Development of a percussion sensor for wood plague evaluation PERSEFONE

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ABSTRACT

The present article describes and demonstrates an equipment and methodology for assessing the severity and spread of diseases in trees quickly and objectively. The concept is based on a simple principle: a sick tree does not sound the same when it is hit as a healthy one does. Many tree diseases dry the leaves and branches of the trees. If a tree loses water its density is reduced, so the frequency of the sound that it makes when it is hit (acoustic response) will vary. The measurement of said frequency would be the equivalent of measuring humans' body temperature.

Keywords: pine, tree, disease, lecanosticta acicola, acoustic response, natural frequency

1. INTRODUCTION

To be or not to be sick is a binary concept, but it is well known that medical technology goes much further. From simple thermometers to advanced data analysis techniques, it is possible to determine the severity and spread of diseases that affect humans and those that affect animals. However, when diseases affect the plant kingdom, the technologies available are very limited. To date, the most widely used method of determining the health of a tree is still to consider its visual appearance. Over the past years, the *lecanosticta acicola* fungus or "brown band" has been devastating the pine forests of northern Spain. This fungus happens to dry the leaves and branches of trees. The breakthrough character of the present work comes from a basic mechanical principle: If a tree loses water its density is reduced, so the sound that it makes when it is hit, also known as its acoustic response, is higher. If the tree is healthy it will grow, so the sound will be the same or deeper. The human ear cannot distinguish these variations or to quantify them, but a microphone with an acquisition system can.

Fig. 1. Pine twigs infected by *lecanosticta acicola [4]*

After initial proofs of concept on real trunks, the function that relates the frequency increase to the degree of dehydration of the tree, and therefore to the severity of the disease, has been identified. Then, the method has been tested in a real forest of sick pines and compared with visual inspection by an expert. After several months of tests, it has been concluded that the trend of the acoustic method coincides with the visual assessment, with the difference that it is objective, while visual inspection is not. It has even demonstrated to be able to foresee the healing of trees before new leaves start to sprout.

2. STATE OF THE ART

Lecanosticta acicola is the causal agent of a disease called brown band or brown spot [1]. It is original from United States, from where it spread to other continents, arriving to Europe in the 20th century, where it caused important damages in several species of pines [2]. The symptoms are more visible in late spring and early summer, when yellowish bands in needles and reddish mottling appear, maybe accompanied by a droplet of resin [3]. Hence its definition as brown band. Heavily infected pines often show twigs that only carry the current year's needles. Indeed, as the fungus *lecanosticta acicola* does, a lot of diseases provoke a reduction of the trees' mass, by dehydrating the tress or making them lose their foliage. This directly affects their natural vibration modes. In a healthy tree, it can be noticed that the natural frequency of these modes is reduced due to the natural growth. However, when the tree is infected and dries out, this effect is reversed, so the natural frequencies are increased. This growth is linked to the degree of dehydration of the tree, and therefore, to the progression of the disease. Currently, there are devices that either by ultrasound or impact, can determine properties of the wood such as hydration level or the presence of holes made by insects. For both cases, the main drawback is always the same: all the trees are different from each other and, in addition, they are covered with an irregular bark that distorts and attenuates the sound signal. This is the reason why their use is limited to already processed wood (planks) or to complex and slow analyses of individual trees. There is no solution that contemplates the analysis of whole forest.

3. BREAKTHROUGH CHARACTER OF THE PROJECT

With the current wood quality characterization methodologies, it is possible to obtain the speed of sound, and with it, the elastic modulus of the wood, which is linked to its quality, but not to its degree of dehydration. Although the principles used are similar to the characterization system for boards, the proposed sensor responds to a problem common to commercial solutions: all the trees in a forest are different from each other. Both ultrasonic systems and tapping systems require a smooth and homogeneous surface, so real trees such as conifers cannot be treated. Ultrasounds have coupling problems and commercial tapping sensors cannot distinguish which are the natural modes of the tree. The simple fact of hitting the wood repeatedly and recording the sound is a simple idea, already existing in nature (woodpeckers and aye-aye lemurs), but which gives solution to the problem. An acoustic coupling system is not required, since the surface is hit, and the signal is captured acoustically (from the sound emitted into the air). The distinction of the natural modes of the tree is made by measuring several acoustic responses on the same tree and selecting the main frequency peak.

