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# PRINCE OF SONGKLA UNIVERSITY
## FACULTY OF ENGINEERING

**Final Examination**: Semester 1 **Academic Year**: 2011

**Date**: 30 July 2554 **Time**: 09.00-12.00 (3 hours)

**Subject Number**: 241-500 **Room**: A401

**Subject Title**: Research and Development Methodologies

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**This exam paper has 7 pages. It contains exam sheets, 3 questions 20 marks (20%). There are three articles attached with this exam paper, these are:**

Article A : *The Economics of Pricing Radio Spectrum*

Article B : *Tongue Image Classification Based on the TSVM*

Article C : *High-frequency Densitometry – A New Method for The Rapid Evaluation of Wood Density Variations.*

**All materials except a computer are allowed.**

**Instructions to Students:**

- Write your answers in Thai or English.
- Write your name and ID on every page.
- Any unreadable parts will be considered wrong.

**Cheating in this examination**

Highest punishment: Expelled.

Name____________________________ Surname____________________________ ID_____________

1. From three reprinted articles as attached, thoroughly discuss, rationally criticize and justify based on your knowledge and opinion whether they are "true" research publication.

(20 points)

**Article A**

Name________________________Surname________________________ID___________

## Article B

Name______________________Surname______________________ID__________

## Article C

Name______________________Surname______________________ID__________

2. If you interest in doing a research related to **Article B**,

2.1 what will be your research topic and why? (5 points)

2.2 From the research topic you have selected, list all possible *keywords* (in minimum) and pick two most important *keywords* you plan to select for literature review process. Discuss thoroughly how your *keywords* and main *keywords* are derived from. (15 points)

Name________________________Surname__________________________ID____________

3. From the reprinted **Article C**, summarize the research methodology process in procedures and discuss each procedure, given the references that related to each procedure as needed (if available). (10 points)

# THE ECONOMICS OF PRICING RADIO SPECTRUM

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## ABSTRACT

Radio spectrum is a common access resource that can be used to support many different applications. This short paper outlines how economic principles can be applied to arrive at administered incentive prices for radio spectrum. Such prices accord with economic efficiency.

## INTRODUCTION

Radio spectrum is a finite common access non-exhaustible resource that is used in many different applications, supporting both consumption and production activities. Over the last twenty years there has been a marked increase in the use of and demand for radio based services. Within households the use of radio has grown substantially, and the popularity of cellular telephony and wireless communications more generally has led to a substantial increase in the demand for radio spectrum. In this short paper I focus on the key economic factors affecting radio spectrum, that is demand and supply, and assess how these can be used to determine spectrum prices.

Unlike most other inputs used by firms in production, in most countries of the world it is currently not possible to trade radio spectrum frequency rights and obligations (notable exceptions are Australia, Guatemala, New Zealand and the United Kingdom (UK)). Following the passage of the European Union (EU) Regulatory Framework for Electronic Communications in 2002, member states of the EU may permit trading in spectrum (see article 9(3) of the Framework Directive, 2002/21/EC). The UK has introduced legislation permitting trade in radio spectrum (Communications Act 2003, Section 168), and the regulator OFCOM is currently consulting on proposals for spectrum trading.

Where markets are not permitted to operate they are said to be missing or incomplete and it is known in economics that this can give rise to inefficiency, particularly in circumstances where demand exceeds available supply. An obvious remedy to this inefficiency would be to allow trade in radio spectrum, and many practitioners view this as a desirable long-term policy solution.

However, shifting from the current command-and-control management of radio spectrum prevalent in most countries to a regime where spectrum trading occurs should be undertaken gradually. This is partly due to history having locked in many frequency bands to specific uses (e.g. through the international radio regulations managed by the ITU) and thereby limiting the extent to which trading can occur, partly because institutional arrangements to support spectrum trading require time to become established, and partly because there are many potential disruptions that be associated with a big-bang approach.

One gradual approach towards spectrum trading is via administered 'incentive pricing'. The Radiocommunications Agency in the UK (now Ofcom) first introduced incentive pricing for radio spectrum in 1998. Incentive pricing is intended to promote economic efficiency by establishing administered prices that reflect (estimated) opportunity costs of radio spectrum.

In this short paper the economic rationale for 'administered incentive pricing' of radio spectrum is discussed. The structure of the paper is as follows. Section 2 discusses the allocation, assignment and characteristics of radio spectrum. In section 3 economic efficiency is discussed. Section 4 describes the application of the Smith-NERA least-cost-alternative method and its relationship to efficiency. Section 5 concludes.

## ALLOCATION, ASSIGNMENT AND CHARACTERISTICS OF RADIO SPECTRUM

Radio spectrum $S$ is a finite non-exhaustible common access resource extending between the frequencies 9 kHz and 3000 GHz. There are many public and private uses to which radio spectrum can be put, just as land can be used for many different purposes. International coordination has traditionally determined the uses to which radio spectrum is put and how much frequency is allocated to a use.[1] For example, the frequency range 87.5 MHz to 108 MHz is allocated to FM sound broadcasting providing national, regional and local VHF radio services.[2]

At the national level the use of radio spectrum $S$ in most countries is currently managed closely by government agencies rather than by market forces. The management of spectrum by government is usually predicated on protecting property rights, promoting the benefits associated with coordinating use and national security.

In many countries the primary tool of spectrum management by government is a licensing system. Although some frequency bands, such as frequencies around 2.4 GHz, are licensed exempt and akin to a 'commons', the majority of frequencies require users to hold a licence from government to access radio spectrum.[3] Licensing effectively makes many frequencies bands in the radio spectrum a *de facto* private good.[4] The issuing of radio spectrum licences to users is known as the assignment of radio spectrum.

The allocation problem effectively involves the division of the radio spectrum $S$ into a collection of frequency bands which are allocated to uses. Stating this formally, let $s \in S$ be a frequency within the radio spectrum, then for an integer $j \geq 1$ define $b_j = (s_{j-1}, s_j) \subset S$, where $0 < s_{j-1} < s_j$, as frequency band j.[5] If there are N possible uses for radio spectrum, the allocation problem may be solved by dividing $S$ into N frequency bands $b_j$ for $j=1,...,N$.[6]

There is little discretion in the short- to medium-term (which may be up to ten years) for individual national states to affect radio spectrum allocation. However, while fundamental changes to the way radio spectrum is allocated across uses is generally not feasible, changes to allocations at the margin are increasingly possible – giving scope for policy intervention. This could be achieved by setting administered spectrum prices $a_j$, where the price is set in relation to frequency band j.

## RADIO SPECTRUM PRICING AND EFFICIENCY

The key policy question for radio spectrum pricing policy is:

- What factors ought to determine the selection of an administrative prices $a_j$?

In many countries the criteria for setting the prices for frequency bands has been driven primarily by cost recovery.[7] In some countries however, such as the UK, use has been made of Administered Incentive Pricing (AIP), where the primary criterion for setting prices is economic efficiency rather than administrative cost recovery 9though the two coincide where there is excess supply).

