Fuzzy Logic Intelligent system for an Automatic medical waste segregation

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Abstract. AUTOM is an acronym given to a commercially designed automatic waste disposal master tool for medical laboratories and clinical waste separation through this research study. In this research, a fuzzy rule-based system is designed which can segregate 24 different waste types which are selected from 8 more common medical waste groups. In the proposed system, after capturing each frame some pre-processing operations are done, features are extracted, fuzzy parameters, fuzzy terms and fuzzy rules are determined and finally a rule with a maximum certification degree is fired. In the designed fuzzy rule-based system 24 roles corresponding to the 24 detectable objects exist, 14 fuzzy parameters are defined, and a maximum of 3 fuzzy terms for each fuzzy parameter have been considered. The system is flexible on different light conditions, view degree of the camera, and 360˚ object rotation. Our experiments on a real environment and using both new and used wastes have shown up to 94% of better performance of the system developed.

Key words: Automation, Clinical waste segregation, Fuzzy intelligent system, Fuzzy rule-based system, Hazardous waste.

1. Introduction

Large hospitals, according to studies, generate 2.0 kg of garbage per bed every day. 0.5 kg of this can be classified as biological risk waste. Injuries from infected sharps and Hepatitis B, C, and HIV infection can occur if hospital trash is not handled appropriately and thrown off [1]. Burning, chlorination, baking soda, packaging, and UV irradiation are all options for treating this massive level of healthcare waste. Automatic trash classification is essential for all these systems.

The unit operations' optimal values of the output indicate that the integrated biological system in this study is ideal for the rapid growth of bacteria [2]. Massive plastics are mainly utilized to produce bottles, packaging, and bags. Intelligent sorting systems, based on image recognition and classification, have been developed [1]: (1) shape recognition[3], (2) linear discriminate analysis (LDA) applied to gray level histogram on images Error! Reference source not found., (3) using other physical properties such as density, near-infrared spectroscopy (NIR) Error! Reference source not found., or (4) studying the difference of in the transmittance (or absorption) between different plastics to an infrared InGaAsP laser [4]. Usually, the recycling process development investigation is focused on automatic sorting for massive plastics. Several reviews can be found for this issue. Further literature studies have proved the vulnerability of...
waste disposal. Construction of buildings, waste disposal, and other practices have all led to the contamination of Sungai Kerayong. Most of the sediments that emerged from mines effluent, domestic waste, and soil erosion are raising the value in suspended solids [8].

This paper uses a diary methodology to study the impacts of air pollution ratings on employees’ routine physical resources and behaviour. According to multilevel data obtained over 2 weeks from 155 employees in metropolitan China, ratings of air pollution severity deplete workers' self-control resources [10]. Hospitals are currently looking for disposable pharmaceutical products that can be disinfected and recycled to cut patient costs by 40% to 60% [11]. The algorithm, and a parallel version, are detailed in the Fuzzy module of the free computer algebra software Sage Math. Solve Fuzzy System, or SFS, is an efficient technique for finding actual solutions of computation systems with symmetrical L-R fuzzy numbers as coefficients and constrained support and objective distribution functions are L and R. The real solutions of a system can be derived from the solutions of some polynomial systems with real coefficients [12]. It presented a numerical approach for generating this index as well as a way of computing them. When comparing two fuzzy sets, the comparison should be available to respond where the order of the fuzzy sets cannot be identified, and hence their order is ignored. Two crisp relations with shared factors over a collection of fuzzy sets with trapezoidal classifiers were generated using the probability-based preferred intensity index. There exist a stringent order relation and the rest is a relation that reflects order indifference, based on the parameter value [13].

