

Developing a Fuzzy Logic Controlled Agricultural Vehicle

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Abstract

This paper describes the design of a fuzzy controlled robot for use in an agricultural environment. This environment comprises of an open, but irregular terrain either supporting crops or sparsely populated with objects. This results in complex problems of identification, monitoring and control.

In this paper a fuzzy controller is identified which when used with a novel sensor design can deal with both crop tracking and cutting.

The controller was tested on an in-door mobile robot using two ultrasound sensors. The controller showed a good response in-spite of the irregularity of the medium as well as the imprecision in the ultrasound sensors. This Controller will be implemented on both electrical and diesel powered vehicles which can navigate in out-door farm environments.

1- Introduction

The problem of a decreasing agricultural workforce is universal. Therefore, there is a need for fully automated farm machinery, including the development of unmanned agricultural vehicles. Most field tasks in agriculture can be placed in one of two categories:

- a) Those based on crops planted in rows or other geometric patterns that involve making a vehicle drive in straight lines, turn at row ends and activate machinery at the start and finish of each run. Examples of this are in spraying, ploughing and harvesting.
- b) Those that involve locating objects in an area and performing operations on them. Examples would be collecting bales or trailers.

In an agricultural setting the inconsistency of the terrain, the irregularity of the product and the open nature of the working environment result in complex problems of identification and sensing errors and control. Problems range from dealing with other autonomous units in the working area (e.g. individuals or other mobile machinery), or coping with the consequences

of the robotic tractor being deeply embedded into a dynamic and partly non-deterministic physical world (e.g. wheel-slip, imprecise sensing and other effects of varying weather conditions on sensors and actuators). All these problems provide fuzzy controllers with good opportunities to work, as they excel in dealing with imprecise and varying conditions which characterises such situations.

AI techniques including expert systems and machine vision have been successfully applied in agriculture. Recently, artificial neural network and fuzzy theory have been utilised for intelligent automation of farm machinery and facilities along with improvement of various sensors. Li and Wilson [5] developed an intelligent steering control algorithm for a vision-based agricultural vehicle guidance system, Schallter[7] has developed a new algorithm for bale detection in an open field. Cho[2] have used a simulation of a fuzzy unmanned combine harvester operation. Ziteraya and Yamahaso[11] showed the pattern recognition of farm products by linguistic description with fuzzy theory was possible. Zhang et al [10] developed a fuzzy control system that could control corn drying. Yamasita[8] tested the practical use of the unmanned vehicle for green house with fuzzy control. Mandow[6] had developed the greenhouse robot Aurora, but the application and environment variation in the greenhouse is restricted with respect to the outdoor situations.

Most of these techniques have only been examined as simulations and little work has been done in implementing a real robot vehicle using fuzzy logic which can operate in open agricultural situations. The aim of this paper is to develop a fuzzy vehicle controller for real farm navigation and apply it to crop harvesting. An emulation of "crop-following" (which is also an example of fence following) is presented and its response and control surfaces are analysed.

This paper is divided as follows, in section 2 the problem definition is introduced. In section 3 a brief introduction to fuzzy logic controllers is given and the sensors and controller design is discussed. In section 4 the response and the experimental results are introduced and finally a conclusion and future work is offered.

2- The Problem Definition.

In this section we introduce the architecture of the robot and describe our novel sensor design which is suitable for sensing crop boundaries.

The robot is designed to harvest a crop by following its edge while maintaining a safe distance, in this case 45 cm from the vehicle, while at the same time allowing the cutter, which is fixed to the side of the vehicle, to cut the crop. Figure (1a) shows a hay harvester with the associated cutting technique being depicted in Figure (1b).

We operate two kinds of outdoor robots, an electrically powered vehicle and a diesel powered vehicle. They form the test-bed for the out-door agricultural experiments we undertake. The electric vehicle[1] is more portable and has less safety restrictions making it more suitable for some experimental situations.