In a review [2] of spectrum management policy commissioned by the UK government it is stated that AIP ought to be chosen in a way that encourages productive efficiency:

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1 The United Nations organization the International Telecommunication Union oversees international coordination of radio spectrum via the World Radiocommunication Conference, see http://www.itu.int/ITU-R/conferences/wrc/index.asp.

2 By allocating this frequency range to VHF broadcasting, manufacturers of radio sets have designed equipment to operate around these frequencies. As a consequence, consumers possess equipment to receive VHF broadcasting within the frequency bands 87.5 MHz through to 108 MHz. While in principle it is possible to re-allocate these frequencies to another potentially higher-value use, there would in practice be a significant cost associated with reconfiguring or replacing the equipment used to receive sound broadcasting. In the future `smart radios' may lessen the need for such rigid allocations of radio frequencies, see http://www.sdrforum.org/ for information about software defined radios.

3 Licences provide both rights and obligations. Rights provide for access to specified frequencies at particular times, and obligations may include constraints on system apparatus (such as constraints on power, physical size, etc.).

4 An alternative way to manage radio spectrum would be as a commons, in much the same way oceans are managed. This approach has been discussed by [1].

5 The use of open intervals can be justified in terms of guard bands.

6 This is a simplification because in practice some uses share frequency bands.

7 Typically administrative charges $a_j$ are set to recover the costs of spectrum management directly attributed to users, and may also include an element to reflect common (overhead) costs.

"The fundamental mechanism by which the spectrum management regime could contribute to economic growth is through ensuring that users face continuing incentives towards more productive use of this resource. The review considers that these incentives should be financial and based on the opportunity cost of spectrum use. In this way, spectrum would be costed as any other input into the production process. Price signals about the cost of using spectrum would be disseminated throughout the economy. This information should enable dispersed economic agents to make their own judgements about their use of spectrum and the alternatives open to them to meet their organisational goals."[8]

Opportunity cost is defined in [2] as: "the value of an asset or resource in the next best alternative that is foregone by virtue of its actual use."

A necessary condition for productive efficiency is the equalization of the marginal rate of technical substitution between inputs across sectors (and across firms within a sector). This suggests that for radio spectrum use to satisfy productive efficiency the marginal rate of technical substitution between radio spectrum and another substitutable input should be equal across firms in the same sector, and across firms using these inputs in different sectors.

The justification for ensuring that the use of radio spectrum satisfies productive efficiency can be found in [3] which states that a policy maker choosing taxes in a second-best setting should not tax the use of inputs. It is further stated that the use of inputs in a competitive economy should satisfy conditions necessary for productive efficiency if a second best outcome is to be achieved.

Setting the price for spectrum so that productive efficiency is promoted, both within sectors and across sectors, is therefore desirable. One method that can be applied to ensure productive efficiency is achieved is known as the Smith-NERA method, see [4].

## THE SMITH-NERA LEAST COST ALTERNATIVE METHOD

The Smith-NERA method works by identifying the rate of technical substitution between radio spectrum and another input such that the quantity of output produced by a firm using radio spectrum is assumed to be constant. In other words, if the value of the input, say labour, is paid X dollars per unit of time, we could ask how much extra labour would be required to maintain output constant if the amount of spectrum is reduced by say 1 MHz. As the price of labour is determined on a competitive market, this approach identifies the value of spectrum at the margin in term of other commodities bought and sold on markets.

One of the strong appeals of the Smith-NERA least-cost alternative method is its simplicity. Furthermore, applied correctly it permits the promotion of productive efficiency. In this section the method is illustrated and its application demonstrated.

### Applying the Smith-NERA Method

Suppose firm $i$ in sector $j$ which uses spectrum $s_{ji}$ and another input (say base stations $b_{ij}$) produces output $q_{ji}$. The firm's output can be expressed as:

$$q_{ji} = f(b_{ij}, s_{ji}) \qquad (1)$$

Assume the firm maximizes profit and hence minimizes its costs. If a unit of spectrum $\Delta s$ is added to or subtracted from $s_{ji}$, a compensating change could be made in the amount of the other input $b_{ji}$ such that total output is unchanged at $q_{ji}$. By doing this the rate of 'technical substitution' between the two inputs can be assessed. For a $\Delta s$=1 there would be an implied change $\Delta$b, and where the latter is multiplied by its price (which is determined on a competitive market) this allows for a monetary representation of the rate of substitution. By applying the same procedure in other sectors, comparisons can be made across sectors using the common unit money (which means comparisons can be made across sectors where different inputs substitute for spectrum).

In Table 1 below we present a hypothetical example illustrating the Smith-NERA least cost alternative method. The values in the cells are calculated as described in the preceding paragraph. Hence, 100 in use I, frequency band $a$ is the value, expressed in money terms using the least-cost-alternative input, of the marginal unit of spectrum. For example, a

8 Para. 22, page 7, [2].

unit of spectrum may be worth four base stations which each have a price 25. The values in the other cells also represent the value of a marginal unit of spectrum. For productive efficiency to be satisfied, spectrum ought to be allocated across uses so that these values are identical. It can be seen in the table that they are not equal. The example is an illustration of productive inefficiency.[9]

Table 1

| | Frequency bands | | | |
|---|---|---|---|---|
| Uses | a | b | c | Non radio spectrum input |
| I | 100 | 75 | 0 | 0 |
| II | 35 | 60 | 30 | 0 |
| III | 10 | 10 | 15 | 5 |

Further application of the Smith-NERA method leads to recommended prices for radio spectrum consistent with productive efficiency.

Consider the values in the row associated with Use I. The marginal value of frequency band *a* in Use I is 100 and the marginal value of frequency band *b* in Use I is 75. Note that frequency band *b* is an imperfect substitute for frequency band *a* in Use I. However, the marginal value of frequency band *b* in Use II is 60. Society would be better off therefore if some of frequency band *b* were re-allocated to Use I. This is because a marginal unit of frequency band *b* applied to Use I could produce the same output in Use I while freeing up enough resources to compensate Use II (and hence maintain a constant output in Use II) and provide some extra resources for additional production in the economy.

The above can be stated in terms of opportunity costs. The opportunity cost of frequency band *b* spectrum in Use II is 75, the foregone saving in terms of least-cost-alternatives that would arise if the frequency band were used in Use I (the next best alternative). By expressing the value of marginal spectrum in terms of opportunity cost, it is possible to address the issue of pricing radio spectrum.

What should the administrative price be for radio spectrum frequency band b? This is determined by permitting variation in the frequency bands allocated to the three uses. It is clear that more of frequency band *b* ought to be allocated to Use I, and more frequency band *c* should be allocated to Use II.

## CONCLUSION

The Smith-NERA least-cost-alternative method provides a relatively simple tool for identifying value ranges which can be used to guide the setting of administrative prices for radio spectrum. The prices established accord with the principle of opportunity cost and are consistent with the objective of achieving efficiency (in particular, productive efficiency).

