Fuzzy Set Classifier for Waste Classification Tracking

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Abstract

We have developed an expert system based on fuzzy logic theory to fuse the data from multiple sensors and make classification decisions for objects in a waste reprocessing stream. Fuzzy set theory has been applied in decision and control applications with some success, particularly by the Japanese. We have found that the fuzzy logic system is rather easy to design and train, a feature that can cut development costs considerably. With proper training, the classification accuracy is quite high. We performed several tests sorting radioactive test samples using a gamma spectrometer to compare fuzzy logic to more conventional sorting schemes.

Introduction

The Department of Energy has an urgent need for the development of waste processing and cleanup technologies. Over the past few years, the Advanced Process Technology Program at Lawrence Livermore National Laboratory has been developing robotics and automation technology to support cleanup and reclamation efforts. In the Interactive Controls Laboratory we have developed a sensor-based robot system for material sorting tasks.

Robotic sorting of materials in a waste stream has been largely motivated by the DOE cleanup needs. A large fraction of the buried radioactive waste must be dug up and repackaged because contaminants are leaching into underground water tables. Hazardous waste stored in barrels at local sites must be resorted, according to federal guidelines, into categories of high level, low level, transuranic, and mixed waste, and disposed of accordingly. Certain materials, such as lead and stainless steel, can be reclaimed after being cleaned of radioactive contamination. Low level and mixed radioactive waste must be sorted into categories, such as burnable or vitrifiable, for later volume reduction and storage. Using robots instead of radiation suited workers reduces the exposure risk to humans, and also improves the reliability and speed of operation.

Weapons dismantlement is now an important issue. Technologies need to be developed to handle the waste materials derived from dismantlement. In particular, recycling of depleted uranium alloys has historically not been done, but new federal guidelines will require it. The recycling of alloys U-Ti and U-Ni will require segmentation and tracking in order to prevent cross contamination.

Fuzzy Set Classifier

Unlike a standard industrial assembly line robot application, where parts and manipulation tasks are well defined, waste sorting is an unstructured task, where materials to be manipulated have unknown size, weight, and composition. The materials must be scanned by sensors located upstream and an intelligent robot control system must be able to decide what to do based on the sensory inputs.

We have developed an expert system based on fuzzy logic theory to fuse the data from multiple sensors and make waste material classification decisions¹. Figure 1 shows a block diagram of the robot control system. Sensing instruments include an optical profiler, gamma spectrometer, metal detector, force sensor (for weight), and machine vision system. From these measurements we can infer size, density, metal content, and radiation content, then, using the rule base, determine if the object is lead, steel, plastics and other light materials, or radiation contaminated versions of these. The rule base consists of linguistic inference statements such as, for example:

- (if weight is heavy and size is small then density is high)
- (if density is high and metal content is high then object is lead).

These rules are derived from experience by human operators with the detectors and a set of known test items. These rules can be coded into a computer so long as the computer has an exact definition of terms like "heavy" and "high." As humans, we associate vaguely defined properties with these terms. To employ this same idea of vagueness in a rigorous mathematical context, a theory of fuzzy sets has been developed². Within this theory, a new type of object, called the fuzzy set, is introduced which is a generalization of the ordinary set. Fuzzy set operations, analogous to the logical operations on ordinary sets, are defined accordingly (see Figure 2) and it is then a simple matter to implement a fuzzy logic inference engine on a computer. A fuzzy logic system takes input data from an experiment, applies the rules in its rule base, and comes up with conclusions. The output is a list of possible conclusions along with their degrees of confidence. If a hard decision must be made, as is the case in the waste sorting application (where the robot arm is instructed to place objects in various waste streams) then the conclusion with maximum confidence is taken.

