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# Fuzzy Logic Analysis of Photovoltaic Data for Obstacle Avoidance or Mapping Robot

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***Abstract*—The utilization of only existing radiant sources in autonomous and mobile robotics is a relatively new field. These radiant sources, referred to as ambient radiation were "the noise and errors" in the production of various range finding and obstacle locating sensors. The research looks to developing methods to utilize this "noise" for autonomous robot mobility and addresses the inherent problems associated with dynamically changing environment analysis. A fuzzy logic topology is adapted in the processing of amplified data from an array of sensors in photovoltaic mode. The "fuzzified" data may be used for the purposes of obstacle avoidance or for higher level applications such as item location, fire detection and environmental mapping.**

***Index Terms*—Fuzzy control, robot control, obstacle avoidance sensors.**

## I. INTRODUCTION

In dealing with autonomous robot mobility and addressing the inherent problems associated with dynamically changing environment analysis, this paper proposes a fuzzy logic topology for the processing of amplified photovoltaic data from an array of sensors in photovoltaic mode, forming a $360^{o}$ circumference in any given environment. The resulting "fuzzified" data may be utilized for the purposes of obstacle avoidance or within higher level applications such as item location, fire detection, item location or area mapping.

"Imprecise" or "vague" expressions are appropriate adjectives when describing fuzzy logic. Specifically it is upon this basis that the method of control was chosen. Expressions like "nearly", "about", or "far" are terms used by humans that have little if any relationship to the absolutes of first-order logic, just as terms referring to radiation intensities in a dynamic environment cannot by their nature be absolute. A combination of the type of sensors being used and the need to minimize the number of calculations or instructions required was another focus for the choice. A true or false mode of analysis merely emphasizes the fact that we wish to attain the highest possible precision without accounting for the inherent, imprecise nature of reality. In essence, fuzzy logic is a precise logic of imprecision [1].

A further option was that of utilizing probability theory to present a closer to real-world model however this model as such still requires the obtaining of information about the environment of an autonomous device with a high precision factor. Fuzzy logic therefore allows for vagueness in collected data and is in fact able to exploit these variances with a level of tolerance. Ease of implementation and cost-effectiveness has resulted in fuzzy logic becoming popular where differential equations offer no solution or have become cost prohibitive. The author has also looked at subsumption architecture as described by Brooks [2], however this architecture has its own inherent problems as described by [3]–[5] who developed a subsumption based system using fuzzy logic based techniques to fuse certain output behaviours [6].

Autonomous robot's control modules which carry out autonomous functions on the basis of information obtained from the sensors control the driving equipment in a way that ensures a robot will move towards its appointed target whilst avoiding obstacles. Data acquisition and transfer is another essential ability of the robot. These methods are utilized to deliver new tasks, correct the initial tasks and to send additional information about the environment. If the task is performed by several robots they must communicate in order to achieve the goal [7].

As humans we "see" the world in a particular "way", suited to our own senses and irrespective of our varying levels of intelligence, just as an ant "sees" its world also in a particular "way". Both however are quite adept in the art of autonomous mobility, both also possess no additional object avoidance emitters and rely instead upon the abundant radiant sources pervading the environment. Target, goal and shortest distance to the objective are not the basis of this research, alternatively those of investigating, roaming and performance of task without inflicting injury or damage must take a priority in a world where mobile robotic devices are becoming increasingly prevalent.

## II. THE PHOTODIODE SENSOR ARRAY

The sensor array is designed with eight banks of three differing types of sensor. The lower sensors as depicted in Fig. 1 are near-infrared sensors with a wavelength value, λ of approximately 700 nm to 1100 nm with a peak sensitivity of 900 nm, which allows an accurate measurement covering 400 nm of the near infrared spectrum. In Fig. 1 the second row of sensors, are covering that portion of the visible

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spectrum, with λ of around 400 nm to 700 nm and a spectral peak of 550 nm inclusive of infrared rejection filters.

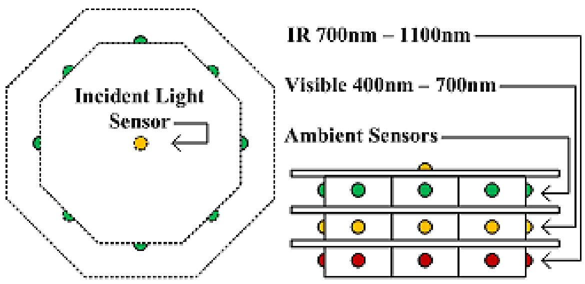


Fig. 1. Sensor array configuration.