## REFERENCES


[1] Faulhaber, Gerald R. and David Farber (2002) "Spectrum management: property rights, markets, and the commons", mimeo, University of Pennsylvania.

[2] Cave, Martin (2002) Review of Radio Spectrum Management, for Department of Trade and Industry and H M Treasury, March.

[3] Diamond, Peter and James Mirrlees (1971) "Optimal taxation and public production 1: Production efficiency and 2: Tax rules", *American Economic Review*, 61, 8-27 and 261-78.

[4] Smith-NERA (1996) "Study into the use of spectrum pricing", report for the Radiocommunications Agency by NERA and Smith System Engineering, April.


9 If re-allocation of radio spectrum were not possible, then the values in Table 1 could be compatible with productive efficiency. In particular, if firms in each use area differ and the values in the cells represent averages, then productive efficiency would be achieved in each use area if the price of spectrum were set equal to the identified opportunity cost.

# Tongue Image Classification Based on the TSVM

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***Abstract*—Tongue image classification plays a very important role in the Traditional Chinese Medicine (TCM) modernization. However, the number of training samples labeled by the authoritative TCM experts is small since it is a hard work to confirm the type of the samples, which need a lot of time and human labor. Meantime the separable boundary obtained by these labeled samples is rough and imprecise. Meantime unlabeled samples are abundant and easy to obtain. Transductive support vector machine (TSVM) is a method to reduce human labor and improve accuracy since the unlabeled samples can be joined to train the classifier to provide much more classification information during training. The experimental results show that the TSVM classifier can improve the right classification rate so it is a promising method in the TCM study.**

**Keywords-Tongue image classification, Traditional Chinese Medicine, Transductive support vector machine**

## I. INTRODUCTION

Tongue diagnosis is an important part of the inquiry diagnosis in TCM. Physicians examine the tongue color, shape, textures and so on to judge the patient's health conditions. Based on tongue image and other information, the possible causes of diseases can be concluded and the treatment is then implemented.

However, tongue diagnosis is usually based on the inspection from the eye. The environmental factors, such as different light sources and brightness, can affect the physicians in making accurate diagnosis. In addition, the examination outcome in traditional tongue diagnosis could not be described scientifically and quantitatively.

In recent years, the studies on tongue image characterization in TCM have been widely emphasized [1]. Quantitative analysis of tongue images based on image processing and pattern recognition is a trend in TCM Modernization. The first exploratory experiment about this was carried out in 1985 by the University of Science and Technology of China. Their work shows that it is feasible to study the tongue image by this means. Nevertheless, at that time most of the existing research work could not solve the color distortion in tongue image acquisition and did not implement the automatic classification of tongue features.

To improve the research of tongue characterization, we applied the image analysis in characterizing tongue diagnosis in 1990s. An objective tongue analysis instrument named Tongue Image Analysis Instrument (TIAI) was developed [2]. Several algorithms on color calibration, tongue image segmentation, quantitative analysis and qualitative description and so on have been presented in [2]. Their effectiveness has been verified by more than 3000 tongue images in hospitals.

However, since the number of training samples labeled by the authoritative TCM experts is small, support vector machine (SVM) is selected to classify the tongue images. The labels of training samples must be decided by 3-5 experts with rich experience, which need a lot of time and efforts. A large amount of labeled samples could not be obtained under this condition. As far as the recognition is concerned, the classification information from these labeled samples is not enough and the separable boundary by them is rough and imprecise. At the same time, the unlabelled samples are easy to obtain for us. For example a large amount of unlabeled samples can be collected if a physical examination is carried out. So if the classification information from these unlabeled samples is used, the performance of the SVM classifier can be improved. This is so-called the idea of semi-supervised learning. In the semi-supervised learning, the unlabeled samples are jointed to train the classifier to improve its generalization performance. Since the classification on the tongue proper and tongue coating by SVM has been made some achievements in [2], in this paper SVM [3-5] and transductive SVM (TSVM) [6-8] is selected to improve the performance of the original classifier.

The rest of this paper is organized into three sections. Section 2 shows the basic theory on the SVM and TSVM. In section 3, the experiment on tongue image classification based on TSVM is proposed. Section 4 conclusions are given.

## II. SVM AND TSVM

### *A. SVM*

SVM is a state-of-the-art method and has been applied to many fields such as face recognition, text classification and so on in the machine learning. Compared to the artificial neural network it is based on the structure risk minimization and has the better generalization performance. Its basic theory is described as following.

Suppose there are two kinds of samples and their types are positive class and negative class respectively. As Figure 1 the black points represent the positive samples and the blank points represent the negative ones. The classifier H with maximal margin is called a support vector classifier, in which the samples which lie in the margin are called support vectors. To

This paper is supported by National Natural Science Foundation of Beijing, China (4092009) and Youth Science Foundation of Beijing University of Technology, Beijing, China (X1002012200802)

the nonlinearly separable problems, the kernel function $\phi$ is introduced to map the samples to a new space in which they are linearly separable completely or linearly separable approximately as figure 2 which is from [5]. In fact the inner is calculated by the kernel function rather than is obtained in the mapping space. That is why SVM can solve the problems with high dimension features and can avoid the "dimension Disaster ". Since the labeled samples are small in some cases such as the labeled tongue images in TCM, the SVM classifier trained by them cannot reflect the distribution of the whole samples.

Under that there are some unlabelled samples, how to add them to train a classifier becomes an important problem in machine learning. TSVM is a promising method to solve it.

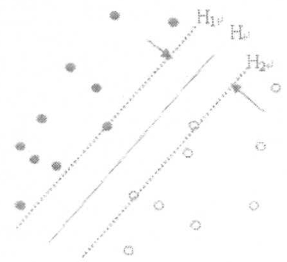


Figure 1. An example on support vector classification

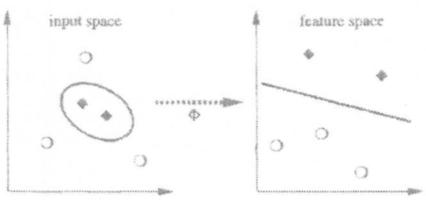


Figure 2. The idea of solving the nonlinearly separatable problem in SVM

## B. TSVM

Suppose there are l labeled samples and u unlabelled samples in data set. The feature vector of i-th labeled sample is $\vec{x}_i$ and its class label is $y_i$, where $y_i \in \{1,-1\}$. $y_i^*$ is the class label of the i-th unlabelled sample and it needs to be decided after training TSVM classifier. $\xi_i$ and $\xi_j^*$ are the slack variable corresponding to i-th labeled sample and i-th unlabelled sample respectively.

$$(\vec{x}_1, y_1), (\vec{x}_2, y_2), \cdots, (\vec{x}_l, y_l)$$

represents the training set with labels and

$$(\vec{x}_1^*, y_1^*), (\vec{x}_2^*, y_2^*), \cdots, (\vec{x}_u^*, y_u^*)$$

is the data set without class labels. A binary TSVM in [6] is proposed and its formulation is as equation (1).