Environmental data can be organised and analysed using relational databases and GIS, the Geographical Information System. The coastal resource information system for change of climate has been built to be easy and versatile. Variation in the degree of information given for each attribute and country is possible thanks to the database structure [14]. A distance in between the sum of upper semicontinuous fuzzy subsets of a finite-dimensional Euclidean space but also its T-convex hull has an upper limitation. As a result of this discovery, we describe an iterative approach for generating a T-convex hull of an upper semicontinuous fuzzy set. As an extension of the conclusions about t-norm fuzzy sets, we offer an example from a game-theoretic situation where t-norm fuzzy sets were utilised to handle uncertainty in a recurring two-player game [15]. In this research, a fuzzy rule-based system is introduced. The input of the system is a 2D RGB online captured frame and the output of the system is an array that shows the certainty factor of belonging of each object in the frame to a waste type and a waste class. The considered classes and subclasses in this project include Microbiological Waste (Ampoules, PCR Tubes, Petri dishes, Sample Tubes), Non-Recyclable (Ceramic Mugs, Feeding Bottles, Food Containers), Pathological Waste (Bandage Spool, Bottles, Cotton Balls, Gauze Pads), Pharmaceutical Waste (Inhalers, Medicine Bottles, Pipettes, Vials), Recyclable (Aerosol Cans, Forks, Juice Bottles, Mineral Water, Paper Cups), Sharps (Razor Blades, Scalpel Blades, Scalpels, Syringes). To classify the waste types, a fuzzy intelligent system is utilized including 24 rules and several fuzzy terms which are based on the extracted features from the input frame.

2. Intelligent Model Development

A flowchart of the method which is followed in this research to segregate the wastes is shown in Figure 1. Generally, this process is combined with two main steps; first, some pre-processing operations are applied to the image to enhance image quality, separate objects, and eliminate the unwanted area of the image. In the rest of this section, after a brief view of the utilized fuzzy system, our method is described in detail.

2.1 Fuzzy Intelligent System

Fuzzy logic is a multi-valued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, etc. Notions like rather warm or pretty cold can be formulated mathematically and algorithmically processed. In this way, an attempt is made to apply a more human-like way of thinking in the programming of computers (“soft” computing). Fuzzy logic systems address the imprecision of the input and output
variables by defining fuzzy numbers and fuzzy sets that can be expressed in linguistic variables (e.g. small, medium, and large).

A fuzzy rule-based approach to modelling is based on verbally formulated rules overlapped throughout the parameter space. They use numerical interpolation to handle complex non-linear relationships. Many existing systems need the rules to be formulated by an expert. Fuzzy rules are linguistic IF-THEN- constructions that have the general form "IF A THEN B" where A and B are (collections of) propositions containing linguistic variables. A is called the premise and B is the consequence of the rule. In effect, the use of linguistic variables and fuzzy IF-THEN- rules exploits the tolerance for imprecision and uncertainty. In this respect, fuzzy logic mimics the crucial ability of the human mind to summarize data and focus on decision-relevant information.

For incorporating membership values representing ambiguous knowledge, fuzzy logic offers a variety of appealing aggregation operands. In functional form, a fuzzy set's membership function can be a normal distribution function, a triangular function, a trapezoidal-shaped function, and so on.

Because specifying the control rules in fuzzy systems is frequently quicker and better, needing fewer rules, the systems run faster than traditional systems. Fuzzy systems are frequently tractable, robust, and reduced.

The following is the method for achieving the fuzzy output of such an expert knowledge base [9].

The shooting level of the $i$th rule is evaluated by:

$$ A_i(x_0) \times B_i(y_0) $$

The output of the $i$th rule is calculated by:

$$ C_i(w) = A_i(x_0) \times B_i(y_0) \rightarrow C_i(w) \text{ for all } w \in W $$

The overall system output, $C$, is obtained from the individual rule outputs $C_i$ by:

$$ C(w) = \text{Agg}\{C_1, ..., C_n\} \text{ for all } w \in W $$

2.2 Waste Segregation Method

The model development has followed the flow chart as presented in Figure 1. Applying some pre-processing operations on the captured image. Each process and the effect of its application on the image is illustrated in Error! Reference source not found.. The steps involved in this method are explained below.