The top row consists of light emitting diodes (LED's) which in reverse bias mode, offer the feature that an LED will be receptive to wavelengths of light, less than their own peak wavelength and covering that area of the visible spectrum of λ = 520 nm to 400 nm with some incursion into the ultraviolet region of the spectrum to as low as 200 nm.

## III. Amplification in Photovoltaic Mode

The project utilizes 24 transimpedance amplifiers as the method to convert the photodiode current to a voltage and keep the diode voltage at zero as in Fig. 2. It is a useful application of an inverting amplifier (Current "in", Voltage "out"). The amplifiers accurately amplify the signal from the sensors and this data may be collected for fuzzification. When radiation hits the photodiode a current is generated that flows through $R_f$ to the output (no current flows into the op-amp). The output voltage will be negative. If the diode polarity is reversed the output voltage will be positive.

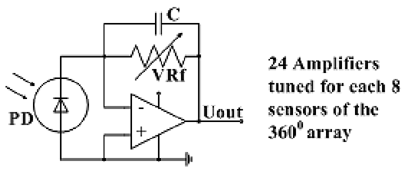


Fig. 2. Photovoltaic amplification.

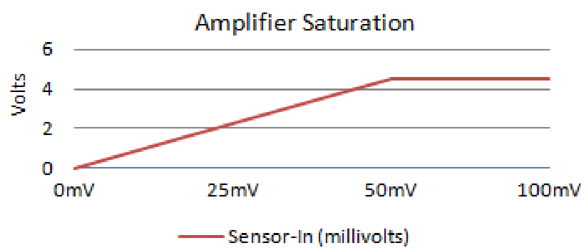


Fig. 3. Trans-resistance amplifier limits.

The output voltage vs. incident light can be linear over 7–9 orders of magnitude as in Fig. 3. Electrical response depends on the response of the detector due to incident radiation across its substrate. The sensor system outlined in this paper has two basic elements. These are the sensors and the amplifiers with the addition of a governing fuzzy logic controller.

## IV. Amplification Considerations

The output voltage, being a function of the amount of radiation sensed at the input is the basis for the sensor array. Therefore we are interested in the responsivity of the sensors [8]. The photo sensors used are in effect small flat-plate capacitors with a typical capacitance of approximately 30 pF. Insulation resistance is $5\times10^{12}\ \Omega$. Sensors are followed by transimpedance amplifiers for current mode. Using expression

$$I\left(\frac{R_f}{\sqrt{1+\left(2\pi f R_f C\right)^2}}\right). \qquad (1)$$

We estimate the expected initial signal to be obtained from each sensor which is further adjusted utilizing a potentiometer for the feedback resistor. Here: $I$ – 0.5 to 1 µA/W which is typical of many photo sensors; $R_f$ – the value of the load or feedback resistor; $C$ – the sensor capacitance for voltage mode, typically 30 pF, or use stray feedback capacitance for current mode, typically 0.03 pF [9].

The simple amplification circuit Fig. 2 converts a current generated by the photo-diode to voltage. The variable feedback resistor $R_f$, sets the operating voltage point at the inverting input and controls the amount of output. The output voltage is calculated simply using Ohm's Law $U_{out} = I_s R_f$. The resultant output is presented in Fig. 4. The output voltage is proportional to the amount of input current generated by the photo-diode, with said output voltage tuned according only to sensor type.

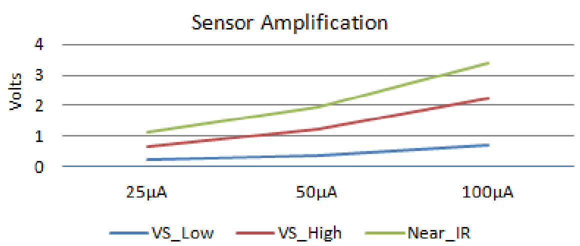


Fig. 4. Amplification adjusted for infrared, upper-visible and low-visible light.

## V. Membership Functions

As the primary purpose of fuzzification is to more accurately assess the variance of the many voltages produced across the array sensors, the control scheme has been left open ended, leaving the overall output to be adjustable in line with the subsequent usage, be that mapping, obstacle avoidance or any number of other applications.