$$\begin{aligned} &\min_{w,b,\xi_i} \frac{1}{2}\mathbf{w}^T\mathbf{w} + C\sum_{i=1}^{l}\xi_i + C^*\sum_{i=1}^{u}\xi_i^* \\ &y_i(\mathbf{w}.\mathbf{x}_i + b) - 1 + \xi_i \geq 0 \\ &y_i^*(\mathbf{w}.\mathbf{x}_i^* + b) - 1 + \xi_i^* \geq 0 \\ &\xi_i \geq 0, \xi_i^* \geq 0 \end{aligned} \qquad (1)$$

To non-separable case by the linear classifier, the kernel function is introduced to map the samples into a new space in which the samples are separable fully or approximately separable by the linear classifier. In nature, TSVM is an extension of standard SVM with unlabelled samples. Figure 3 from [5] shows an example on TSVM, in which the labeled samples are marked as +/-, the unlabeled samples as dots. The dashed line is the solution of the inductive SVM (Standard SVM).The solid line shows the TSVM. It can be seen that unlabeled samples can provide some classification information so as to improve the classifier's performance. It is noted that not all the classification problems with unlabelled samples can be solved by TSVM. The condition that the samples need to satisfy is given in [6]. The experiment in next part shows it is valid for tongue image classification.

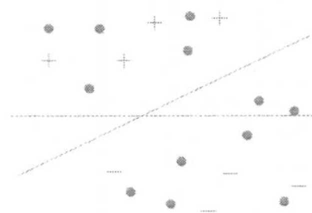

Figure 3 An example on the TSVM

## III. TONGUE IMAGE CLASSIFICATION EXPERIMENT

The data experiments on the tongue proper color and tongue coating color are carried out. The RGB is selected to the feature space for classification. Before the experiment the testing data is first calibrated to the standard space to make the tongue color approach the real tongue as soon as possible [2]. According to suggestions of several TCM experts, the tongue proper color is classified to 6 types such as red tongue, light red tongue, dark red tongue and so on and the color of tongue coating is classified 9 types such as thin while coating, white coating and so on[2]. In this experiment, the light red tongues and other types of tongues are organized into 5 binary-category classification problems and the thin white coating and other coatings are organized into 8 binary-category classification problems. Thus there are 13 binary-classification problems. The radius base function

$$K(x,y) = e^{-g\|x-y\|^2}$$

is selected to train the SVM classifier. Here the parameter g = 0.1. The condition on the experimental data sets is as chart 1, in which the "labeled", "unlabeled" and "testing" represent the number of labeled samples, unlabeled ones and testing ones respectively.

TABLE I. CONDITION ON THE EXPERIMENTAL DATA

| | labeled | unlabeled | testing |
|---|---|---|---|
| 1 | 31 | 1394 | 356 |
| 2 | 27 | 1211 | 312 |
| 3 | 21 | 823 | 213 |
| 4 | 56 | 2647 | 669 |
| 5 | 23 | 924 | 240 |
| 6 | 31 | 3631 | 1121 |
| 7 | 34 | 3250 | 1150 |
| 8 | 22 | 2329 | 791 |
| 9 | 19 | 1866 | 675 |
| 10 | 19 | 1880 | 680 |
| 11 | 25 | 2650 | 907 |
| 12 | 51 | 4518 | 1421 |
| 13 | 17 | 1740 | 643 |

The labeled samples are selected from the hospital and their labels are decided by 3 authoritative TCM experts. The testing samples are collected in physical examinations and their labels are obtained by a TCM doctor.

The experiment includes three parts.

1) Labeled samples are trained and then testing samples are classified

2) Labeled samples and unlabelled samples are trained and then testing samples are classified

3) Labeled samples and testing samples are trained and then testing samples are classified.

In the 3rd part, we assume the testing samples as the unlabeled ones in order to improve their right classification rate. Note that this method is unsuitable to the real-time classification in this case.

The experimental results are as Fig.4 and Fig.5 respectively. In these two figures, the yellow rectangle represents the right classification rate of testing samples by TSVM and the green rectangle shows the right classification rate by Inductive SVM (Standard SVM).

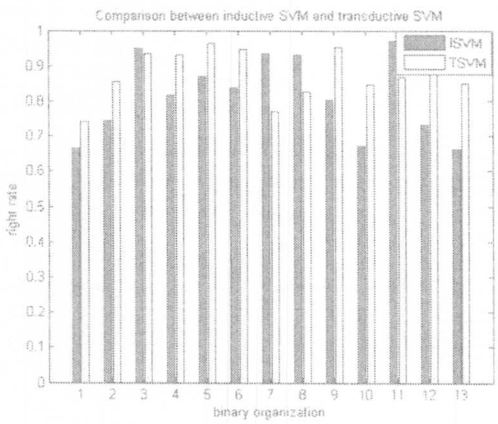


Figure 4. Unlabeled samples are trained

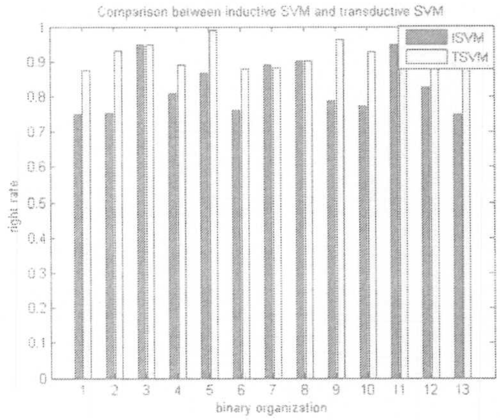


Figure 5. Testing samples are as the unlabeled ones

From the experimental results we can see that the testing results by the TSVM are better than the ones by the standard SVM in most cases. However, there are three bad cases who are 3th, 7th and 8th binary-category classification problems in these experiments. The main reasons are as following.

1) The 7th, 8th and 9th binary classification problem is difficult to separate and their separating boundary is fuzzy. That is to say, these samples don't satisfy the low density assumption fully.

2) The kernel function parameter selection is not carried out in training TSVM classifier. If the model selection is done, the results should be better than the ones described as above.

In addition, TSVM is a NP hard problem in maths and it is very difficult to obtain the optimal solution, which has an effect on the experiments results.

From the experiments on the tongue color and coating color, TSVM is a potential method in TCM characterization and modernization. We can also see that if much more unlabeled samples are joined to train, the right classification rate can be lower. So the selection on the unlabeled samples is also an important issue to study further.

## IV. CONCLUSION

Tongue image classification is an important part in TCM modernization. However, it is difficult to obtain the labeled samples since a lot of time and human labor is needed. Meantime the unlabeled samples are easy to obtain and TSVM is a promising method in which the classification inform provided by unlabeled samples can be used. The Experimental results show that TSVM can improve the right rate of tongue image classification in most cases. We will study the optimization of TSVM and the selection of unlabeled samples which are joined to train to obtain the better performance.