Other papers reported problems using certain types of sensor in outdoor environments. One solution is to use simple touch sensors [2] which have ON-OFF states only which are not efficient for fuzzy control. We propose to use a mechanical wing which is simply a 50cm. elastic rod connected to a variable potentiometer providing a varying voltage which can then be converted to digital value through an analogue to digital converter. In this way we can have a cheap sensor which gives a continuous signal reflecting distance from the crop edge (and other obstacles). The sensor configuration for crop harvesting implemented on the electrical vehicle is shown in Figure(2a) and the computer controlled diesel vehicle is shown in Figure(2b). The systems described are under construction, so in order to test the fuzzy control

architecture, we used an in-door mobile robot (Trillian) with two ultrasound sensors in the left side each making angle of 40 degrees with the vertical. The test vehicle is VME based with VxWorks¹ RTOS.

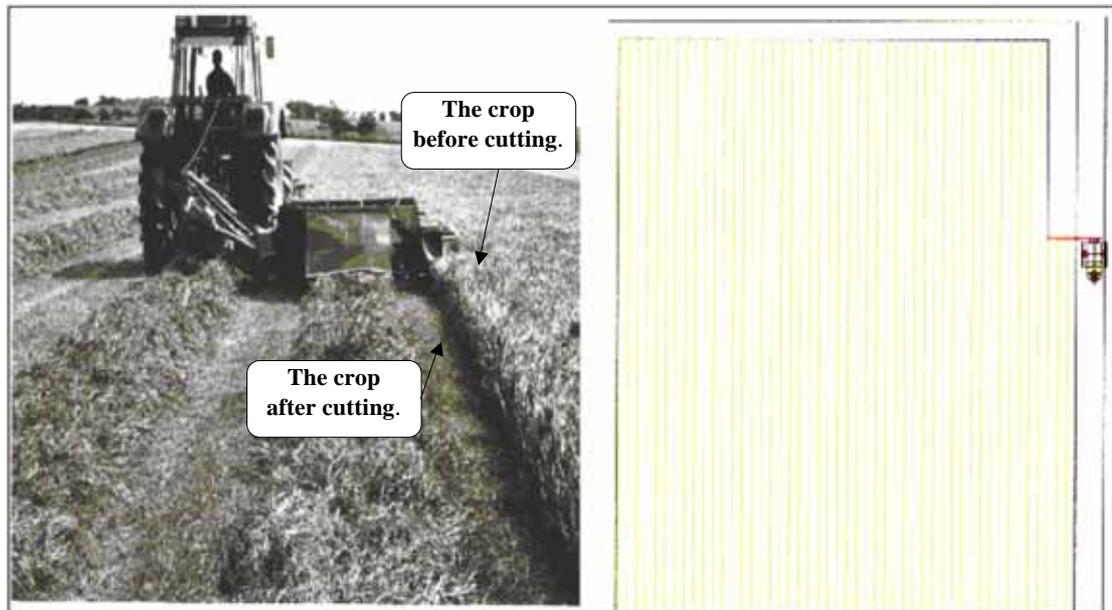


Figure (1a)

Figure (1b)

Figure 1 : a) A real world manned harvester to cut hay, b) The harvesting technique.

This in-door experiment is more demanding than using our mechanical wings due to the problems associated with unreliable readings resulting from the use of ultrasound.

3- The Fuzzy Logic (FLC) Controller Design

Lotfi A.Zadeh introduced the subject of fuzzy sets in 1965[9]. In that work Zadeh suggested that one of the reasons humans are better at control than conventional controllers is that they are able to make effective decisions on the basis of imprecise linguistic information. He proposed fuzzy-logic as a way of improving the performance of electromechanical controllers by using it to model the way in which humans reason with this type of control information.

Figure(3) shows the basic configuration of an FLC, which consists of four principal components :

- a) The fuzzification interface which performs the function of fuzzification that converts input data into suitable linguistic values, which may be viewed as labels of fuzzy sets.
- b) The knowledge base comprises knowledge of the application domain and the attendant control goals. It consists of the database and the rule base. The database provides the necessary definitions which are used to define linguistic control rules and fuzzy data manipulation. The rule base characterises the control goals and control policy of the domain experts by means of a set of linguistic control rules.

¹ VxWorks is a trademark of Wind River Systems Inc.

- c) The decision making logic which is the kernel of an FLC, it has the capability of simulating human decision-making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.
- d) The defuzzification interface which performs defuzzification, which yields non-fuzzy control actions from an inferred fuzzy control action.

In the following analysis we will use a singleton fuzzifier, triangular membership functions, product inference, max-product composition, height defuzzification. The selected techniques are selected due to their computational simplicity.