Three sets of functions were created to express degrees of membership for each set of three sensors, all having a membership from 0 to 1. The crisp values, represented in millivolts, mV, specify a range of 0 mV to 4500 mV, presenting the broadest range available before saturation occurs in the transimpedance amplifiers. A one third membership input graph is denoted in Fig. 5, (a), representing the limit of the lower visible spectrum photodiodes as 0 to 1000 mV, in Fig. 5, (b) the limit of the visible spectrum photodiodes as 0 to 2500 mV and in Fig. 5, (c) the limit of the infrared photodiodes as 0 to 4500 mV, representing the real time capabilities of the selected sensors.

The scheme requires three membership functions for each bank, totalling eight sets in all, giving a total of 24 input membership functions with eight output membership functions. Simulation has been accomplished using linear, triangular functions in line with the requirement for simplicity of modification and high speed computation and computational times in simulation resulted in data analysis every 0.05 seconds.

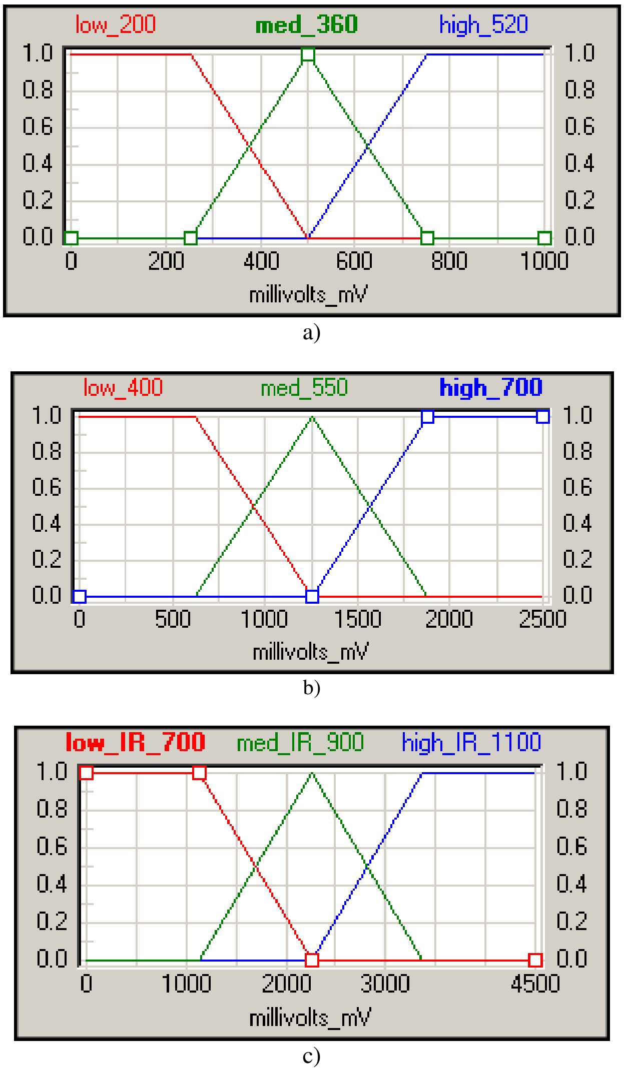


Fig. 5. Membership function of visible spectrum low (a); membership function of visible spectrum high (b); membership function of near infrared (c).

The use of linear functions is not critical but allows for visual adjustment of the membership functions and a more accurate assessment may be had with "S" curve functions as in Fig. 6. The resultant membership functions allow the photovoltaic data to be fuzzified then de-fuzzified for an output value based on various weighting of the system. In the paper the output function was related to PWM motor drivers and as such would be synonymous with the autonomous device navigating using photovoltaic however it must be noted that with the ease of adjustment in any of the membership functions many varying behaviours may be attained, dependent only on the user's requirements.

## VI. Assumptions for Weighting Sensors in Fuzzy System

### A. *Upper level sensors*

These sensors have two tasks, being to determine the ambient light level in conjunction with the incident light meter located at the apex of the array. The "incident light meter" is not specifically referred to within this paper however provides an active light monitoring and control to all array sensors. The upper level sensors measure that light in the level of the spectrum from midway (green) to the lower range (blue) infringing marginally into the ultra violet region. So for testing and evaluation the preliminary assumption is that for the upper level sensors, the brightest illumination in the environment will be the priority.