## REFERENCES

[1] Lansun Shen, Baoguo Wei, Yiheng Cai ,Xinfeng Zhang, et al, Image Analysis for Tongue Characterization, Chinese Journal of Electronics, , Vol 12(3), pp. 317-323,2003

[2] Lansun Shen, Yiheng Cai, Xinfeng Zhang, Acquisition and analysis on tongue image in TCM, Beijing University of Technology Publishing, Beijing, 2007

[3] Vladimir N.Vapnic, The nature of statistical learning theory, Springer Verlag Press, 1995

[4] John Shawe-Taylor & Nello Cristianini, An introduction to support vector machines and other kernel-based learning methods, Cambridge University Press, 2000

[5] Bernhard Schölkopf, Alexander J. Smola, Learning with Kernels: Support Vector Machines, Regularization, Optimization, and Beyond, MIT Press,2001

[6] Joachims, T. Transductive inference for text classification using support vector machines. Proc. 16th International Conf. on Machine Learning, Morgan Kaufmann, San Francisco, CA, 200-209

[7] Chapelle, O., Zien, A., & Sch¨olkopf, B. Semi-supervised learning, MIT Press, 2006

[8] Xiaojin Zhu, Semi-Supervised Learning Literature Survey, http://pages.cs.wisc.edu.sixxs.org/~jerryzhu/research/ssl/semireview.html

IAWA Journal, Vol. 24 (3), 2003: 231–239

# HIGH-FREQUENCY DENSITOMETRY – A NEW METHOD FOR THE RAPID EVALUATION OF WOOD DENSITY VARIATIONS

by

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SUMMARY

A new method called HF-densitometry is introduced, which measures relative density variations along wood surfaces utilizing the dielectric properties of wood. The method is based on the propagation of continuous electromagnetic waves in a high-frequency (HF) transmitter-receiver link of an extremely small electrode system, which is in direct contact with the wood surface investigated. The electromagnetic field emitted by the transmitting electrode propagates through a small volume of the wood sample to the receiving electrode, located very close to the transmitting electrode. The received signal strength is directly influenced by the dielectric properties of the material along the propagation path. The variation of the relative dielectric constant in different wood structures is correlated with the density variations in a way the received signal strength increases with increasing wood density. The dielectric measuring device, developed on the basis of the new method, allows non-destructive, extremely fast measurements of wood density variations. The new HF-densitometry method was compared to X-ray densitometry by performing measurements on an identical spruce sample.

***Key words:*** Dielectric constant, wood density, direct contact dielectric measurement device, high-speed measurement, high-frequency transmission-receiving link.

## INTRODUCTION

Because wood density variation within annual tree rings may provide substantive climatic information, wood density is of interest to dendroclimatology (Polge 1978; Eckstein et al. 1979; Jacoby 1982; Schweingruber 1982). In particular, maximum density seems to correlate best with different environmental factors, such as air temperature (Parker & Henoch 1971; Rothlisberger 1976; Schweingruber 1990), precipitation (Polge 1971; Akachuku 1985) and the lengths of flood-free periods on floodplains (Worbes et al. 1995). In case of a low variability of ring widths, wood density was found to be a more sensitive indicator of climate (Eckstein et al. 1979). Intra-annual density variations of tree rings have been also used to indicate effects of anthropogenic air pollution (e. g., Eckstein et al. 1974; Ohta 1978; Greve 1984; Lewark 1986). In tropical trees intra-annual density variations were utilised to identify tree-ring boundaries that were barely visible to the naked eye (Worbes et al. 1995; Tomazello et al. 2000; Vetter 2000).

Over the years, different methods have been developed to measure wood density variation in annual rings and, according to Schweingruber (1990), only X-ray densitometry has proved suitable. This method was first introduced to the field of wood analysis by Polge (1963), and was further developed by various researchers (Polge 1978).

Although being reliable, X-ray densitometry suffers from relatively high equipment costs, time-consuming preparation and measuring procedures (Schweingruber 1990; Vetter 1995). During the past two decades direct scanning X-ray densitometry systems have been developed (Hoag & McKimmy 1988; Evans 1994), at which the attenuation of an X-ray beam passing through the wood specimen is directly measured by a scintillation detector, and correlated to the wood density variation.

This paper introduces a new type of densitometry, based on dielectric properties of wood. The relative dielectric constant and the dielectric loss factor are closely related to wood density, frequency of the altering electric field (Torgovnikov 1990), moisture content (Trapp & Pungs 1956; Kabir et al. 1998) and temperature (Trapp & Pungs 1956). These relationships are applied to determine wood density or the wood moisture content. Dielectric effects have been also applied to wood heating, drying and gluing.

Based on the relative dielectric constant, this new method was developed to measure intra-annual density variations along wood surfaces. The new method works from wood surfaces, is fast, non-destructive and of relatively low cost because of the easy handling.

## METHODS AND MATERIALS

The central part of the new method, called HF-densitometry (patent pending), is a micro-electrode system designed as a slit-shaped probe (Fig. 1), which is placed at the tip of a steel conical shaped cylinder (Fig. 2).

The lateral resolution of the system is defined by the width of the scanning slit. When applied to measure density variations, the slit-shaped HF-probe has to be oriented perpendicularly to the scan direction and needs to touch the wood surface to move along at a certain pace (Fig. 3).

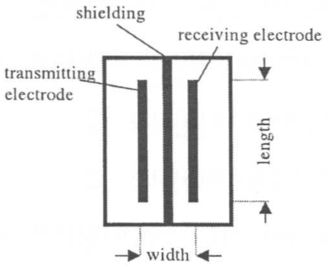

Fig. 1. Bottom view of the probe.

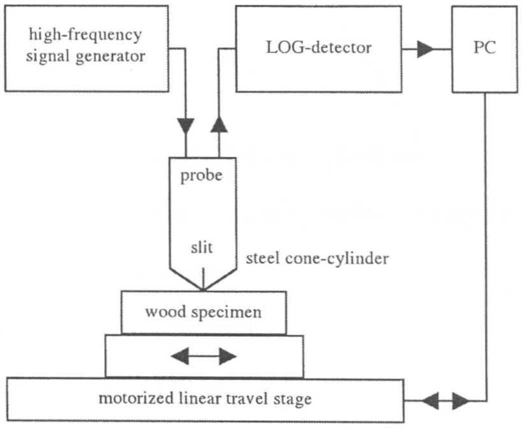

Fig. 2. Schematic diagram of the experimental setup.

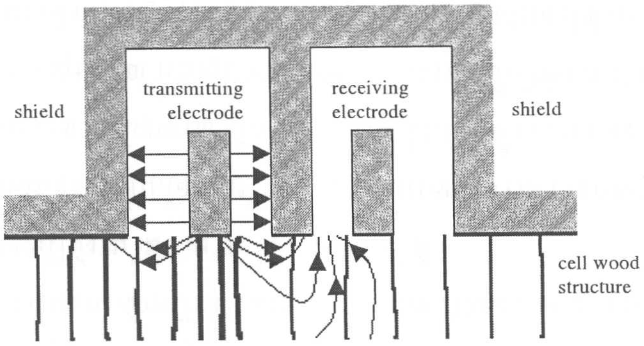


Fig. 3. Schematic cross section of the electrode system close to the wood structure.

