Fuzzy Control Application in Swarm Robotics Cars

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***Abstract*—This article deals with an example of applications FLC (Fuzzy Logic Controller) on the robot with a specific role in team of the swarm robots. With use of FLC it is possible to effectively describe and capture the desired system behaviour. Moreover, there is ensured system robustness and consequently also the resistance to unexpected events due to the vagueness of linguistic description. The FLC robot includes a full range of various sensors that collect data and navigate the whole swarm in open area. Communication among team is realized via Bluetooth and Wi-Fi technologies. This robot contains a series of sensors as ultrasound, gyroscopic sensors, LIDAR (Light Detection And Ranging), and camera.**

Keywords—fuzzy; sensor; swarm; communication

I. Introduction

Collective of robots, which are usually described in robotics like a swarm, can be used for wide range of purposes. Inspiration and given name of these robots came from animals, more precisely from collective of bugs like ants, bees or termites. These animals can work like complex and precise system despite their size and small nervous system. Key element in swarms, in both nature and robotics, is in their number. Individuals have only limited options and can precept only fraction of their surroundings, but in sheer number they can use different mechanics and perceive whole information and act like one organism. Nearly everything can be accomplished by their number. Their biggest advantage is usage of simple, substitutable individuals in contrary to a single sophisticated unit. Swarm collective in robotics usually consists of identical individuals, but sometimes there is requirement which must be utilized by unit with special equipment. This behaviour can be observed in bee or ant colonies that consist of queen, workers, fighters, scouts, etc. We can achieve this relationship in robotics, too, if we diverse special hardware equipment between specialized groups of robots. In contrary to swarm ideology, we must give these individuals or small units some sort of intelligence and autonomy. Due to that, other members can have just basic sensor equipment for navigation but use shared complex information about surrounding and carry out different tasks. For purpose of creating more natural intelligence we can use and benefit from choice of linguistic description of control system. This way, we can describe a reaction of unit on events alike organism in a real-life.

II. Objectives of the Project

Problematic of the main project deals with design and construction of multiple robotic platforms what will be used to form swarm. They will be used for experiments, testing new approach and education purposes. This specific project deals with controlling of prototype afore-mentioned mobile platform with use of sensors like on autonomous cars. For this project were given these goals.

1) Autonomous movement in surrounding: first iteration, in which robot is moving on its own in an open area with primary use of data from ultrasonic sensors.

2) Advance data processing: second iteration, in which robot is using data from camera and LIDAR to move, find obstacles and defined objects.

3) Interpretation of data from sensors: third iteration, in which robot use all data acquired from sensors to describe his surroundings and upload information to shared map.

4) Movement adaption according to map: in the last iteration, the data acquired by all robots will be used to accomplish a given goal.

III. Description of the Hardware Structure

The basis of the robotic platform is RC car model LRP S8 Rebel in scale 1:8. From this model, the chassis and the motors were taken. The forward and reverse movement is provided by the BLDC motor with hall sensors with power 2.3 kW when the 14 V is used and by the electronic speed controller (ESC) with active cooler. The steering is handled by the hobby servo. The chassis design is based on Ackerman steering geometry with four wheel drive. The source of energy is two cells Li-pol battery with capacity 8000 mAh and nominal voltage 7.4 V.

The main sensor for obstacle detection is a small LIDAR RPLIDAR A2. It is intended specially for use on mobile robots. The measured area has radius of 6 m. In the task of detecting the obstacles, the LIDAR is supplemented with eight ultrasonic distance sensors, which are situated equally around the robot. The next sensor, which is used on the robot, is 10-DOF sensor (degrees of freedom). It includes three axis accelerometer, three axis gyroscope, three axis magnetometer, and barometer. For the purpose of the global navigation in the outdoor areas, the GPS module is used. The local navigation makes use of the quadrature encoder located on the shaft of the driving motor. It is essential to take care of battery to avoid the possible damage, so the

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voltages of both cells are measured independently and also the actual current drawn from the battery.