2.2.1 Normalizing RGB image and setting light coefficients.

To reduce the effect of different light conditions in the image capturing process, triple RGB elements are normalized. First, the image is binaries. The average of each R, G, and B element in the background pixels (In the binaries image pixels which are detected as non-object pixels) is calculated. The average of all background pixels is calculated. Finally based on the difference of average of each element and calculated total average, corresponding values are updated. Sometimes based on the light condition, the range of intensity values of different pixels (including the ones that belong to the various kinds of wastes and background) is too limited, so their separation is not possible. To solve this problem, this range should get widen. This process can be applied in two steps. First when the final binary image is extracted. (Extraction binary image is one of the most critical steps. By this process, object areas in the image are separated from background pixels). Second in decision making and while intensity is used as a feature to detect the waste type. In both steps based on the range of the average intensity values in background and object Gray-scale pixels, a coefficient is defined and applied to the corresponding intensity values.
2.2.2 Converting RGB image to Gray-Scale image

2.2.3 Building binary image

2.2.4 Releasing unwanted borders of the binary image
Because of the inaccurate view of the camera, usually, there is an unwanted light border in the captured image as the image object. Thus, the border should be removed before classification. This process is done by sweeping the image on each side. Each vertical and horizontal line in which all of its pixels are detected as non-background pixels is removed from the image.

2.2.5 Applying noise reduction on the binary image

![Flowchart](image.png)

**Figure 1.** Fuzzy Medical Waste Segregation Flowchart
2.2.6 Segmentation and labelling existing objects
The labelling operator is applied, and objects are counted in the binary image. In the next step, small portions are ignored. To do so, several pixels of that section is counted and is compared with a threshold value. The threshold is calculated based on the size of the corresponding image.

2.2.7 Separating overlapped objects
After applying morphological operations on each object and separating different parts of results, they are compared with the original binary image, and overlapped objects are separated.

2.2.8 Finding the corners of objects and
2.2.9 Rotating each object to its horizontal position.

2.3 Extracting proper features for each object from the corresponding captured image
Classification is done based on the information achieved from the captured image. All the extracted information from the image cannot be investigated for classification and several more informative features should be selected. The utilized features or a combination of them should be able to distinguish objects from each other.

Since the designed classification is not a history-based method, it only uses features extracted from the current capture frame. The captured image is a 2D colour image. Therefore, only the features are accountable which are extracted from spatial information of each pixel or each object of this image. From all features, geometric features like length, width, the ratio of length on width, diameter, object geometric shape, and so on are more effective in this project. They are accountable because of their independence to the light and environment condition and similarity of different objects which are categorized as a waste type. RGB colour information is less utilized because of the light condition, proximity of camera and objects, and light effect on the colour and intensity of captured object. HSI colour model which is used in these kinds of projects is investigated but because of the above reasons, they are utilized less. The final utilized features include the following:

- How much the object looks like a square?
\[ S_i = \min \left\{ \frac{1 - \delta_{h_i}}{l_i}, \frac{1 - \delta_{l_i}}{h_i} \right\} \times \beta \]  

(4)

Where \( \delta \) stands to \( i^{th} \) object \( \delta_{h_i} \) is the standard deviation of the height of different parts of an object. \( \delta_{l_i} \) is the standard deviation of the length of different parts of the object. \( l_i \) and \( h_i \) refer to the mean of length and height of different parts of the object. And \( \beta \) is a coefficient that is set to 0.8 for small objects and 1 for big objects.