The main part of the HF-probe is a pair of very close and parallel electrodes: a high-frequency transmitting electrode and a receiving one. Both electrodes are hermetically shielded from each other by a thin metallic foil to prevent mutual interference, or direct 'crosstalk' between the two electrodes, except for the tip area of the slit-shaped electrode system.

The electromagnetic field induced in front of the linear transmitting electrode by the high-frequency generator (output voltage 5 Volt rms) is close to a half-cylindrical shape. A very tiny part of this field propagates to the parallel linear receiving electrode, where a signal of a few hundred micro-Volts ($\mu$V) is induced. Without a wood specimen in position the space in front of the electrode system is air-filled with a relative dielectric constant of 1.00059.

The 'crosstalk' between the transmitting and receiving electrodes in the HF-probe is significantly enhanced with a wooden surface placed in front of the slit-shaped electrode system, the wood having a relative dielectric constant in the range of 2 to 6 (Torgovnikov 1990).

When the slit of the HF-probe is moved along the radius of a cross section of a gymnosperm, the received signal may reach several milli-Volts (mV). The detected voltage is higher in latewood than in earlywood because of its higher local relative dielectric constant. Wood density variations caused by different ratios of cell wall to air-filled cell lumens directly influence the dielectric behaviour of the wood structure, which gives rise to different coupling values within the electrode system of the HF-probe.

The schematic diagram of the experimental apparatus to measure density variations in wood surfaces that was used within this investigation is shown in Figure 2.

A high-frequency generator producing a 10 MHz sinusoidal signal with a power of 50 mW was connected to the transmitting electrode through a shielded coaxial cable on one side of the dielectric HF-probe, and to a high-frequency receiver with a logarithmic rectifying characteristic on the other side. The frequency response of the receiver was limited to 1 kHz bandwidth by an internal low-pass filter. The received voltage was fed into a fast A/D converter of a personal computer, which also controlled the motorised stage. The wood specimen was placed on the table of the translation stage. The slit of the probe was oriented perpendicularly to the measured radius. The air gap between the wood surface and the electrodes was minimised by using a spring loaded device at a load of 1 N, which kept the probe close to the wood surface. Thus, the electromagnetic field between the transmitting and the receiving electrodes was forced to propagate through wooden material only.

The geometry of the electrode system defined the lateral resolution of the measuring system. In this work the electrode system of the self-made probe was 0.12 mm wide and 2.0 mm long. The effective measuring range of the HF-probe was limited by the transmitted power and by the sensitivity of the receiving system. The range was experimentally determined in the following way: the volume in front of the measuring slit of the HF-probe was filled with a stack of equally thick PETP (polyethyleneterephthalate)-foils, a homogeneous dielectric material with a relative dielectric constant value of 3.2. The foil stack was completed by a thin layer of electric conducting chromium on a glass plate, which acted as a reflector of the electric field in front of the HF-probe. When the thickness of the PETP-foil stack was raised stepwise, the detected signal approached asymptomatically a final value, which was the critical indication of the maximum measuring range.

The highest usable scanning speed was limited by the bandwidth of the receiver to about 100 mm/s at 0.12 mm lateral resolution. However, it was much more limited by the sample rate of the used A/D converter to about 10 mm/s.

To compare the newly developed HF-densitometry with the established X-ray densitometry, a radial profile of a Norway spruce (*Picea abies* (L.) Karst.) was scanned with the HF-densitometer, and then by X-ray densitometry which was done by the Swiss Federal Research Institute (WSL), Birmensdorf (CH). The comparative measurements were performed on a cross section of a Norway spruce from the so-called Kaiserstuhl in Baden-Württemberg, Germany, including tree rings from 1972 to 1994. The sample was air-dried under ambient laboratory conditions for approximately 12 months.

For the described dielectric measurement this specimen was planed and smoothed by an ultra-precise diamond flycutter (Spiecker et al. 2000). This milling technique produces even surfaces with low roughness and very low sub-surface damage regions. The high surface quality helped avoid air gaps between the HF-probe tip and the wood surface, which would have reduced the accuracy of the dielectric measurements.

The specimens should be air-dried because free water (above fibre saturation point) in the cell lumina influences the relative dielectric constant and therefore the 'density' value as a result of the very high dielectric constant $\varepsilon'r$ of water ($\varepsilon'r = 81$) (Trapp & Pungs 1956; Khalid et al. 1999).

The basic steps of the X-ray densitometric analysis of the sample were the following: A small twin-bladed circular saw was used to cut out a slice of uniform thickness of 1.25 mm. Prior to radiography, the wooden slat was adjusted to a moisture content of 9%. A radiograph of the slat was produced on a photographic film after 45 min exposure of a 12 kV and 12 mA X-ray beam. After that, the film was developed using an automatic processor with standardised processing. Density variations along a radius were measured by scanning the photographic film with a micro-densitometer. The measuring slit, defining the lateral optical resolution of the film, was 10 $\mu$m wide and 500 $\mu$m long.

Using the SAS® statistical package, a t-test was applied to prove that the measurement results that were made with the two different methods are not significantly different. By means of the TTEST procedure an approximate t statistic was computed for testing the hypothesis that the means of the two groups of observations are equal.

## RESULTS AND DISCUSSION

The results of HF-densitometry and X-ray densitometry of the same Norway spruce sample are shown in Figures 4 & 5.