The 32bit microcontroller STM32F4 with core ARM Cortex M4 was chosen for the control task on the middle level. It provides enough performance to ensure the required performance and it is equipped with many other resources, too (memory, peripheries, and pins number). This chip enables very fast processing of all acquired information and their distribution to the superior system, which is formed by small computer Raspberry Pi 3. This version includes the WiFi and Bluetooth module, which could be used for communication purposes with the next robots or other systems. The external camera module is connected to the Raspberry Pi. It has the resolution 8 MP and is capable to record the video in several modes, for example with 1080p resolution and 30 fps.

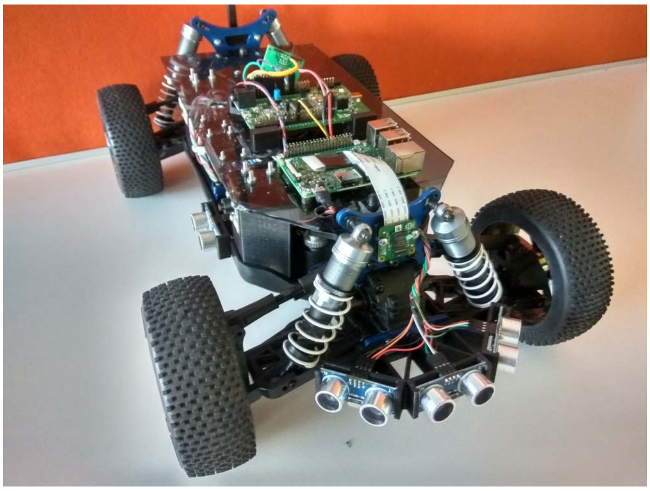

Fig. 1. Prototype of robotic platform

IV. DESIGN OF CONTROLLING SYSTEM

This experiment is focused on designing autonomous controlling system, which will be used in final swarm collective, especially in mobile units of ‘scout’ type. In Fig. 2, the pyramid diagram of perception can be seen. Each mobile robot unites data from its sensors and carries them to higher layers.

A. *Coding theory*

Because the given goal is complex, we use non-standard approach. Mobile robots programs usually consist of one super loop with switch structure. This loop ensures reaction on different events and is responsible for transition between given states. The loop is the basis of the code and consists of conditional structures and event handlers. These standard elements can be improved by use of FLC system. Using linguistic description more dynamic system can be developed, which will react non-linearly to different situations.

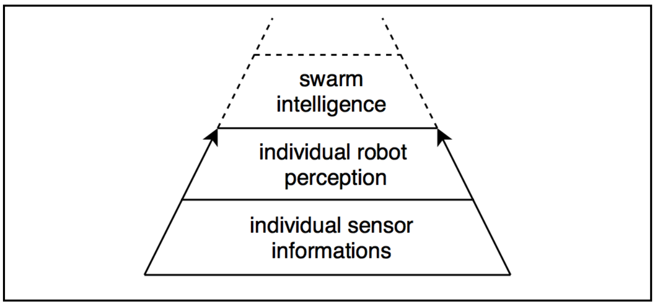

Fig. 2. Layers of perception

B. *Basic of FLC systems*

Systems based on fuzzy logic are widely used for robust regulators and auto-tuning mechanism, where we need to take in account multiple variables to make right adjustment. [12]

One of the first and most commonly used FLC systems by the general public were in washing machines and dishwashers. Systems programmed by „expert in specific domain“ utilize their knowledge to choose the best parameters (e.g. length of washing, temperature) for given inputs (e.g. type of dishes).

Same system was applied in the industry applications like smelter [9], blast furnace [7], waste water treatment plants [6], energy converter control [5] or application like an inverted-pendulum system [8], noise suppression [11], etc. Other common application of fuzzy logic is in regulators [9].

There are three key elements of fuzzy control system.

1) Fuzzyfication of imputs: use of membership functions to divide and describe full range of values.

2) Base of knowledge: summary of rules which describe combination of input membership functions for given output functions

3) Output defuzzification: use one of many types of defuzzifications to get required output value. Mostly used methode is the method COG (Center Of Gravity) .

Moreover, fuzzy system can be divided into two major groups by their model type. These models differ by mean of their defuzzification.

1) Mamdani model: uses membership functions on input and output of system. Output function must by defuzzified by one of the methods to get sharp number. Most common method is COG.

