

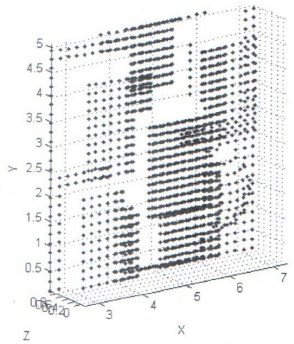
In terms of fuzzy logic, it can be described using next IF-THEN rules type:



Principle of laser scanning TVS

A. **Sectoring of the terrain**

Laser scanning TVS can give the exact coordinates of any selected point on surface of obstacle. However, they cannot process all surface at the same time, and requires certain time to scan whole 3D sector. It is expedient to split terrain into sectors, sharing the task of monitoring between robots in group; it could be useful also due to different position of each robot in sector such distributed scanning will give more explicit information as cloud of points (Fig. 4).



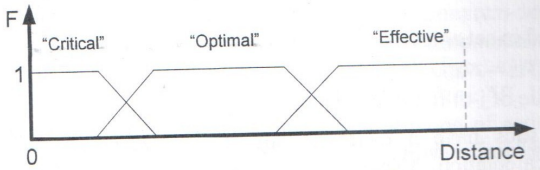
Example of over detailed surface scanned by TVS

B. **Resolution stabilization**

The information about an obstacle for robot to avoid collision must contain general data (width, depth, height and large convexities, etc.), as a simple 3D figure with low resolution. The [5] recommends three different angles 14.5636°, 5.5455°, 1.9091°, representing three types of resolution as a lenguistic variables: "Low", "Medium" and "High". Amount of points per one meter of arc with 160° FOV (using the 14.5636° angle) next results are resieved: the resolution is 11 points per meter that is enough for the robots described in [5]. Radius of a one meter arc with this angle equal to 0.358m with 11 points per meter resolution (Fig. 5). According to the calculation the avarage angles based on the initial resolution of 14.5636° shell be 10.059°, 3.011°, 1.34°. As can be seen, avarage angle for the "critical" range in the end of the distance will give a small resolution equal to 5-6 points per meter. In this case it is nessesary to increase the resolution. That is why the limit value of angle for "critical" range will be taken. The set of angles will be changed to next 5.209°, 3.011°, 1.34°.

Basing on the idea splitting striking distance into three scanning ranges zones (Fig. 6): **the zone of effective scanning range** – the radius at which the system is able to determine with sufficient accuracy an obstacle to initiate rescheduling of the trajectory; **the zone of optimal scanning range – t**he area in which the robot is able to determine the size and shape of the

IF distance IS critical THEN speed EQUAL zero AND resolution EQUAL low
IF distance IS optimal THEN speed EQUAL slow AND resolution EQUAL medium
IF distance IS effective THEN speed EQUAL fast AND resolution EQUAL high

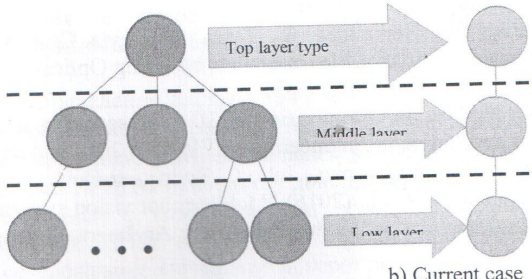


Membership functions of linguistic variable "striking_distance"

Implementing variable frequensy of data storing will help to leave conventionally equal level of obstacles detalization in the memory of robot. On this stage occur the need of data exchange between the individuals in group solving the task of obstacle avoidance and direct motion planning for reaching the goal by group of robots.

III. Communication system

After describing fundamental components of mobile robot motion planning, we shall now focus on forming knowledge around the improving method of leader changing system and dynamic network forming for data transferring within robotic group [7-8]. This task is the dissemination of information feedback (PIF – propagation of information with feedback) is formulated as follows for current case: robot after collecting some amount of data about environment (message M) spreads it between the group members. Previously was reviewed [7] the model of data transferring as strategy of centralized hierarchical control (Fig. 7). When using the strategy of centralized management of a robotic group R, every robot Ri (i = 1, 2,…, N) of group transmits data about his state and information obtained about the environment in the central control device (robot chosen by the voting process). For a hierarchical strategy of centralized management network between robots can be represented with layers. Layers can be separated into three types: **top layer** – a single central control device which merges data and initiates backwards propagation; **middle layer** – group of control devices for existing to send their data and data from lower levels (layers) to top layer; **low layer** – can communicate only with the elements of middle layer, sending the data and receiving merged.



a) General model b) Current case

Strategies of centralized hierarchical control

For current case of group of three robots, leader-changing method [7] is changing the distribution layer inside the group. To define behavioristic roles for a group of robots will be implementing linguistic variable p = "pattern of layer". It uses three levels scale of M = {«lower layer", "middle layer", "top layer"}. So, many alternatives of P can be represented as:

$$P = \{p_1, p_2, \ldots, p_n\}, \quad (6)$$

where p_i – alternative "pattern of layer", at i = 1..n .

Than is necessary to determine the characteristics for evaluating the robot. Next of them are offered:- c_1 = "visibility of a goal";- c_2 = "the heuristic distance to the goal";- c_3 = "density of obstacles in FOV";- c_4 = "visibility of other neighbor robots";- c_5 = "availability of communication channel in group";- c_6 = "workload (amount of currently calculated tasks (processes))";

These characteristics are used in set and describing each of the i-th robots separately:

$$C_i = \{c_{i1}, c_{i2}, ..., c_{ik}\}, \quad (7)$$

where c_j – characteristic value of i-th robot at $j = 1..k$.

As each of the characteristics have a different value it is necessary to make a normalization of each of them for calculation. Also each of the characteristics must have weight based on the predetermined set of weights:

$$W = \{w_1, w_2, ..., w_k\}, \quad (8)$$

where w_j – the j-th characteristics weighting, $\sum w_i = 1$.

Evaluation of the i-th robot takes the following form:

$$e_i = \sum_{j=1}^{k} w_j c_{ij} \quad (9)$$

IV.Conclusion

The present article offers the original solution able to improvement of communication inside robotic group. All tasks discussed in paper have a common point, guided only by information obtained by local interactions with the environment by proposed TVS, group of robots need to reach the goal using motion planning and communication algorithm. Using only pathfinding algorithm mentioned in [7] without data exchange within the robotic group shows results 2.17% – 15.76% worse than using offered corrections (longer trajectories).

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