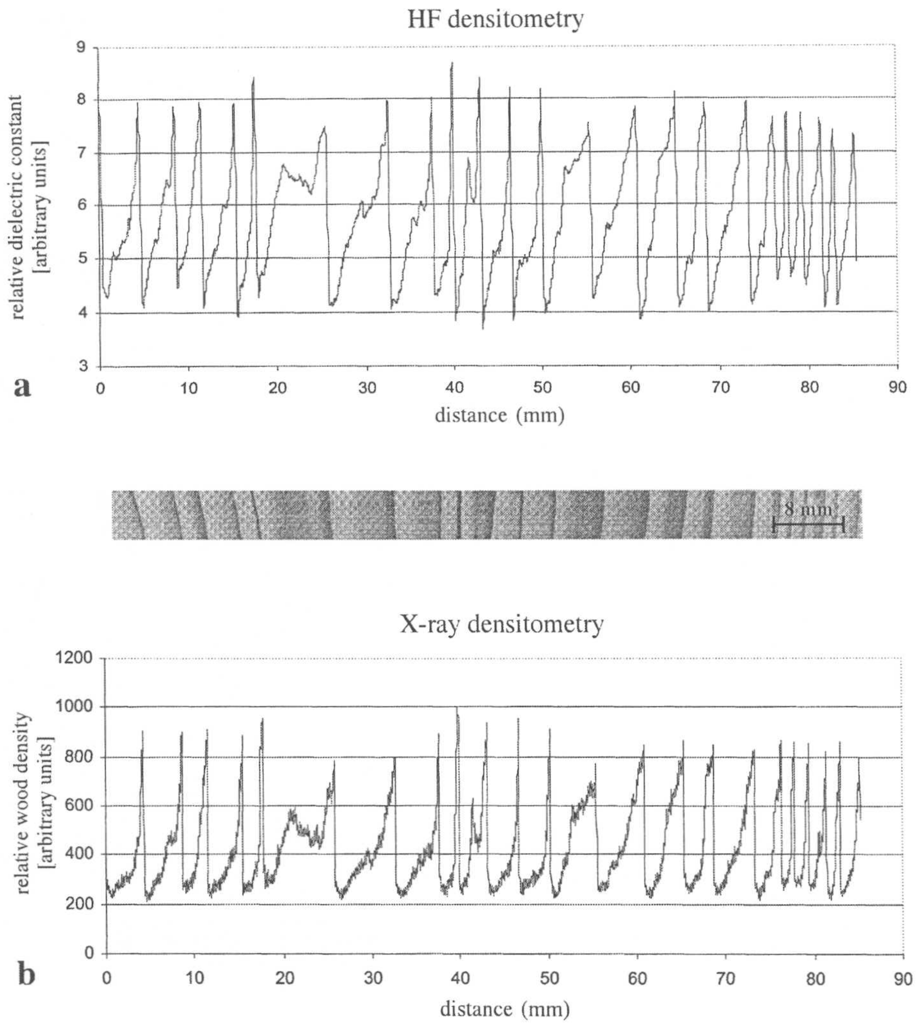


Fig. 4. Radial relative dielectric constant (a) and radial wood density (b) profiles of a Norway spruce measured by HF densitometry (a) and X-ray densitometry (b).

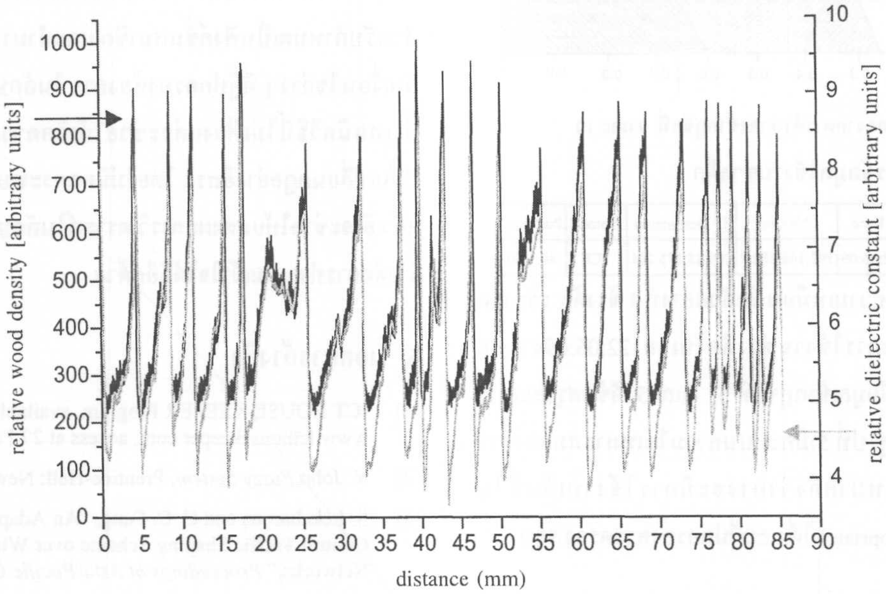


Fig. 5. Superimposed profiles of the radial relative dielectric constant and radial relative wood density of the Norway spruce specimen, as shown in Figure 4.

The profiles obtained by the two methods were almost identical; the t-test showed that the results obtained from the two different methods did not differ significantly. The results from the test of equality of variances showed that the assumption of unequal variances is reasonable for these data. The probability value associated with the test was 0.2605.

At the tree-ring boundaries (distance range from 0 to 15 mm) the negative slopes of the X-ray densitometry profile are steeper than the comparable slopes of the dielectric density profile. However, this cannot be seen in Figure 5, because of the weak resolution of the graph. The reason for this higher contrast in the X-ray densitometry probably is that the optical slit is always positioned parallel to the tree-ring boundaries, while HF-densitometry was performed at a fixed position for a given sample. As seen from the micrograph in Figure 4, the tree-ring boundaries in the distance range 0 to 15 mm are oblique. The effect of an oblique slit position relative to the tree-ring boundary on the measurement of the maximum density value is discussed in detail by Lenz et al. (1976) and Schweingruber (1988). The peak heights of the profile measured with the new method differ from those performed with the method of X-ray densitometry, probably because of that constant slit positioning. Technically, it should be no problem to develop a system, at which the measuring slit can be positioned parallel to the ring boundaries, e. g. by an image analyser. However, to overcome this deficiency of the new dielectric probe a special type of a multiple-channel HF-probe is under development. In this type of HF-probe the signals of a linear array of identical smaller receiving electrodes will be analysed in such a way that the tree-ring boundaries are reconstructed precisely using a mathematic algorithm. In this case an additional positioning of the measuring slit is not needed. Therefore, with the newly developed HF-densitometry method an accurate determination of extremities like the maximum ring densities should be possible in the future.

The apparent low signal-to-noise ratio of the dielectric profile (Fig. 4a) compared with that of the X-ray profile (Fig. 4b) may be due to the much higher sample rate combined with a higher spatial resolution of the X-ray densitometry.

The main reason for the lower relative wood density values in earlywood measured with HF-densitometry (Fig. 5) may be the excited wood surface layer, which was much thinner than the 1.25 mm-thick slice used by the X-ray densitometry. From the experiment described above, the measurement depth of the HF-system used was found to be approximately 0.35 mm. It is well known that an oblique direction of a fibre can obscure X-ray images (Schweingruber 1990). With increasing thickness of the penetrated layer this effect will become greater (Lenz et al. 1976). However, it is much more likely that the logarithmic function of the rectifying detector of the transmitting-receiving link distorts the transfer-function between real wood density and measured output voltage of the detector.

The oblique fibre direction could also be a reason for more gradually sloping transitions close to the minima between the earlywood and latewood in the X-ray densitometry graph.

Furthermore, small differences between the two results could result from differing moisture contents at which the two measurements were performed. According to the literature the moisture content affects dielectric properties (Kollmann 1982; Khalid et al. 1999) as well as X-ray results (Schweinguber et al. 1978).

The comparative measurements performed on the same spruce sample indicated that the relative dielectric profiles are highly comparable to X-ray densitometric data. Both methods are based on the spatial change of cell wall proportion. Contrary to X-ray densitometry, the probe of the dielectric HF-densitometric method is in direct contact to the wood surface. Therefore, this surface should be prepared in a way that the roughness is low, the evenness is high and the sub-surface damage region is much smaller than the measuring depth of the probe (0.35 mm). In this study a diamond flycutter was used to fulfill these conditions. On the other hand it is known that other preparation techniques like sawing, machining and sanding can also produce surfaces with high quality. A list of sample machining techniques can be found in Olson et al. (1978). However, the influence of the surface quality on the HF-densitometric data needs to be further investigated.