2) Takagi-Sugeno model: uses membership functions only for input of system. In contrast to Mamdani method, each rule have its unique matematic function. Function consists of inputs in form of variables. Sharp output numbers are given by these mathematic functions weighted average. Weight of each rule is defined by degree of belonging given by rules expression.

C. Application of FLC system

We can utilize FLC system in this application due to use of Raspberry Pi 3 with corresponding computing power. For this purpose, a library in programming language Python with visualization was created. This library is used to work with Mamdani model of FLC controller, which consists of fuzzyfication of inputs, processing rules and defuzzification by COG method. Model Takagi-Sugeno has smaller computational demands, but was excluded from this part on behalf of different characteristic of output function. This model will be used later.

Library was created to be less computationally intensive. It uses basic instruction without complex multi-iteration loops, integrations, etc. One of the most demanding processes is defuzzification. To decrease the computational demands, membership functions can be defined just by triangle or trapezoid. With these limitations we can define 'area' and 'centre of gravity' of this function with basic mathematic operations. When we create a membership function, all parameters will be computed and saved like constants. In every other iteration these constants will be just multiplied by input variables.

Library is written in object-style code (as can be seen at Fig. 3), but will be rewritten to simple variant to be used at low-level platforms in programming language C.

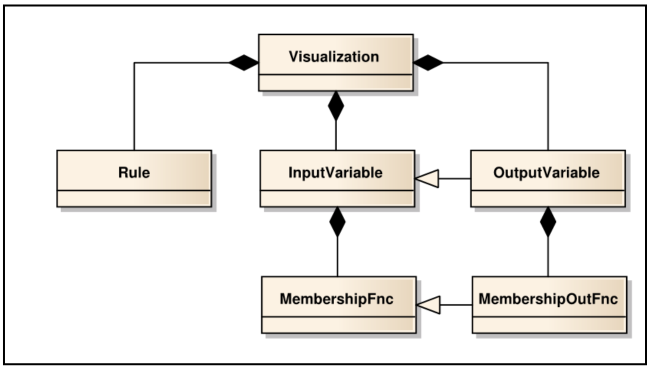

Fig. 3. Class model of fuzzy library with all objects

In the first iteration of experiments, fuzzyfication of only ultrasonic sensors was used (Fig. 4). Data measured by the ultrasonic sensors were primarily used to control angle of Ackermann steering gear (Fig. 5). Secondary, there were used to control the speed of robot including its reverse. In this variant a problem occurred. Mobile platform get into deadlock because of zero feedback from FLC system. This situation can happen, when robot arrives into a narrow passage with an obstacle at its end (see Fig. 6). In the next iteration, a complex movement system utilizing fuzzy logic will be created. Switch structures will be enhanced by fuzzy logic to determine next move with the use of data from others sensors. The robot will be aware of surroundings and be able to recognise different obstacles.

