Recording Bioelectromagnetic Fields of Apple Leaves

{Technical report on experiments performed at FiBL Institute in September 2000}

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Introduction

Main motivation for the measurement of bioelectromagnetic (BEM) fields of leaves with Kirlian photography stemmed from three observations:

(a) relatively successful use of Kirlian photography for medical diagnostic purposes, especially as an early warning system for detecting changes in the state of an organism [1,3];
(b) previous research proved that it is possible to detect and find useful information in BEM fields of seeds of plants [6] as well as other non-human objects [4,5,7];
(c) a method of acquiring information on the state of a plant would be very useful.

In cooperation with a team of scientists headed by Dr. Franco Weibel we carried out several experiments at FiBL Institute, Frick, Switzerland in September 2000. The goals of these experiments were to find out whether and how can we measure leaves of plants with Kirlian camera and how can we use Kirlian photographs in regards with the above-mentioned observation (c).

To make Kirlian photographs of BEM fields of leaves we used Kirlian camera developed by Prof. Korotkov from St. Petersburg Technical University [1]. For the analysis of the acquired photographs we used machine learning methods, especially See5 program for generation of decision trees developed by Prof. Quinlan [2].

Leaves recording feasibility study

Our first goal was to find out whether and how could we measure leaves of plants with Kirlian camera. To this end we measured a large number of leaves from different plants (in the end we mainly focused on apple leaves) with various settings for the camera parameters, various methods of positioning the leaf on the electrode and various methods of leaf grounding. Based on this experiments we concluded that it is possible to measure BEM fields of leaves and we developed the following technique to do this:

- leaf is placed between two glass petrium dishes of slightly different size so that the smaller one can be put inside the larger one (with the leaf in between);
- the leaf is usually too large to fit on the electrode and the petrium dish in its entirety, therefore we record the upper part of it and the lower part with the stem is left sticking out of the petrium dishes;
- leaves are recorded face down;
- leaves are sometimes wet, they should be dried using a cloth;
- larger petrium dish is about the size of the camera electrode and is put on the electrode (see Figure 1);
- the grounding is best implemented by attaching a crocodile pin to the stem and the main vein of the leaf that is sticking outside of the petrium dishes, the pin is wired to the ground outlet of the camera;
- to firmly hold the leaf in its place weight of some sort needs to be put on top of the smaller petrium dish – we used a transparent glass filled with a certain amount of water to preserve access to outside light when making an 'area shot';

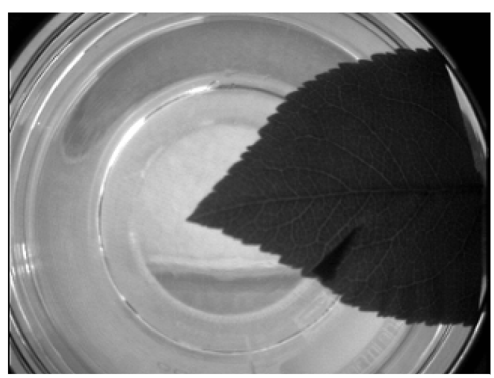

Figure 1: Leaf position on electrode

- to calculate the area of the leaf we make a recording without covering the camera (to prevent outside light), for this we need transparent weight mentioned before;
- camera parameters are Exposure = 1, Range = 2, 3 or 4 (preferably all are used with the same leaf, from smallest to largest to obtain different sets of data);
- sometimes several hours pass between picking and recording the leaves – meanwhile keep them in a plastic bag stored in a cooler box filled with 2-3 cooling elements and a moist sponge for humidity;
- leaves, that are most representative of the tree's condition are those in the middle of the branch, grown in last year;
- electrode and both petrium dishes need to be cleaned often.

Differentiating between sick and healthy trees

After concluding that we can successfully measure apple leaves with our technique we proceeded towards our next goal, that is finding out whether these measurements can be of any value in regards to assessing the state of a plant. For this experiment we needed two trees, preferably of the same sort, of which one was in good and one in bad condition. Luckily, we were able to find two such trees – they were of the same variety (s35), the same age and they are growing only one meter apart.

We picked 31 leaves from each of the two trees – leaves from the middle of last year's branch were selected. They were stored according to our technique in a cooling box and recorded within a few hours after picking. All leaves were handled the same, which means that the same conditions were satisfied for all leaves of both trees. Each leaf was recorded 8 times: 6 recordings at three different range settings (2, 3 and 4) with 2 recordings per range for backup purposes, plus 2 recordings for calculating the area of the leaf. At the end of the recording phase of the experiment we thus constructed a database of 62 samples of leaf BEM field – 31 samples per tree. Each sample consists of 8 abovementioned recordings.