The equation that maps the system input to output is given by :

$$\frac{\sum_{p=1}^M y_p \prod_{i=1}^G \alpha_{Aip}}{\sum_{p=1}^M \prod_{i=1}^G \alpha_{Aip}}$$

Where M is the total number of rules, y is the crisp output for each rule, α_{Ai} is the product of the membership functions of each rule inputs. More information about fuzzy logic can be found in [4].

The membership functions of the inputs denoted by Left Front Sensor (LF) and the Left Back Sensor (LB) are shown in Figure (4).

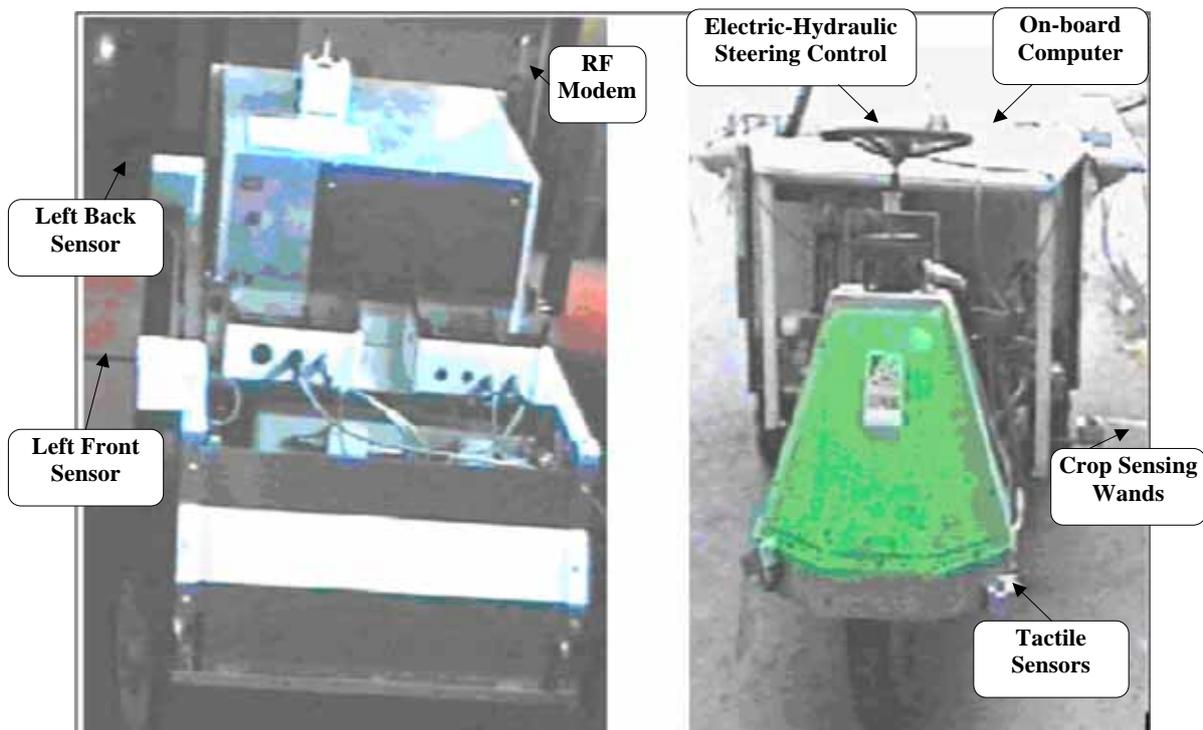


Figure (2a)

Figure (2b)

Figure 2: a) The outdoor electrical robot,

b) The outdoor Diesel robot.

