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FUZZY DECISION ALGORITHM FOR HYBRID FIRE-FIGHTING ROBOTS

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In the process of fire-fighting, robots have been added to ease the workload and increase the safety of human fire-fighters. Hybrid robots have advantages for being able to move on different terrain type, which is why an intelligent decision and control algorithm is required. We propose a fuzzy decision algorithm to decide the walking method which will better help the fire-fighter. The hybrid robot for which we the designed algorithm, has 4 legs with 3DOF each, used for walking and another DOF on each leg for wheels. All the robots' joints have prismatic actuators that provide a higher torque and load.
KeyWords: fuzzy decision, hybrid robots, fire-fighting, predictive platform.

1. INTRODUCTION

This paper aims to develop a decision algorithm for hybrid fire-fighting robots to use when deciding what type of locomotion they should choose depending on terrain type and structure. In order to achieve this task, the robot must be able to detect the terrain through sensors or by doing a visual processing of its surroundings. For this, Lee and Woojin [1] have developed a terrain detection scheme for mobile robots. The detection method use classification criteria obtained through experimental data training on various environments. Another way is to use different sensors [2] or an array of sensors to detect drivable terrain or to use a decision process [3] so that walking robots maintain a stable walk in complex and unstructured terrains. To enhance the walking stability, an adaptive foothold planning method [4] is required, to avoid slip and fall of the walking robots, which may not be needed when the robot has multiple legs which by construction prevent the robot to fall down. In this way the robots have a better way to detect the environment which can further be used in path planning algorithms l[ike the one proposed by Garrido [5] (et. all) in which the algorithm takes into account obstacles, surface slope or roughness and even information of uncertainty.

All the terrain detection and robot walking stability methods are required to control a fire-fighting robot during his fire-fighting activities. For this, the robot must be fire resistant [6] and with fire detection capabilities [7] that can be controlled from a safe distance [8]. Inside a fire scene, the robot must withstand up to 700^{o}C [9] so it will not be destroyed or add fuel to the fire. Inside the fire scene [10] a robot designed by AlHaza [9] (et al) is capable to use fire extinguishers, detect victims and send to a remote location the acquired information.

During the operation of a fire-fighting robot, it must be able to avoid obstacles or very high temperatures [11, 12] before starting the fire-fighting operations. For this the robot must arrive at the scene as fast as possible since the fire can extend very fast which can lead to multiple causalities and material loss. For this, we have proposed a hybrid fire-fighting robot structure with a fuzzy decision algorithm that will allow the robot to decide when to use wheels or legs for locomotion.

The goal of the developed fire-fighting robots is to integrate them in a predictive platform for smart actions in fire-fighting operations and service [13-15].

2. SYSTEM DESCRIPTION

The robot structure that is being used for the smart fire-fighting robot is the one presented in figures 1-3, [16]. The robot was developed with a higher capability of adapting to the environment. As one can see, the robot has 4 walking legs with 3DOF actuated by translation joints for higher torque that increases the robot load. Beside the 3DOF each leg has a wheel (1DOF) which allows the robot to obtain higher speeds on flat terrains.