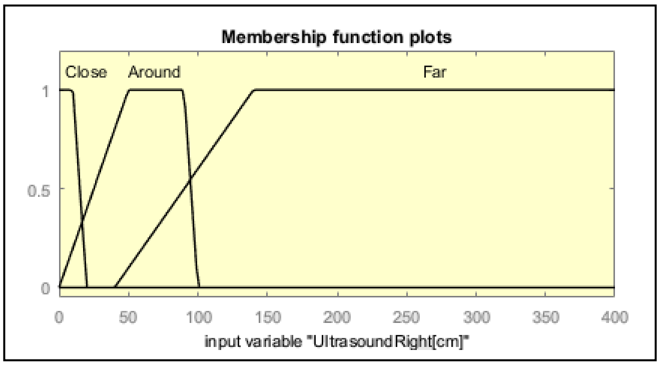

Fig. 4. Fuzzification of ultrasonic sensor

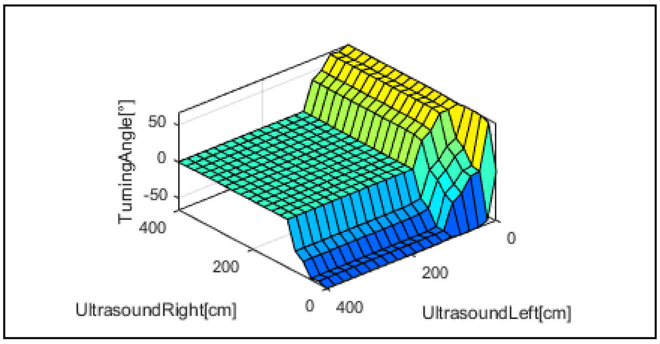

Fig. 5. Graph of dependency of two sensors on angle

Each signal from ultrasonic sensors corresponds to different membership function. Range of input variables correspond to effective range of ultrasonic sensor from 2 to 400 cm and consist of three membership functions. FLC controller in its current state has eight input variables and two outputs. For demonstration purpose, graphs showing membership functions of input variable and 3D maps of rules from Matlab were used. Final controller system consists of eight membership functions. With all ultrasonic sensor used, we can safely move in every direction without risk of collision.

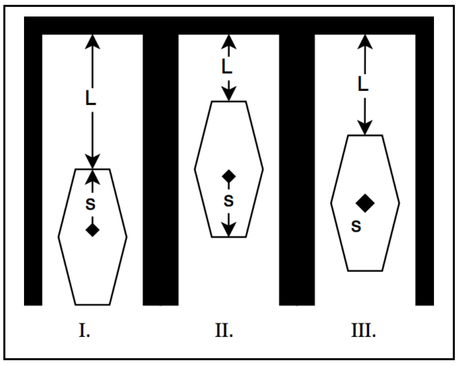

Fig. 6. Deadlock problem; I. Robot gets into narrow passage, value of membership function is 'Around' (see Fig. 4), robot has positive speed. II. Robot detects obstacle, value of membership function is 'Close', robot speed is negative. III. Robot is in optimal distance from obstacle, value of membership function is between 'Close' and 'Around', robot speed is zero.

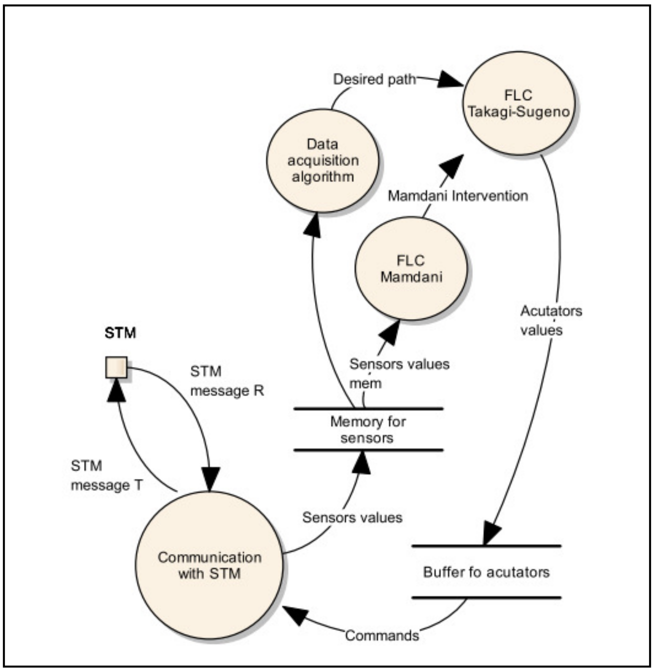

Fig. 7. Graphical interpretation of controlling system

D. *Intersection of controlling systems*

Because we anticipate later changes, we prepared movement system based on model Takagi-Sugeno (Fig. 7.). The system will connect the commands from superior system with outputs given by fuzzy controller. In case of emergency, system will continuously transfer movement control from superior system to fuzzy controller and thus prevent hazards of collision.

Similar system will be able to link the data from robot sensors with information from map to determine optimal route to chosen destination. This system will be based on one of many swarm movement models [10].

This system is needed due to later stages of development, in which this platform will contain basic algorithm to navigate through area. Searching algorithm will be based on GOAP (Goal Oriented Action Planning), which is a method of programming artificial-intelligence in games. This method is simplified version of automated planner STRIPS (Stanford Research Institute Problem Solver) developed by Richard Fikes and Nils Nilsson in 1971 at SRI International [1].