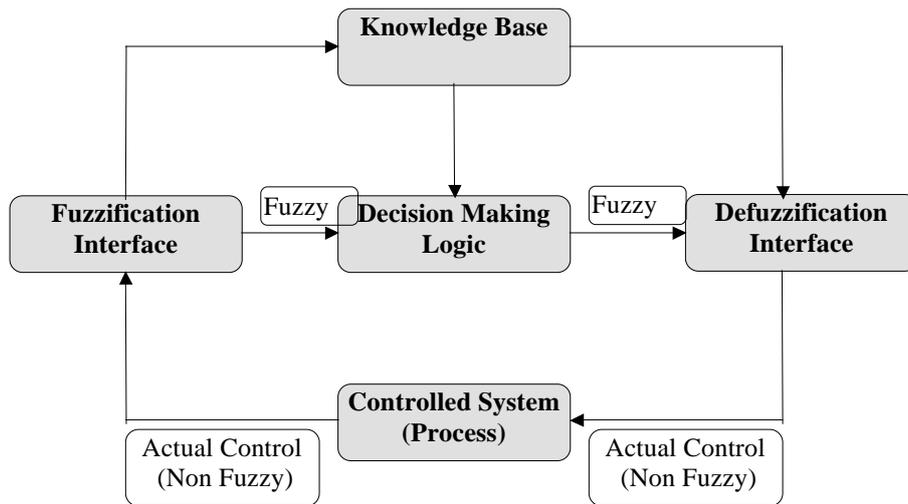


Figure 3 : The basic configuration of an FLC.

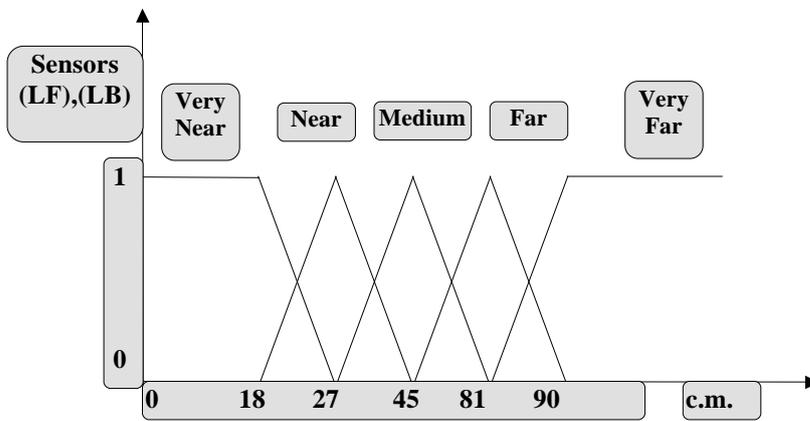


Figure 4: The membership functions of the inputs.

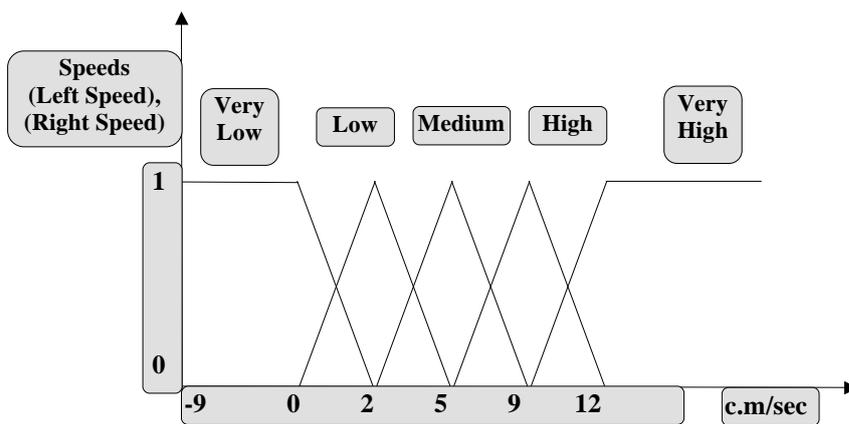


Figure 5: The membership functions of the outputs.

Figure (5) shows the membership functions of the outputs which are the left speed and the right speed. By increasing each of these values, we can increase the speed and by controlling the difference between them, we can control the steering direction.

The fuzzy rules relating the input values to the output values are shown in Table (1). The control surfaces visually present the unknown function articulated by the rules[3]. As shown in Figure (6a,6b) the linguistic rules have been transformed to a mapping from inputs to outputs. These satisfy the stability requirement since small input changes correspond to small output changes (i.e. the surface gradient is not steep).