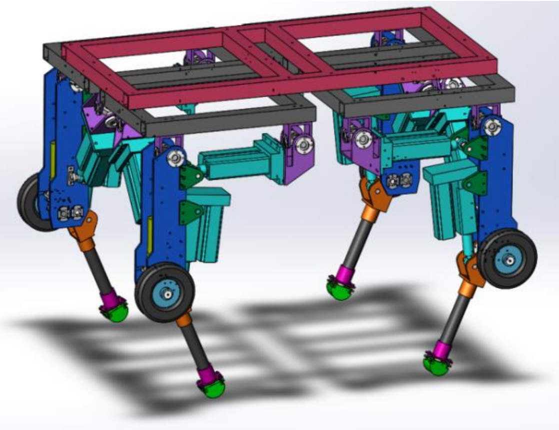

Figure 1 – Smart fire-fighting hybrid robot

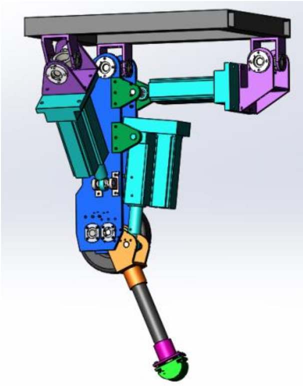

Figure 2 – Robot inside leg view

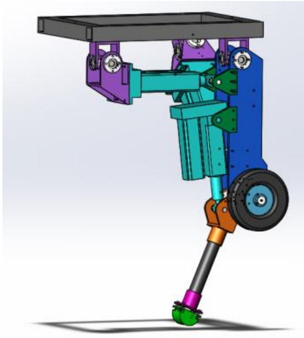

Figure 3 – Robot outside leg view

Combining the high speed of the wheel and the unstructured terrain walking for the legs, the hybrid robot structure provides to a fire-fighting robot the ability to reach the fire scene in a short time and then to be able to walk in the fire scene by avoiding and overcoming obstacles which could not be done by a wheeled mobile robot.

3. DECISION ALGORITHM

To control the hybrid robot we have designed a two-step fuzzy decision algorithm (figure 4), to optimize the robot speed on different terrains and the control law used for different stages in the robot walking motion.

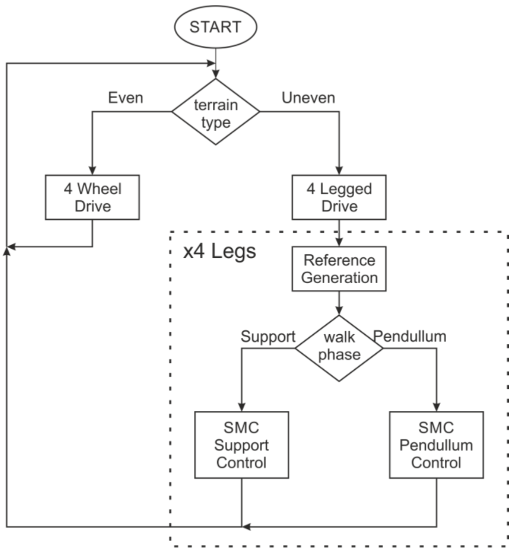

Figure 4 – Two-step fuzzy decision algorithm

The first step in the fuzzy decision is to decide which type of motion the robot should use at one time. This is highly influenced by the terrain type, the robot required speed and the time between switching from 4 Wheel Drive to 4 Legged Drive. The last parameter, the time between switching motion type, acts as a chattering inducer parameter which ads unwanted frequent switching decisions on the threshold between leg or wheel robot motion. To prevent this, a delay between switching phases or a parameter that acts as a hysteresis parameter is added. This parameter will influence how the fuzzy decision control is designed and used.

The fuzzy membership functions are presented in figures 5-7. These will allow us to get the final decision on how the robot should move (on wheels or on legs) depending on terrain type and the number of obstacles found in its path.

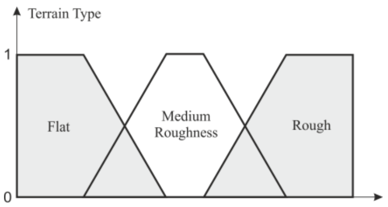

Figure 5 – Terrain type fuzzy membership function

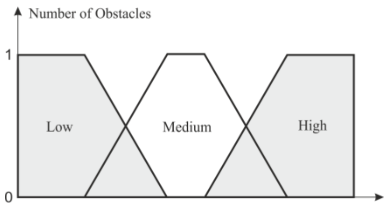

Figure 6 – Number of obstacles fuzzy membership function

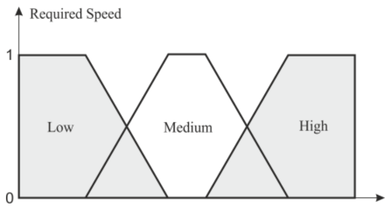

Figure 7 – Required speed fuzzy membership function

Using the membership functions, we have defined the fuzzy rule base presented in figures 8 and 9. Figure 8 presents the fuzzy rule base for terrain type depending on number of obstacles found in the robot path. The output of this rule is the required speed of the robot. This speed is then used with the rule base from figure 9 along with the terrain type, to result an output for the type of motion the robot should use (4 wheel drive or 4 leg drive from fig. 4).