Fig. 2. Aye-aye lemur searching tree worms by tapping the bark

Fig. 3. Field tests in real *pinus radiata* forest

It takes less than 10 seconds to hit about 4 times tree and record its main frequency, so the method can be applied to large areas of forest to assess the severity and spread of a wide range of diseases.

4. PROJECT RESULTS

Laboratory results

The aim of the laboratory scale study has been to simulate and quantify the variation of the natural frequency when the wood suffers from humidity changes. The laboratory test samples have been pine trunks of 230mm diameter (on average) and two different lengths: 0,5m and 1m.

The humidity changes have been forced in a controlled environment. 3 different climatic effects have been simulated:

1) Active exposure to rain effect
2) Active drying (at industrial dryer)
3) Natural evolution indoors, only affected by the humidity of the environment.

Initial measurements of weight, volume and frequency have been done for each sample. Then, these measurements have been periodically repeated as the samples have been exposed to the corresponding climatic effects, to get their evolution. Finally, each sample has been compared with itself in the previous states, stablishing **the experimental relation between the percentage of the decrease in weight of the trunks and the increase of frequency**.

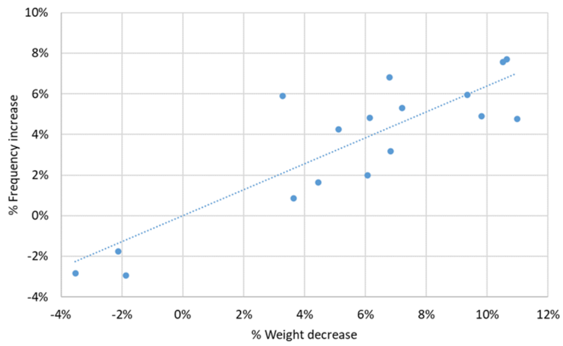

Fig. 4. Relationship between trunks' frequency increase and wight loss

Following these laboratory results, it has been possible to correlate the relationship between the level of dehydration of the sample trunks with the frequencies measured during the hits.

Field tests in a real forest

The last step of the research is the experimental study in the forest, which is pines' natural habitat. As previously appointed, 5 healthy and 5 sick pines have been selected in one forest in Lasao (Basque Country). For each pine, the sound signals emitted when it was repeatedly hit have been transformed into frequency regime, storing their natural frequencies in a database. The process has been repeated for each selected pine in the forest. After periods of several weeks, the measurements have been carried out again, obtaining the evolution of frequency response along time. For each specimen, forestry experts have assessed the evolution of the trees by continuous visual inspection, assigning them a mark according to their condition. The whole testing campaign has taken more than 8 months, which involves the collateral effect of weather and seasons.

It should be noted that once a tree is completely dead, its behaviour becomes unpredictable, changing indistinctly its natural frequency evolutions over the time due to climatologic conditions that it has been exposed to. This fact relies on the huge rates of humidity they would have gained or loosed in the weeks before the tests. All the trees that died during the field tests have been discarded from the experimental procedure. Indeed, in a real scenario they should be cut to avoid accidental falls.

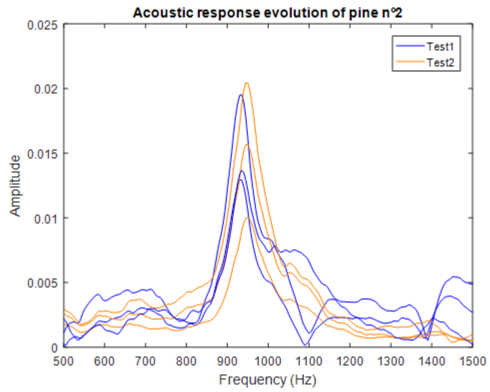

Fig. 5. Frequency drift of a sick specimen after 1 month of disease evolution

Fig. 5 shows an example of the frequency peak measurement after 3 hits. All of them show a very clear peak at 934Hz (blue lines). On month later, the frequency of the present specimen has increased to 948Hz (orange line) which is equivalent to the loss of 2.37% of its mass.

