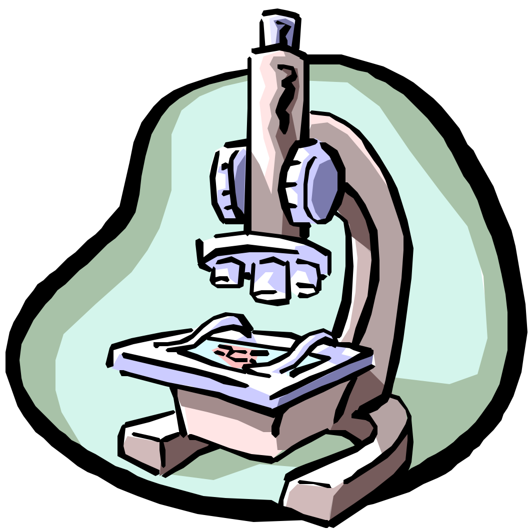
Application of a Back-Propagation Algorithm for Feature Classification of Steel Alloys

"Automated Microstructure Characterization using Machine Learning"



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1.0 Abstract

Quantitative Metallography is an interesting idea that has been, primarily, performed manually through image analysis software and experienced visual determination. I propose a Neural Network algorithm for classification of a metals and structure from an optical-microscope sourced image.

I have discussed this idea with Dr. Alan Anderson, Research Scientist, of the Materials and Metallurgical Engineering Department. There is a need for a research project to be designed, planned and implemented, which involves the automatic recognition of microstructures, using Microscopy tools and advanced computer science techniques, such as image processing, feature determination and extraction and a machine-learning-based classification system, such as a Neural Network or other type of classifier.

Project Timeline

I. Identify features needed for classification of microstructures.
II. Create database for features, storing relevant attributes.
III. Research ANN algorithm or algorithms needed for optimal classification.

IV. Design and implement edge detection and other algorithms for feature extraction from image.
V. Implement ANN.
VI. Testing of accuracy.
VII. Authorship of Paper and Presentation.
VIII. Presentation in Fall 2003.

2.0 Introduction

The disciplines of Image Processing and Neural Networks can be applied to many fields of engineering for the automatic classification of the properties of microstructures of metals.

3.0 Materials Engineering Introduction

Grain boundaries/Size

The grain size is a standard measurement described by the ASTM (American Society for Testing of Materials). This is typically based on the magnification of the image and the number of grains per square inch.

Orientation

Shape

Shape is a very important factor in both qualitative and quantitative analysis of the microstructure of materials. It is also very difficult to evaluate. In the simple case, we attempt to model the exact shape of the image by using a known shape.

There are 3 cases

Fuzzy logic for Shape Analysis?

Elongation	**Irregularity**	**Analyzed shape**
Low	Low	Circular

Low	High	Compact, irregular
High	Low	Long and smooth
High	High	Long and irregular

Particles with elongation less than 0.2 or greater than 0.9 are not thin.
Particles with elongation between 0.4 than 0.7 are thin.
The rest of the particles are partially thin.

Fuzzy logic allows us to measure how near a particle is to regular. We can have regular, irregular, almost regular, weakly regular, etc.

Calculating Percentage of a Material in a Given Image

This is a measure of the grain size. The volume of a grain in a metal is an important measure.

4.0 Various Micrographs and Properties

4.1 Annealed Microstructures

The following micrographs are examples of annealed microstructures. They are all treated and prepared in the same way, and the micrographs are at nearly the same magnification. The significant difference is the chemical composition, specifically the amount of carbon present.

The thermal treatment is

1) Heat to 950 C
2) Air-cool

Metallographic preparation is

1) Mounted in Bakelite
2) Polished using 240 followed by 400, followed by 600 grit silicon carbide paper cooled in water during polishing
3) Finish polishing using 1, followed by 0.3 micron-meter alumina polishing power in water.
4) Etched form 10 t0 20 seconds in Nital (97% Ethanol + 3% Concentrated Nitric Acid)
5) Photographed using white light -- no filters.