Terrain Type / Number of Obstacles	Flat	Medium	Rough
Low	High	High	Medium
Medium	High	Medium	Low
High	Medium	Low	Low

Figure 8 – Terrain type on number of obstacles fuzzy rule base

Terrain Type / Required Speed	Flat	Medium	Rough
Low	Wheels	Legs	Legs
Medium	Wheels	Legs	Legs
High	Wheels	Wheels	Legs

Figure 9 – Terrain type on required speed fuzzy rule base

4. RESULTS

Having the membership functions and the rule base tables (fig.5-9) we have developed a Matlab Simulink project using the Fuzzy Toolbox to implement the fuzzy logic controllers. Figure 10 presents the the fuzzy logic controllers used to obtain the motion type value. The first fuzzy logic controller uses the terrain type and number of obstacles values to compute the required speed fuzzy value. This speed is then used in the second fuzzy logic controller along with the terrain type value to obtain the motion type fuzzy value. This final value is required to get the final decision.

To decide on the motion type we now have to defuzzyfi the obtained value, which can we easily achieved knowing that for wheels the algorithm will return a value lower than 0.5 and for a leg based motion, the algorithm will return a value greater than 0.5;

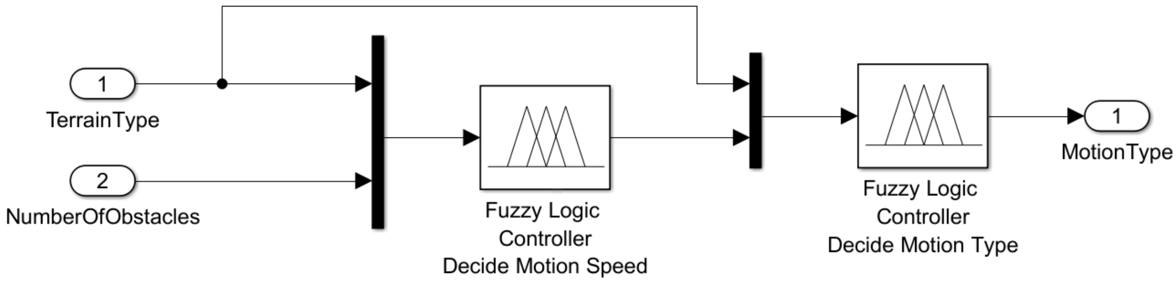

Fig. 10 – Fuzzy logic controllers used in a Simulink block

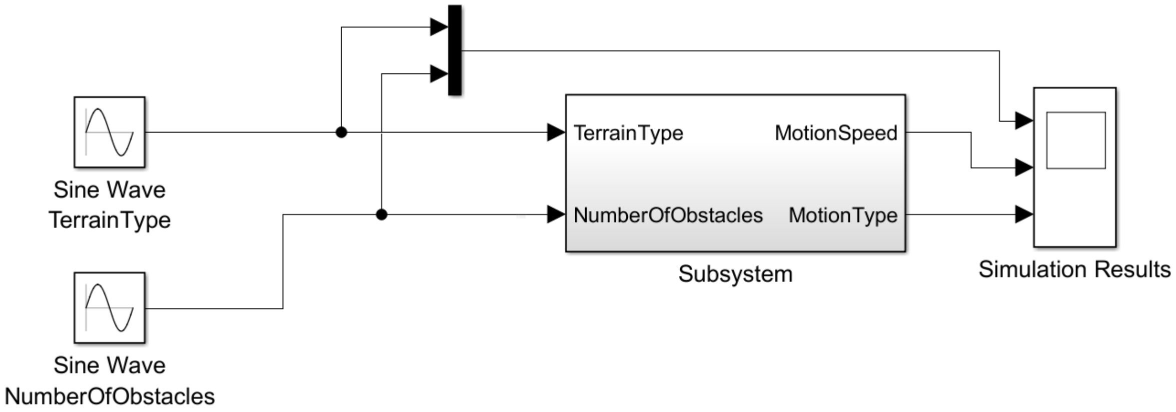

Figure 11 – The Matlab Simulink motion type deciding algorithm

Figure 11 presents the entire simulation where for inputs we have used two sine waves to generate as many combinations as possible, and the result will be stored within a scope component, called Simulation Results.