| LF SENSOR | LB SENSOR | LEFT SPEED | RIGHT SPEED |
|------------------|------------------|-------------------|--------------------|
| VERY NEAR | VERY NEAR | HIGH | VERY LOW |
| VERY NEAR | NEAR | LOW | VERY LOW |
| VERY NEAR | MEDIUM | LOW | VERY LOW |
| VERY NEAR | FAR | LOW | LOW |
| VERY NEAR | VERY FAR | LOW | LOW |
| NEAR | VERY NEAR | LOW | LOW |
| NEAR | NEAR | MEDIUM | LOW |
| NEAR | MEDIUM | MEDIUM | LOW |
| NEAR | FAR | LOW | LOW |
| NEAR | VERY FAR | LOW | LOW |
| MEDIUM | VERY NEAR | VERY LOW | MEDIUM |
| MEDIUM | NEAR | VERY LOW | MEDIUM |
| MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| MEDIUM | FAR | MEDIUM | LOW |
| MEDIUM | VERY FAR | MEDIUM | VERY LOW |
| FAR | VERY NEAR | LOW | MEDIUM |
| FAR | NEAR | LOW | MEDIUM |
| FAR | MEDIUM | VERY LOW | LOW |
| FAR | FAR | VERY LOW | MEDIUM |
| FAR | VERY FAR | VERY LOW | HIGH |
| VERY FAR | VERY NEAR | VERY LOW | MEDIUM |
| VERY FAR | NEAR | VERY LOW | MEDIUM |
| VERY FAR | MEDIUM | LOW | MEDIUM |
| VERY FAR | FAR | LOW | HIGH |
| VERY FAR | VERY FAR | LOW | LOW |

Table 1: The fuzzy rule base.

3-Experimental Results

Figure (7a,7b) shows the in-door robot in operation. The robot response was drawn with a pen fixed in front of the robot.

It tries to maintain itself within 45cm from the emulated crop edge Figure (7a). When the vehicle emulates cutting the crop Figure (7b), it continues going inwards to complete the harvesting operations. The cutting action was simulated by reducing the size of the fence.

Note that the response is smooth especially when the robot turns. This is due to the smooth transition between rules and the smooth interpolation between different actions which are characteristics of fuzzy logic.

Note also that the robot succeeded in maintaining itself at a constant distance from the emulated crop in-spite of irregularities and non-uniform surfaces .

It is clear that the controller can deal with the imprecision from the ultrasound sensors and can follow a smooth and accurate track using only two ultrasound sensors.