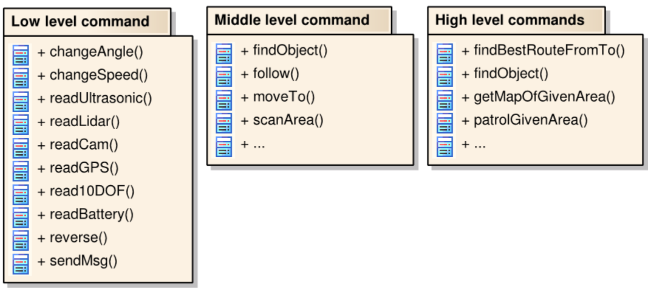

Fig. 8. Example of possible action rutines

Controlling system enables the use of action routines, which will describe all actions that robot can perform and can help him to accomplish his goal. Action routines will be divided into multiple levels according their complexity. First level will include basic movement commands. The higher level command, the higher complexity and abstractness of command (see Fig. 8). Action routines from higher level will usually consist of one or multiple commands from lower levels. These action routines will contain preconditions and they will be rated by their difficulty and possible gain to enable alternative approach of solving problems. How this system should look like is illustrated in Fig. 8.

E. *Inter robot communication and data acquisition*

Another step to form swarm collective is a creation of communication network. This network will serve to transfer data between robots, uploading them to map and it gives us the possibility of direct control and debugging. There is separated article dealing with problematic of data acquisition and low-level controlling of hardware platform.

All data from the sensors are processed by STM and transferred by serial communication to Raspberry Pi (Fig. 9). These data are transferred to Raspberry Pi. After that, data are broadcasted by build-in Wi-Fi module. Because of high quantity of outgoing information, we need to separate each data stream. To do that, we used multiple ports for this issue.

With this system every other robot can listen do data stream of other robots and make active use of their information. This method will be subjected to experiments to find optimal usage of this information to our application.

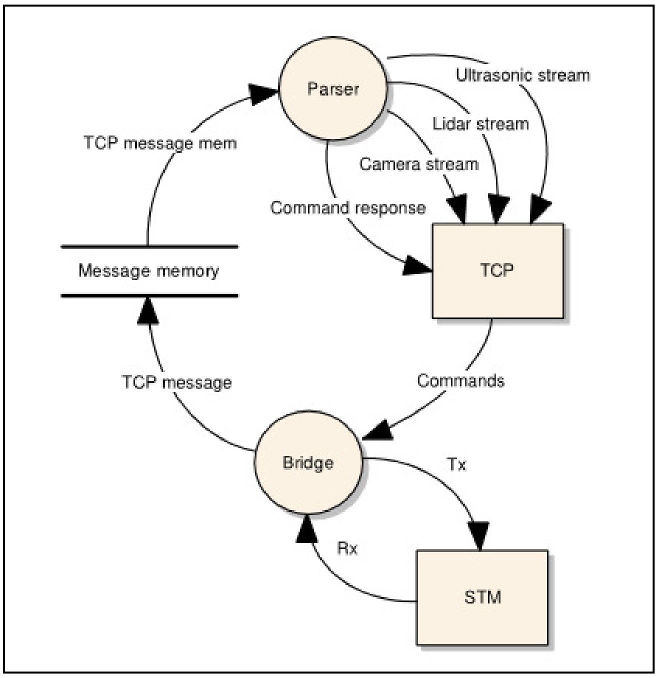

Fig. 9. Bridge between UART and TCP communications

V. Conclusion

The article has dealt with the design and realization of the controlling system for robotic platform used for swarm robotics. Because of size of this unit, they will operate in smaller number than typical swarm application. This paper focused on description of basic components of controlling system at Raspberry Pi with basic introduction of fuzzy logic and its key components. All parts of controlling system are briefly described, including the Fuzzy library and different parts of decision mechanism. Control system is based on fuzzy logic approach. Multiple fuzzy models were used to create motion control system for this mobile platform.

This project is in early stage of development and therefore experiments were made only at one unite. Main goal of this phase was creation and practical use of fuzzy system for low-level of motion control. This system is used to prevent collisions with obstacles even when superior system is controlling movement of the platform. In future research, advance algorithm for movement control will be applied.

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