- The ratio of max length to a max height of the object.
- The ratio of max length on mode height of the object.
- The ratio of waste’s Length on its mode Height (Height with most frequent)
- The ratio of the height of the object to the height of the image.
- The ratio of the length of the object to the length of the image.
- How many degrees of having two lumps.
- Distance between two lumps on the object
- HSI color model (Hue, Saturation, Intensity) and mean of each element all over the object.
- How much the object looks like a trapezium?
- How many degrees of having two height levels.
- How many degrees of having a hole inside the object.
- How much the object looks like a circle?

\[ C_i = \left( \frac{1 - C_{i_r}}{C_{i_r} + N_{i_r}} \right) + 2 \times \text{Ratio}_r \]  

\[ \text{Ratio}_r = \min \left\{ \frac{1 - \left| 2 \times r - h_i \right|}{2 \times r}, \frac{1 - \left| 2 \times r - l_i \right|}{2 \times r} \right\} \]  

(5)

\( r \) increases step by step from zero to whenever the number of pixels at radius \( r \) which are belonged to the object, \( C_{i_r} \), be less than the pixels which do not belong, \( N_{i_r} \).

How much the object looks white?

\[ W_i = \frac{\text{mean}\{R, G, B\}}{\text{mean}(\{|R, G, B| - \text{mean}\{R, G, B\}|)})} \]  

(6)

where R, G, B refer to an average value of red, green, and blue values respectively of all object pixels.

A ratio of mean I (Intensity) on mean H (Hue).
- Size of the object.

2.4 Determination of fuzzy parameters

Extracted fuzzy parameters and corresponding fuzzy terms are listed in Table .

2.5 Definition of fuzzy terms

In this project, many fuzzy terms are defined. This work is done because of two reasons. Firstly, there are 24 waste types and classes. Classification of this number of waste types is only possible using a lot number of rules and to distinct each rule from the others lots of fuzzy terms are required.

Secondly, each fuzzy term is used in different rules, and the definition of computational fuzzy terms instead of computing them is preferable.

Generally, this system is designed based on the definition of many fuzzy terms to increase the power of its ability to classify waste types that are coming from various numbers of fuzzy terms.
2.6 Initializing fuzzy membership function parameters

One of the most effective of the performance of the system is that values are assigned to different parameters of fuzzy membership functions. Considering the nature of the utilized fuzzy terms in this project, three types of fuzzy membership functions are used. Advancing and Dropping Linear Fuzzy Membership Functions, Triangular Fuzzy Membership Functions, and Trapezoid shape Fuzzy Membership Functions. Linear FMF's have two parameters, Triangular FMF's have three parameters, and finally, Trapezium FMF's have four parameters.

According to a large number of utilized fuzzy terms, several fuzzy parameters which should be assigned by proper values are a lot. In this project, values are assigned to the parameters experimentally. Based on the nature of the corresponding fuzzy term, an initial set of values are selected. Fuzzy term values are calculated. Fuzzy rules are fired and based on the accuracy of detected objects these values are adapted.

| No. | Fuzzy Parameters and fuzzy sets                                      |
|-----|---------------------------------------------------------------------|
| 1.  | The ratio of max length on the max height of the object (4 sets)    |
| 2.  | The ratio of max length on mode height of the object (1 set)        |
| 3.  | Degree of having two lumps (1 set)                                  |
| 4.  | Size of the object (4 sets)                                         |
| 5.  | How much the object looks like a square? (2 sets)                   |
| 6.  | How much the object looks like a trapezium? (2 sets)                |
| 7.  | How much the object looks like a circle? (3 sets)                   |
| 8.  | Intensity on Hue (2 sets)                                           |
| 9.  | Hue (2 sets)                                                        |
| 10. | Saturation (2 sets)                                                 |
| 11. | Mean value of white color (1 set)                                  |
| 12. | The ratio of the height of the object on the height of the image (1 set) |
| 13. | The ratio of the length of the object on the length of the image (1 set) |
| 14. | Degree of having two height levels (1 set)                          |

2.7 Definition of fuzzy rules

The decision-maker or classifier of the system is an intelligent system including some rules. The rules are designed based on the fuzzy terms and membership degree that each fuzzy parameter has.

The twenty-four (24) rules are designed for the system. It means for each waste type, a separate rule is designed. Each of these rules calculates the membership degree of the mentioned object in the corresponding class of waste type. So the output of rules is 24-degree values. Finally, the object is classified as a waste type with a maximum value between all rules.