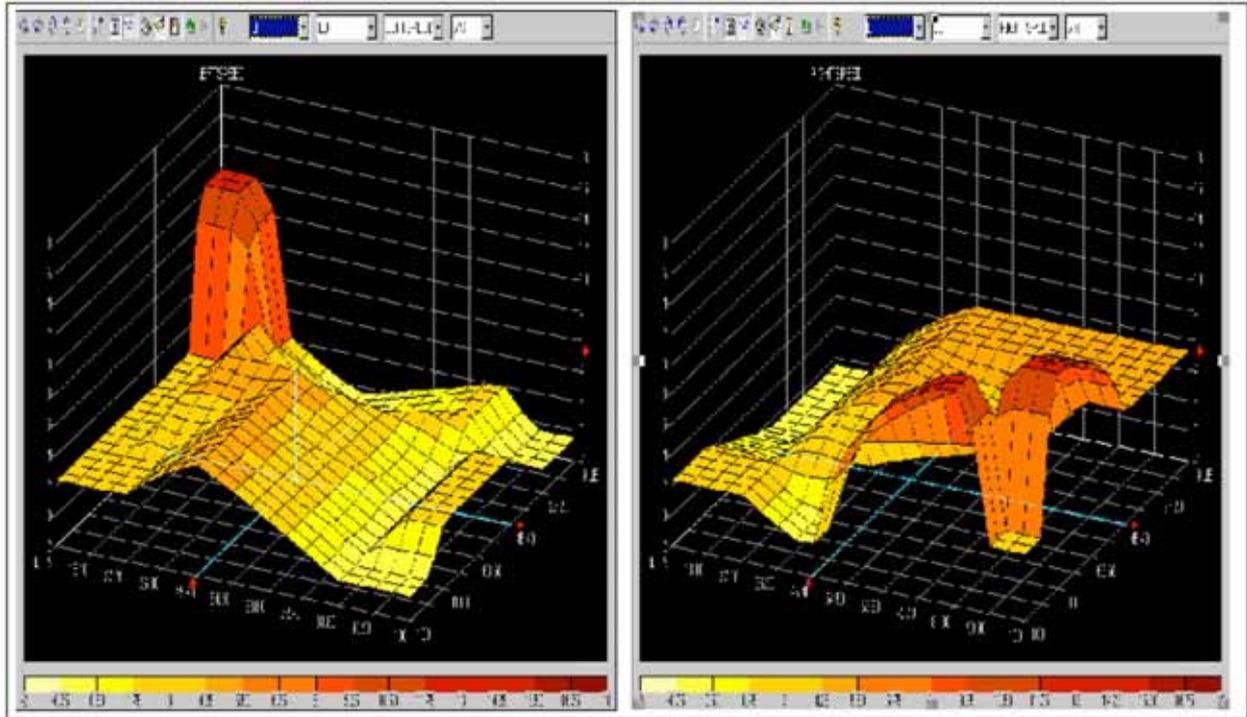


Figure (6a)

Figure (6b)

Figure 6 : a) The control surface of LF and LB sensors against the Left Speed , b) The control surface of LF and LB sensors against the Right Speed.

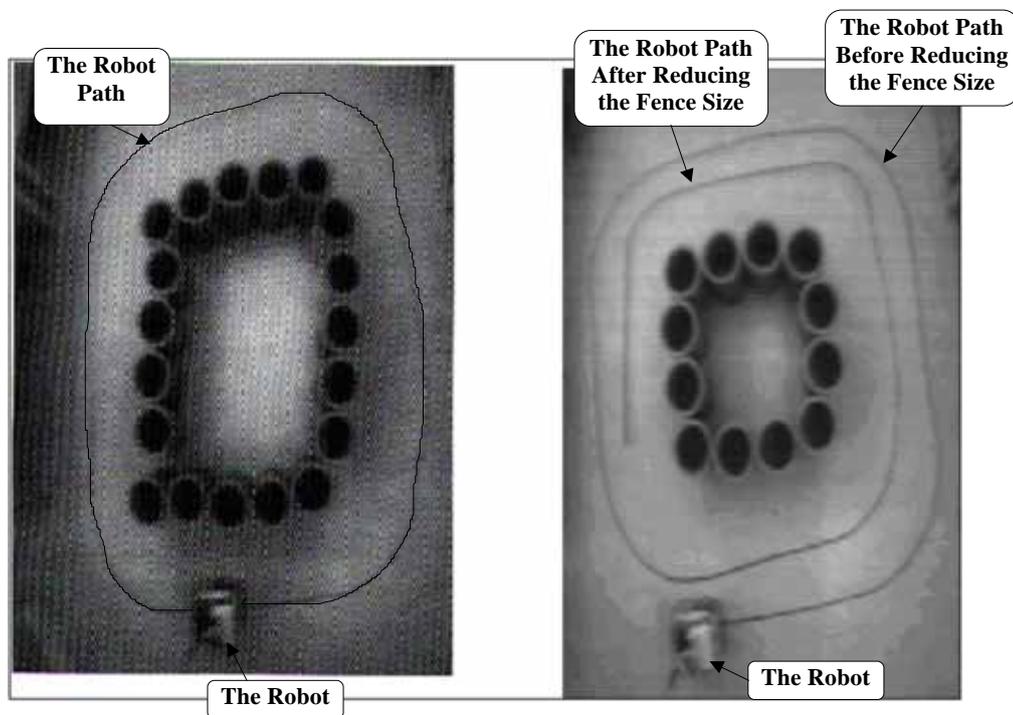


Figure (7a)

Figure (7b)

Figure 7 : a) The robot path before harvesting , b) The robot path during harvesting.

Conclusion and Future Work

In this paper we have developed a fuzzy controller for a robot aimed at automating crop harvesting.

We implemented the fuzzy control architecture on an in-door mobile robot with only two ultrasound sensors. Its control action was smooth and it had succeeded in maintaining itself at a constant distance from the emulated crop in spite of boundary irregularities and the imprecision in the ultrasound sensors. We also introduced a new sensor to be used in robots in open farms.

In the future we plan to transfer this fuzzy control architecture to our out-door vehicles and optimise the control architecture in the real and varied environment of a farm. In addition we plan to investigate the use of fuzzy hierarchical control in bale-collecting applications. However, the main focus of our research will be to investigate GA based methods in respect to adding a learning capability to the controller so that it can adapt itself to the changing conditions of a field.

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