The obtained results after the simulation are presented in figure 12, where the top graph contains two fuzzy values for terrain type and number of obstacles, as inputs to the deciding algorithm.

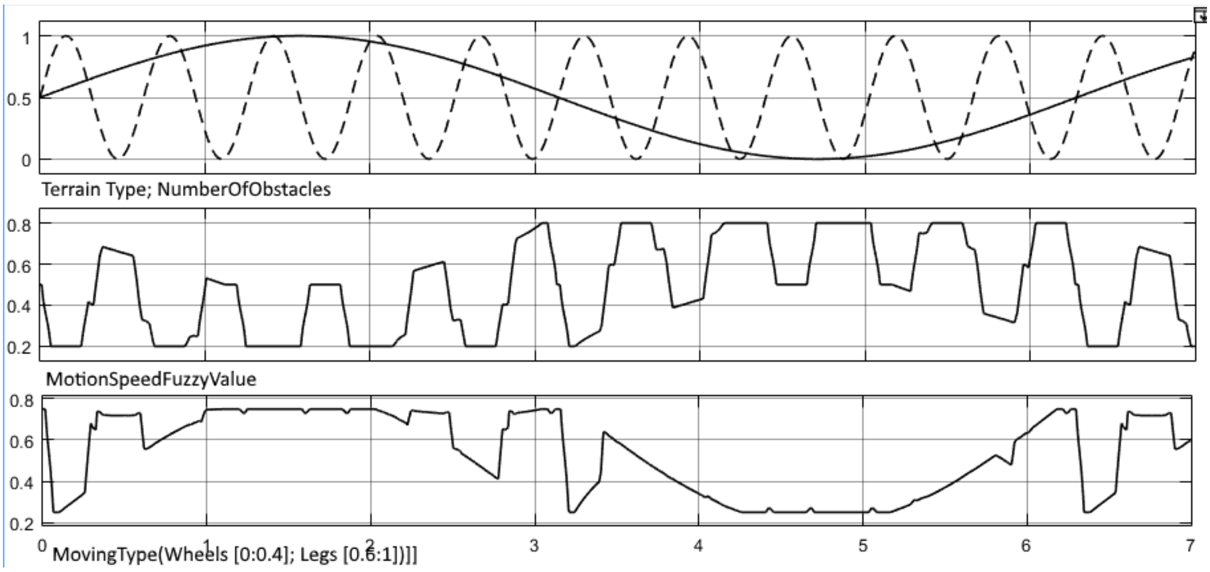

Figure 12 – Results of the fuzzy deciding algorithm

The second graph shows the fuzzy value for the required speed, computed by the first fuzzy logic controller. These values can be decoded using the following rule: Low = [0; 0.325), Medium= [0.325; 0.675], High = (0.675; 1].

The third graph and the fuzzy decision algorithm output is the fuzzy value for the motion type which the robot should use, given the two inputs as terrain type and number of obstacles. The output value can be decoded using the following rule: Wheels = [0; 0.5), Legs = [0.5; 1].

5. CONCLUSIONS

Controlling a hybrid robot through unknown and unstructured terrains means that the on-board AI should be able to decide on its own what type of locomotion it should use for different tasks. For this we have developed a deciding algorithm based on fuzzy logic, to select in an autonomous way the motion method of the robot. Stating that the robot should move at top speed, followed by the required speed membership function, we can decide very clearly which type of motion the robot should use depending on these parameters.

The proposed deciding algorithm uses a two-step fuzzy logic controller which adds a second layer of decision making. This in turn makes the deciding algorithm much more reliable.

Since the aim of the robot is to help fire-fighters in case of disasters, our proposed deciding algorithm has the ability to improve the robots' AI and help build the predictive platform for smart actions in fire-fighting operation we aim to develop.

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