### B. *Middle level sensors*

These sensors measure light over the whole visible spectrum. The mid sensors, having the whole of the visible spectrum as their source would set of course the brightest zone as priority as unlike the other sensors, have a greater ability to detect shaded areas. Shaded areas of course represent a voltaic decrease or variance in each particular sector and logically either indicate an object of low reflectivity or the entrance to a darker environment within that sector. Shaded areas indoors (photovoltaic decrease), generally would point to an obstacle in close proximity, therefore initial priority would be high.

### C. *Lower level sensors*

Measuring the near-infrared spectrum, the IR sensors will always detect infrared radiation as it is everywhere in the environment however we may assume that a higher level of infrared could be damaging to our mobile robot so from this perspective the lowest IR emission should be more preferable and set initially as the priority low. This statement of course reflects the particular goal programming of the mobile robot and may be opposite when searching for hot spots or fire danger.

Modification of all membership functions may be applied within the rule blocks of the fuzzy system which will adapt the output outcome Fig. 6, in line with user requirement.

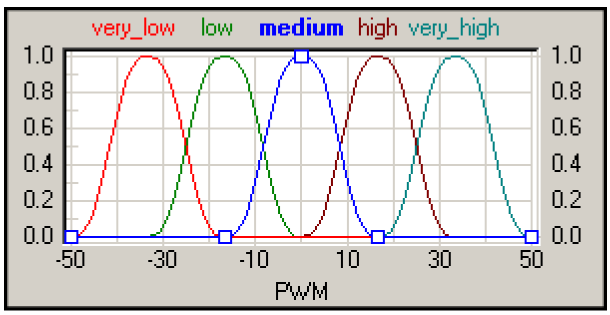


Fig. 6. Module output function.

## VII. Rule Block

De-fuzzification rule blocks consist primarily of if/and/and/then statements followed by a "degree of support", DoS function where either random values or a constant user defined value is assigned to a rule set. For the existing system 135 individual "rules" are developed for each three sensor module of the array Fig. 7.

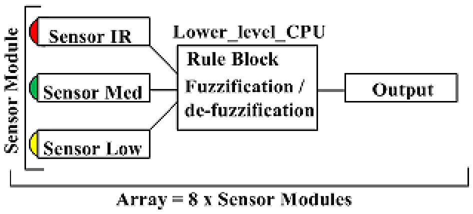


Fig. 7. Function block for single sensor module.

The membership function module as described within this paper is replicated eight times to complete the array in Fig. 1. Three possible scenarios are denoted in Table I, as a simplified example of the associated" if/and/and/then" statements from the rule block. In the first example, infrared radiation is high, mid spectrum light is medium and low spectrum light is high therefore according to the chosen priorities of the system this equates to a danger zone and should be avoided, producing a "then" status of negative 50 PWM which in essence is a reversal at high speed of the motors. Similarly in example two, all sensors indicating "high" likely would denote that the mobile robot has come into contact with direct sunlight and according to its DoS it must stop to recharge its solar batteries, therefore PWM = 0 (stop). The third example simply indicates that all sensors are medium and so we should proceed cautiously, half speed. These are verbal examples only to give a generalized idea.

TABLE I. FUNCTION BLOCK FOR SINGLE SENSOR MODULE.

| if | and | and | op | then |
|---|---|---|---|---|
| IR_High | Mid_S_Med | Low_S_High | => | PWM = -50 |
| IR_High | Mid_S_High | Low_S_High | => | PWM = 0 |
| IR_Low | Mid_S_Med | Low_S_Med | => | PWM = +25 |

The resultant 8 output blocks becomes individual responses which may be directed to a logic array for direct response to drive systems or to an MCU embedded algorithm for further analysis. Further, the generated eight outputs may also become input membership function blocks for additional fuzzification/defuzzification providing perhaps only 2 outputs for "H-Bridge" motor control.

## VIII. CONCLUSIONS

The proposed methodology minimizes the memory usage in the lower processor of the robot and utilizes only minimal resources. A minimum number of instructions are required within the fuzzy logic rule block and those instructions are easily manipulated to gauge their effectiveness. Results at this stage of the research are primarily visual due to the nature of dynamic obstacle avoidance however the generic nature and the capability to utilize any number or variety of sensors, combined with the simplified weighting system of the membership functions are proving a robust system with ample room for modification and improvement. The future aim is to achieve not only an efficient system of obstacle avoidance but also with priority given to the storage and utilization of the photovoltaic data collected and its' possible use.

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