By using a more comprehensive rule more than a waste type can be classified. Using this method and by reducing the number of rules, the speed of the system increases. The system did not follow this method so for each waste type a separate rule exists.

This decision was made due to the low importance of execution time in this project compared to its accuracy. In addition, processing of 24 rules is not time-consumer among intelligent systems with tens of thousands of rules. Furthermore, the extension of the system to classify more waste types in the future is much easier.
3. Results and Discussion
The sample output from the AUTOM system is presented in Figure 3. As it is clear in this figure, all the samples are classified correctly. In addition, Table 2 shows the percentage of correct detection times for each waste type separately.

**TABLE 2. ACCURACY OF DIFFERENT WASTE TYPES**

| Waste Type          | Accuracy | Waste Type          | Accuracy |
|---------------------|----------|---------------------|----------|
| Ampoules            | 92%      | PCR Tubes           | 87%      |
| Petridishes         | 100%     | Sample Tubes        | 85.5%    |
| Ceramic Mugs        | 96.2%    | Feeding Bottles     | 86.4%    |
| Food Containers     | 100%     | Bandage Spool       | 94%      |
| Bottles             | 94.3%    | Cotton Balls        | 97%      |
| Gauze Pads          | 100%     | Inhalers            | 96%      |
| Medicine Bottles    | 94.3%    | Pipettes            | 93.45%   |
| Vials               | 95.4%    | Aerosol Cans        | 88%      |
| Forks               | 96.5%    | Juice Bottles       | 87%      |
| Mineral Water       | 87.5%    | Paper Cups          | 91.5%    |
| Razor Blades        | 100%     | Scalpel Blades      | 97.2%    |
| Scalpels            | 98.2%    | Syringes            | 100%     |

Average 94.06%

**Figure 3.** Output from the AUTOM fuzzy model
In some items such as Mineral Water whose shape is very near to Feeding Bottles and Juice Bottles or Aerosol Cans which do not follow a specific shape in different samples, the results are worse. Briefly average of the accuracy of the system is more than 94% which is acceptable.

- High accuracy of detection in the proposed method.
- There is no limitation on the number of waste types. By adding a new rule, a new waste type is detectable.
- The decision method is conceptual and understandable for human beings.
- Unlike methods such as ANN, detection of a big number of waste types is possible.
- It is not required to provide training samples.
- By using the fuzzy concept, the separation of similar objects is more meaningful.
- The transparency of the system is high. It is possible to explain why and how a decision has been made.
- Technical Challenges and Risks
  - The high number of effective parameters. (Each fuzzy membership function has at least two parameters.)
  - Adding a new type and new rule affects the other performances.
  - Fuzzy parameters should be set manually.
  - The unmanageable effect of environmental conditions on the achieved accuracy.
  - Calculation of fuzzy membership values and sequential investigation of rules is time-consuming.

Like all systems, the proposed system in this research has advantages and some drawbacks. The selected number of these items are listed above respectively as an outcome of this study. The technical preferences and advantages of the new prototype developed will ensure for better waste segregation system than the existing method in practice.

4. Conclusions
In this research, a rule-based waste segregation system was introduced. The main contribution of the system was classifying 24 predefined waste types from 8 medical waste classes. Many fuzzy terms have been utilized to cover all similar states between these waste types and a fuzzy rule-based system is used to calculate the certainty factor of belonging each captured image object to one waste type. This system was run and tested in a real environment and using real waste samples. The results show that on different light conditions, different view degrees of the camera, and different positions of the objects, this system is capable to segregate objects. The technology is adaptable to a variety of lighting situations, camera view angles, and 360-degree object rotation. The tests in a real environment with both new and used wastes demonstrate that the system performs at a rate of 94%-100% for shaped wastes, from 85-93% accuracy for shining objects and up to 97% for shapeless objects.

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