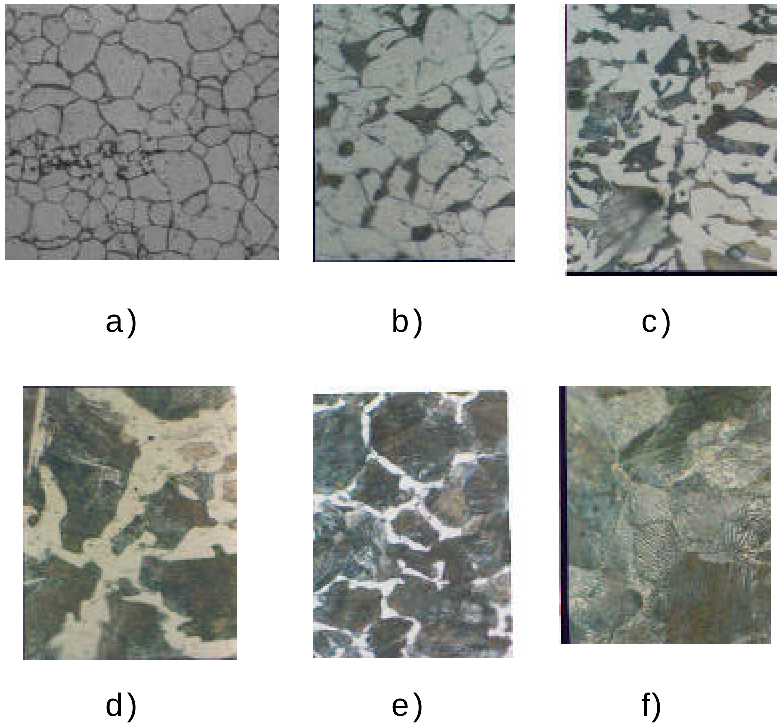
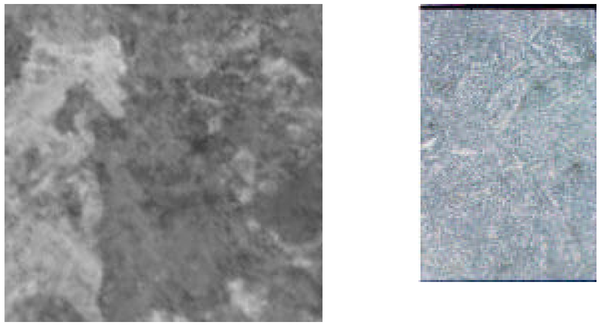


Figure 1. Examples of annealed microstructures: a) pure iron, b) 1010 steel, c) 1035 steel, d) 1045 steel, e) 1070 steel, f) 1.4 wt% carbon steel.

4.2 Quenched Microstructures

The following micrographs are examples of quenched microstructures. Typically they are tempered also to remove residual stresses.

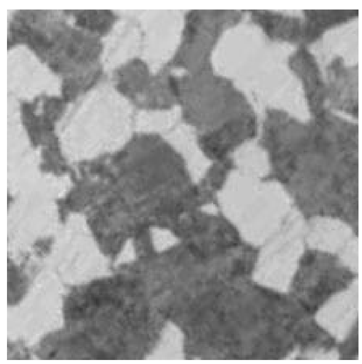
4.3 Equilibrium Microstructures



a) b)

Figure 2. Examples of quenched structures: a) 1045 steel from heat-treated crankshaft, b) 1045 steel quenched and

The following is an example of an equilibrium microstructure formed during slow cooling of a 1045 steel.



a)

Figure 3. Example of an equilibrium microstructure.

5.0 Machine Vision, Image Processing and Analysis

Edge Detection and Boundary Determination

We note that there must be a method for discovering patterns in the images because of the need to extract a feature set to use for a neural network. This involves knowledge of the structures of metals and the physical properties that are affected by etching, polishing, and thermal processing. In order to attempt to discover patterns in the images, we apply several techniques for analysis.

Power Spectrum

The power spectrum of an signal describes the energy vs. frequency of the signal. In a 2-D image, this is a measure of the intensities and their relative frequency in an image.