Experimental Results

We performed an experiment using gamma spectrometer data to compare the fuzzy logic inference technique to a detection threshold method in categorizing radiation sources. In this experiment, four spectral bands resolvable by the sodium iodide detector were selected to correspond to strong emission lines of Americium 241 (50-70 kev), Thorium 232 (210-270 kev), Cesium 137 (600-730 kev), and Cobalt 60 (1270-1430 kev), respectively. However, since the emission spectra for these sources overlap, there is a possibility that information concerning the presence of Thorium, for example, is present in the Cesium band, and so on. Therefore, information useful in the categorization of radioisotopes is contained in the pattern of the counts, not just in the counts per individual band. The rules in the fuzzy rule base were set accordingly. For example,

- (if band 4 is high or (band 4 is high and band 2 is high), then source is Cobalt 60).

Results from one test are shown in Figure 3. Here, we tested sample sources located from 80 to 150 mm from the detector, and also made an equal number of tests with no source present. The fuzzy logic system correctly identified the isotopes with 100% accuracy, while the threshold system had only 94% accuracy (one false alarm) with a 200 count threshold, and 72% accuracy (four incorrect classifications and two false alarms) with a 100 count threshold. As the sources are separated from the detector by larger distances the signal becomes weaker, so the sensor and fuzzy logic system begin to fail to detect the radiation. However, even with weak signals, the isotope signature is often still present. We set up the fuzzy logic system to guess the isotope, even if the radiation count was low. At average separations of roughly 300 mm, the threshold system was failing nearly 100% of the time, while the fuzzy classifier was making correct guesses with about 50% accuracy.

Conclusions

We have used fuzzy set theory in the development of an expert system for hazardous waste sorting and classification. The knowledge base for a fuzzy logic system is oriented toward human linguistic thinking, and therefore easy to program by human experts. The system fuses data from multiple sensors to make reliable classification decisions.

Sorting and classification of materials will be a crucial task in the weapons dismantlement process. Special nuclear materials resulting from dismantlement need to be identified and tracked by an automated system to prevent unauthorized diversion from the recycle stream. The depleted uranium alloys should be segmented from each other to prevent cross-contamination. We see this as a future growth area for multisensor fusion and fuzzy classification systems such as the one we have developed.

References

1. A. Dougan, et. al, "Demonstration of Automated Robotic Workcell for Hazardous Waste Characterization," 1993 IEEE International Conference on Robotics and Automation (submitted).
2. L. A. Zadeh, "Fuzzy Sets," Information and Control, **8**, 338-353, (1965).

Figure 1. Block diagram of the robot control system. Input signals from various sensors are processed to determine the robot's next course of action. The fuzzy classifier categorizes the incoming material and provides this information to the robot driver.

Figure 2. Operations on fuzzy sets. x is a measured quantity. The membership function $m_\alpha(x)$ defines the boundaries of the fuzzy set α . Membership in ordinary sets take on values in $\{0,1\}$ whereas fuzzy sets allow membership in the continuous range $[0,1]$.

Am	1789	-50	-43	4	1 μ Cl sample
bg	10	24	100	2	
Cs	15	5	2020	23	1 μ Cl sample
bg	15	-48	33	-16	
Am	1719	48	20	6	
bg	6	66	23	-21	
Co	24	112	3	-16	1 μ Cl sample
bg	11	58	3	-16	
Am	2043	28	-88	-24	smoke detector
bg	24	-16	11	-2	
Th	-243	1298	-377	-37	Coleman lantern mantels
bg	17	181	-59	7	
Th	88	120	-368	40	welding rods (under box)
Th	303	1187	-1699	-52	welding rods (on top of box)
bg	-6	72	2	-9	
Th	-520	13309	-7058	-146	lens
Th	-891	3111	-1070	86	mantels
Co	-16	120	-26	953	1 μ Cl sample

155 mm

80 mm

• Accuracy (this sample)

Fuzzy logic: 100%
 200 count threshold: 94%
 100 count threshold: 72%

Figure 3. Results from an isotope identification experiment. The highlighted area indicates where the threshold algorithm with a 100 count threshold produces a false alarm (background misidentified as Thorium 232). The fuzzy logic system, relying more on pattern recognition, correctly indicates this as background radiation, i.e., no source present. Some "counts" are negative because of data preconditioning and normalization.

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