All the live trees have followed a very similar drift in frequency compared to the marks given by the experts' visual assessment. However, many of the tests show a very interesting delay in between results. As show in fig 6, the evolution of frequency drift has been almost the same one as the visual assessment of the tree, but during the last three-month period, there is a clear delay in visual assessment evolution. The frequency evolution measured by the sensor determines that the tree is healing, while the expert considers that it is getting worse. Only during the last month, the expert was able to detect that the tree was effectively healing. This fact demonstrates that **the measurement of the main natural frequency of a tree gives can determine the health of the tree even before it shows visual symptoms** (drying/regeneration of leaves)

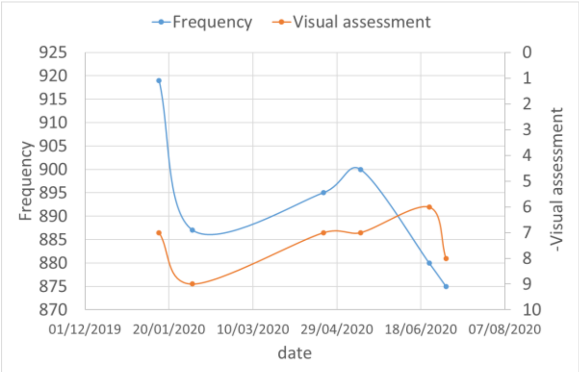

Fig. 5. Evolution in frequency and visual assessment. The secondary axis has been inverted to ease the comprehension of the graph

5. FUTURE PROJECT VISION

5.1. Technology Scaling

Unlike other ATTRACT projects, PERSEFONE needed to perform the conceptual tests on real pine specimens in a real environment, achieving in this way TRL 5. However, to achieve TRL 7, a real prototype should be demonstrated for a whole extension of forest. For said purpose, the following steps should be taken:

- Development of a prototype for rapid sound acquisition and data management

- Measurements of whole forest areas.

- Correlation of results with visual assessment during several months

5.2. Project Synergies and Outreach

Bearing in mind that the goal is to analyse entire forest areas (TRL 7), the prototype must be fast, simple, and autonomous. Accordingly, there needs to be collaboration with companies in the electronics, software, and acoustics sector. Once the first prototype is manufactured, collaboration from a company in the forestry sector will be needed to assess the performance of the device and to obtain feedback from industry.

Some of the companies referring to software and electronics would not only fit in PERSEFONE phase 2, but also in other ATTRACT projects. In this sense, ATTRACT phase 2 could consider a specific cluster for protype development.

Dissemination of results and the interest from potential investors could be channelled through the publication of scientific articles, social networks, press and promotional videos and workshops without compromising the novelty of the research.

5.3. Technology application and demonstration cases

The ability to monitor the health of a whole forest area brings major benefits for various sectors. From a scientific point of view, it can provide a deeper understanding of the development and transmission of diseases on a global scale. For industry, on the one hand it enables smart decisions to be made regarding the cutting down of certain forest areas. On the other hand, depending on how damaged trees are, it can help determine whether the quality of the wood is good enough for it to be used in sectors such as construction. Finally, it can obviously reduce the use of pesticides as they would only be needed in certain areas of the forest. This benefits not only human society but also the local fauna and flora.

5.4. Technology commercialization

With a view to commercializing the technology, once the first prototype is developed and demonstrated, the first step would be to file for an international patent application (PCT) at the Spanish Patent and Trademark Office (Receiving Office). The second step would be to open the product sales to potential clients in the sector of forest care and harvesting.

Due to the good results during the proof of concept, some Spanish forestry companies have shown their interest on the device. Indeed, an immediate application has been proposed and satisfactorily tested to evaluate the effect of different pesticides on sick trees.

5.5. Envisioned risks

The acoustic approach developed in PERSEFONE must face the fact it only has been tested for a given pine specie (*pinus radiata*) and a specific illness (*lecanosticta acicola*). The core risk envisioned for phase 2 is the fact that other tree species and illness could lead to unexpected results that don´t match the reality observed. For example, oak trees can be affected by *erysiphe alphitoides* fungus, but there is no previous data confirming that the present acoustic solution can deal with this kind of disease. Each combination of tree and disease should be previously tested and validated.

5.6. Liaison with Student Teams and Socio-Economic Study

In addition to technology development, the project will be an opportunity for young MSc students and PhD candidates to acquire cutting-edge knowledge. They will learn to co-operate in large highly interdisciplinary project teams with pronounced mutual learning as a foundation for their future careers in this new technology or in similar research fields with comparable scientific complexity. This project also supports 4-6 months internships to promote acquisition of interdisciplinary knowledge, e.g., a mechanical engineer learning about the evolution and spread of tree diseases.

PERSEFONE phase 2 will collaborate with ATTRACT Phase 2 expert-driven socio-economic study taking part in the different activities to be planned such as interviews, open data initiative or technical workshops.

6. ACKNOWLEDGEMENT

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