Skeletonization

After edge detection and thresholding on a specific image has occurred, we need to

An example of image processing on an alloy:
1)

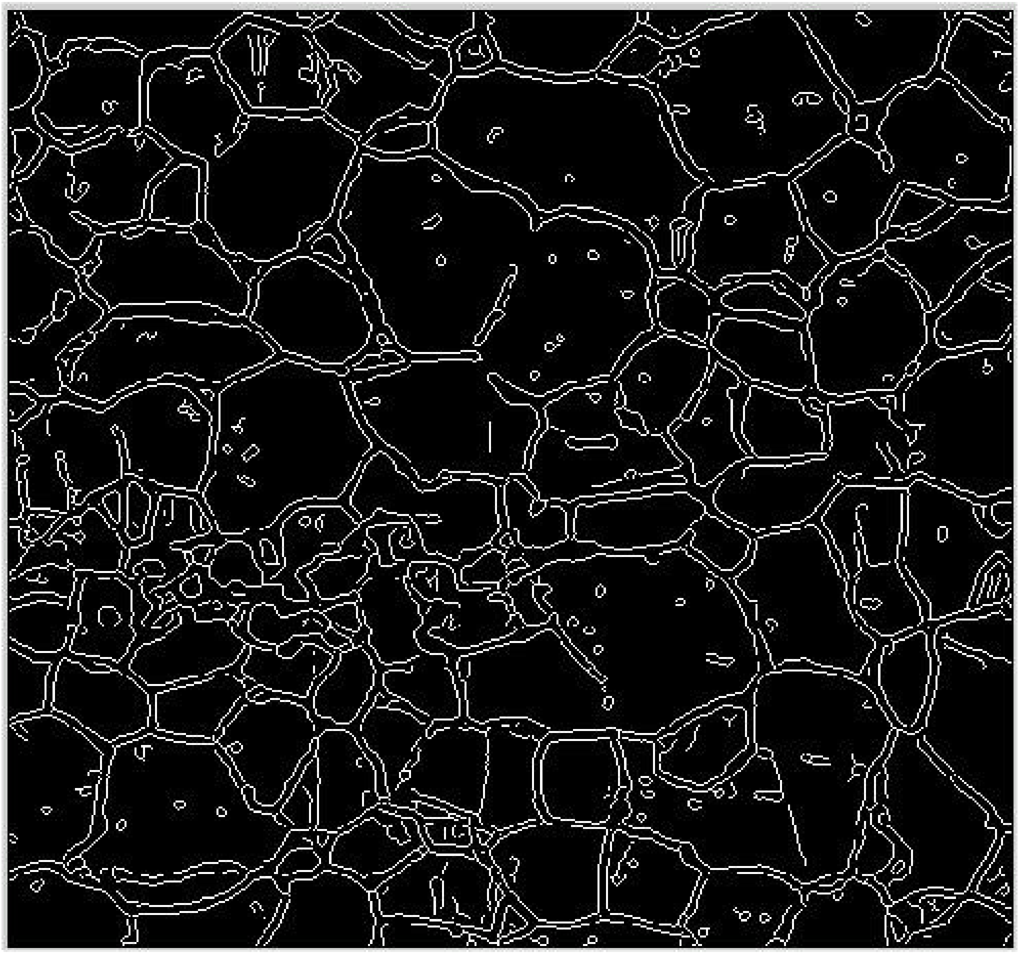


Figure 4, Edge Detected, Thresholded image of Pure Iron from Figure 1

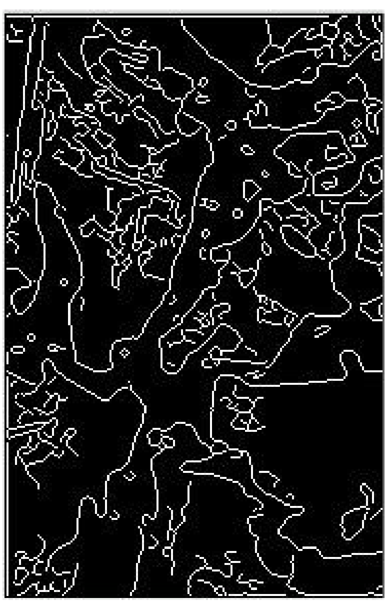


Figure 5, Edge Detection, Thresholded image (1045 steel, figure 1.d), using the Canny