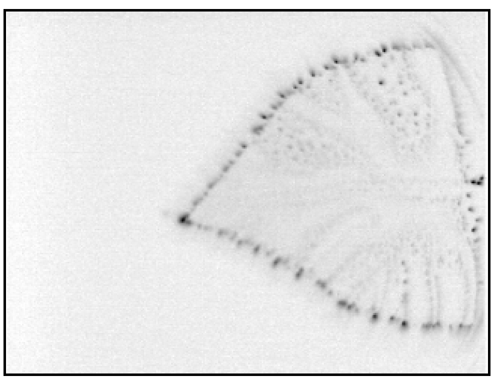

Figure 2a: Healthy leaf

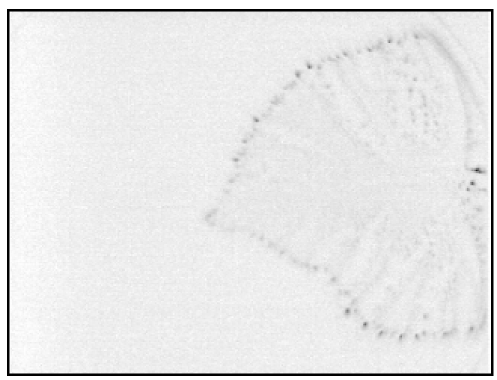

Figure 2b: Sick leaf

Once we had a database ready, we were able to start analysing the images. The idea is to try to find a set of parameters describing the image that can clearly separate sick tree leaves from healthy tree leaves (assuming that the images contain information that makes this differentiation possible). For describing the images with numerical parameters we used GDV Analysis program that is supplied with the camera. This program outputs nine parameters:

1. area of the corona;
2. noise removed;
3. form coefficient;
4. fractal dimension;
5. brightness;
6. brightness deviation;
7. number of fragments;
8. area per fragment;
9. area per fragment deviation.

Parameters 1, 2, 7 and 8 are dependant on the area of the leaf. They were accordingly normalized – area of the leaf was separately calculated.

The analysis itself was performed using See5 program for generation of decision trees. One of the advantages of decision trees is that they straightforwardly point out parameters that most significantly separate different classes – in our case sick tree leaves from the healthy ones.

We tried several different sets of parameters and various images of samples. We obtained best results by using images shot at range 3 and all nine abovementioned image parameters with normalization where needed. Results are presented in Table 1.

Classification error of less than 6% clearly shows that recorded images of BEM fields of leaves contain useful information for assessing the state of the plant. The most important parameter for classification proved to be area per fragment deviation. The generated tree is shown in Figure 3.

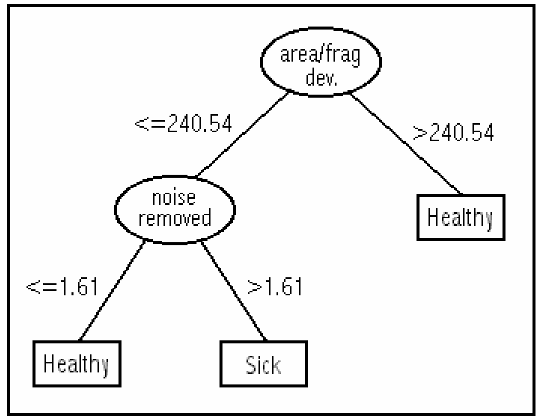

Figure 3: Decision tree for tree state problem

We submitted the generated decision tree to a practical test. A few days after constructing it, we picked 4 more leaves from each of the two trees (8 samples in total). We recorded the BEM fields of these new leaves and used the previously built decision tree to classify them as either sick or healthy. The classification accuracy was 100%, all 8 leaves were classified correctly. This test also somewhat voided the argument that images taken on different days are very dissimilar.

See5 Analysis
Problem: differentiation between sick and healthy leaves (trees)
Classes: Sick, Healthy
Parameters: parameters 1-9, with normalization where needed
Number of cases: 62
Majority class: 50% of cases
Evaluation technique: 10-fold cross validation, 10 repetitions
Classification accuracy: 94.27%
Most important parameter: area per fragment deviation
Classification error if guessing: 50% (based on majority class)
Improvement over guessing: +44.27%
Classification error on training cases: 0%
Additional comments: ----

Table 1: Results of See5 experiment for sick vs. healthy tree problem

Conclusions

As a result of our experiments at FiBL Institute, a reliable method for recording BEM fields of leaves with Kirlian camera was developed and tested in practice. Also, our experiment with sick and healthy apple trees supports our initial hypothesis that BEM fields of leaves contain useful information for assessing the state of a plant. Machine learning techniques proved to be worthwhile in extracting this information.

At the very least we can conclude that there is sense in continuing the research towards developing a method for assessing the state of a plant based on Kirlian photography.

Further work

Plenty of interesting ideas arose during the experiments and subsequent analysis. There are many aspects that can be improved or developed further, most notably:

- recording method could benefit from assuring that lighting conditions are always exactly the same;
- a mixture of other machine learning techniques could be used along with See5;
- further fine tuning of See5 parameters could give even better results (more extracted knowledge);
- more samples would of course greatly improve the quality of the study, however more resources are needed for that;
- a new way of looking at what a sample consists of might be very rewarding: instead of one leaf representing the tree, a set of several leaves could be used;
- new, more specialized, ways of describing the BEM field image with numerical parameters could be developed;
- other ways of exploiting the recorded data might yield further results (currently we use only one image at a time of 6 images that are recorded).

However, most important are ideas regarding the future experiments. We propose to construct a method that would give us a scale, based on some recorded parameters, for evaluating the state of a plant. A carefully devised plan of research should be made to achieve this. We would require several trees that would be in various states (due to illness, bad nutritional conditions or some other factor), which would be under our observation. The trees should be of the same variety, as another experiment we made at FiBL (not described here) suggested that such a scale might differ from variety to variety.

Literature

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