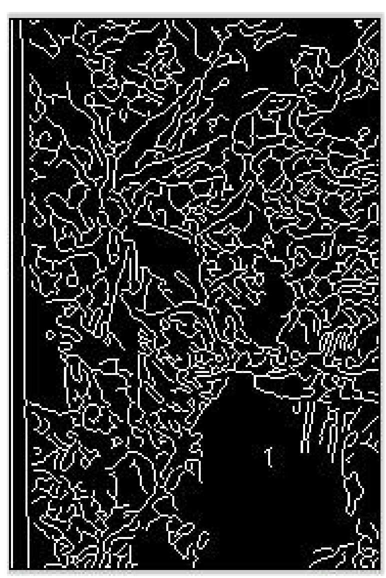


Figure 6, Edge detected, thresholded image of figure 1.f

6.0 Neural Networks

Neural Networks lend themselves to Machine Vision problems because of their ability to generalize and classify unknown data, given a properly trained network.

6.1 Back Propagation

The back propagation algorithm is a Neural Network that involves training the network until a global minimum for error has occurred. This type of "motion" of convergence to a global minimum of error is referred to as gradient-descent. The back propagation method is a supervised learning method because it performs feedback to a previous layer from the output layer, such as the input layer or hidden layer, to update weights so that we eventually are matching our expected output.

The algorithm consists of two phases: a forward phase and a backward phase. The forward phase consists of applying the input vectors (the training set in the 'training phase', or unknown data in the 'classification phase') to a set of weights, which provide output values. In the backward phase, the output values are compared to the expected values; the error associated with the difference is then propagated back to the internal layers and the weights are adjusted by the equation:

$$d_j = O_j(1-O_j)\sum_{p=1}^{N_p} d_p w_{jp}$$

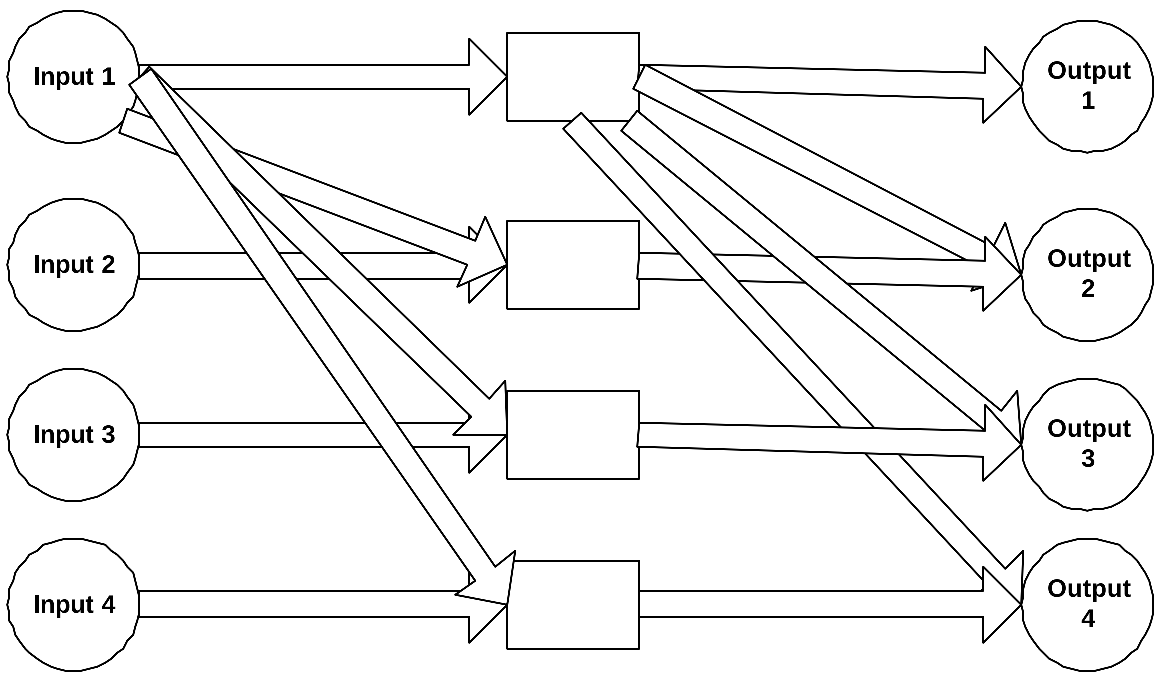
The output layer is updated with a different equation:

$$d_j = (r_j - O_j)O_j(1 - O_j)$$

Where d_j is the

With back propagation, your outputs are the classes you are trying to predict. With respect to microstructures, the distinct "parts" of the image, which are made up of various metals, are the classes.

Back Propagation



6.2 Inputs

This section will discuss the inputs to the Neural Network.

The inputs to the Neural Network are the grain size, orientation, distribution and type of microstructure.

6.3 Outputs

This section will discuss the outputs of the Neural Network.

The outputs of the Neural Network will be makeup of the metal; pearlite, austenite, ferrite, or other structures.

Appendices

A. Glossary

This section lists terminology used and a formal definition of each term. It is by no means a complete description of each process. It has been written for a more general audience.

Alloy: A metal containing multiple constituents.
Annealing: The softening of an alloy by holding it at a particular temperature for a particular period of time. Usually involves the removal of hard structures like martensite.
Artifact: A false microstructural feature that is not an actual characteristic of the specimen; it may be present as a result of improper or inadequate preparation, handling methods, or optical condition for viewing.
Austenite: FCC form of iron. Also, describes the solid solution of carbon in iron.
Back Propagation: A type of Neural Network, which uses feedback, i.e. supervised learning, to perform classification and time series prediction.
Bainite: A slender, needle-like (acicular) microstructure appearing in spring steel strip characterized by toughness and greater ductility than tempered martensite. Bainite is a decomposition product of austenite best developed at interrupted holding temperatures below those forming fine pearlite and above those giving martensite.
Cementite: Intermetallic formed between carbon and iron (Fe_3C)
Etching: Controlled preferential attack on a metal surface for the purpose of revealing structural details.
Eutectic: A eutectic system occurs when a liquid phase transforms directly to a two-phase solid.
Eutectoid: A eutectoid system occurs when a single-phase solid transforms directly to a two-phase solid.
Ferrite: BCC form of pure iron.
Inclusion: Foreign material held mechanically, usually referring to non-metallic particles, such as oxides, sulfides, silicates, etc.
Lamellar: a thin plate or layer.
Martensite: A distinctive needle like structure existing in steel as a transition stage in the transformation of austenite. It is the hardest constituent of steel of

eutectoid composition. It is produced by rapid cooling from quenching temperature and is the chief constituent of hardened carbon tool steels.
Metallography: That branch of science, which relates to the constitution and structure, and their relation to the properties, of metals and alloys.
Micrograph: "Microscopic photograph." Name for an image depicting the microstructure in a material. Typically it is a photograph taken with an optical or electron microscope.
Pearlite: A lamellar structure consisting of alternating layers of pure iron and cementite. Formed only during the slow cooling of an iron-carbon alloy near the eutectic composition.
Peritectic:
Quenching: A cooling technique that causes the temperature of the material to be rapidly decreased. E.g. dropping a red-hot metal into a bucket of water. Cooling rates are very high, but they can be controlled by the thermal conductivity of the quenching material. Common quenching materials are water, salt baths, and oil.
Rolling (Hot or Cold): A deformation process that involves feeding a sheet between two rollers in an attempt to make the sheet thinner.
Stereology: Volume fractions of the phases; (statistical distributions of) size, shape and mutual arrangement of the phases and monocrystalline volume elements (i.e. the grains). [8]
Swabbing: Wiping of the specimen surface with a cotton ball saturated with etchant to simultaneously remove reaction products.
Temper: Re-heating of a metal to reduce internal stresses.
Widmannstatten microstructure:

B. Questions

1. Who will provide the micrographs?

   Dr. Alan Anderson and Dr. Glen Stone of the Material Sciences Department at SDSM&T. This also assumes that the expert knowledge needed will partially come from the Material Sciences Department.

2. Will the micrographs be representative of the data without pre-processing?

Yes. The data will be extracted using optical microscopy techniques. It will be using a small set of the total possible micrographs one could acquire. This is because of the effects of thermal processing, etching,

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