In the scope of this investigation the electrode system of the probe was 0.12 mm wide. The development of small electrode systems depends on the availability of thin electrode and insulation foils, as used in the sandwich construction of the existing system. The smallest possible slit width must be investigated in further research. However, minimum slit size is probably constrained by charge transfer from the transmitter-electrode to the middle-shielding.

The advantages of the new dielectric method to measure density variations can be summarised as follows: no protective radiation arrangements needed, any specimen thickness bigger than measuring depth can be used, method based on a simple measurement procedure, and extremely fast procedure. Therefore, HF-densitometry could become widely used for measuring wood density variations. However, it should be emphasised that the obtained signals are not yet calibrated to density values. For absolute wood density measurements, each measuring system (probe – transmitter – receiver) needs to be calibrated with standards, as is needed for X-ray densitometry.

Currently, work is concentrating on factors that influence the relative dielectric constant and thus the density profile, i. e. orientation of the slit of the HF-probe relative to the tree rings, the surface roughness of the specimen and the moisture content of the specimen.

## ACKNOWLEDGEMENTS

The authors would like to thank Theodor Forster of the Swiss Federal Research Institute WSL, who made the X-ray-densitometry measurements and Felix Baab from the Institute for Forest Growth (Freiburg) for constructing the mechanical components of the new instrument and preparing the wood samples. We also like to thank Jean M. Bennett of Naval Air Warfare Center, Physics Division, China Lake, California, for her helpful comments and assistance in checking the language.

## REFERENCES

Akachuku, A. E. 1985. Intra-annual variation in wood density in Gmelina arborea from X-ray densitometry and its relationship with rainfall. Tree-Ring Bull. 45: 43–53.

Eckstein, D., E. Frisse & W. Liese. 1974. Holzanatomische Untersuchungen an umweltgeschädigten Straßenbäumen der Hamburger Innenstadt. Eur. J. For. Path. 4: 232–244.

Eckstein, D., W. Liese & B. Schmidt. 1979. Dendroklimatologie und Dendroökologie. AFZ 34: 1364–1368.

Evans, R. 1994. Rapid measurement of the transverse dimensions of tracheids in radial wood sections from Pinus radiata. Holzforschung 48: 168–172.

Greve, U. 1984. Holzbiologische Untersuchungen an Fichten (Picea abies (L.) Karst.) unterschiedlicher Immissionstoleranz und Immissionsbelastung. Diss., Univ. Hamburg. 137 pp.

Hoag, M. & M. D. McKimmy. 1988. Direct scanning X-ray densitometry of thin wood sections. For. Prod. J. 38: 22–26.

Jacoby, G. C. 1982. The arctic. In: M. K. Hughes, P. M. Kelly, J. R. Pilcher & J. V. C. Lamarche (eds.), Climate from tree rings: 107–114. University Press, Cambridge.

Kabir, M. F., W. M. Daud, K. Khalid & H. A. A. Sidek. 1998. Effect of moisture content and grain direction on the dielectric properties of rubber wood at low frequencies. Holzforschung 52: 546–552.

Khalid, K. B., M. F. Kabir, W. M. Daud & H. A. A. Sidek. 1999. Multi-component mixture modeling for the dielectric properties of rubber wood at microwave frequencies. Holzforschung 53: 662–668.

Kollmann, F. 1982. Holz und Feuchtigkeit. Teil 1: Begriffe, Bestimmung, Sorption, Feuchtegleichgewicht. Holz-Zentralblatt 91: 1290–1291.

Lenz, O., E. Schär & F. H. Schweingruber. 1976. Methodische Probleme bei der radiographisch-densitometrischen Bestimmung der Dichte und der Jahrringbreiten von Holz. Holzforschung 30: 114–123.

Lewark, S. 1986. Die Methode der Röntgendensitometrie von Holz und ihre Anwendung an Holz Immissionen ausgesetzter Bäume. Forstarchiv 57: 105–107.

Ohta, S. 1978. The observation of tree ring structure by soft X-ray densitometry (I). The effects of air pollution on annual ring structure. J. Jap. Wood Res. Soc. 24: 429–434.

Olson, J.R., D.G. Arganbright & P.T. Rygiewicz. 1978. Increment core planer for X-ray densitometric sample preparation. Wood Science 11: 33–36.

Parker, M.L. & W.E.S. Henoch. 1971. The use of Engelmann spruce latewood density for dendrochronological purposes. Can. J. For. Res. 1: 90–98.

Polge, H. 1963. Une nouvelle méthode de détermination de la texture du bois: l'analyse densitométrique de clichés radiographiques. Ann. Sci. Forest. 20: 533–580.

Polge, H. 1971. Le "message" des arbres. La Recherche 2: 331–338.

Polge, H. 1978. Fifteen years of wood radiation densitometry. Wood Sci. Technol. 12: 187–196.

Rothlisberger, F. 1976. 8000 Jahre Walliser Gletschergeschichte. II. Teil: Gletscher- und Klimaschwankungen im Raum Zermatt, Ferpecle und Arolla. Die Alpen 52: 61–151.

Schweingruber, F.H. 1982. Measurement of densitometric properties of wood. In: M.K. Hughes, P.M. Kelly, J.R. Pilcher & J.V.C. Lamarche (eds.), Climate from tree rings: 107–114. University Press, Cambridge.

Schweingruber, F.H. 1988. Tree rings: basics and applications of dendrochronology. Reidel, Dordrecht.

Schweingruber, F.H. 1990. Radiodensitometry. In: E.R. Cook & A. Kairiukstis (eds.), Methods of dendrochronology: 55–63. Kluwer, Dordrecht.

Schweingruber, F.H., H.C. Fritts, O.U. Bräker, L.G. Drew & E. Schär. 1978. The X-ray technique as applied to dendroclimatology. Tree-Ring Bull. 38: 61–91.

Spiecker, H., M.G. Schinker, J. Hansen, Y.-I. Park, T. Ebding & W. Döll. 2000. Cell structure in tree rings: Novel methods for preparation and image analysis of large cross sections. IAWA J. 21: 361–373.

Tomazello, M., P.C. Botosso & C.S. Lisi. 2000. Potencialidade da familia Meliaceae para dendrocronologia em regiões tropicais e subtropicais. In: F.A. Roig (ed.), Dendrocronología en América Latina: 381. EDIUNC, Mendoza.

Torgovnikov, G.I. 1990. Dielektrische Eigenschaften von absolut trockenem Holz und Holzstoff. Holztechnologie 31: 9–11.

Trapp, W. & L. Pungs. 1956. Einfluß von Temperatur und Feuchte auf das dielektrische Verhalten von Naturholz im großen Frequenzbereich. Holzforschung 10: 144–150.

Vetter, R. 1995. Untersuchungen über Zuwachsrhythmen an tropischen Bäumen in Amazonien. Diss., Univ. Freiburg. 108 pp.

Vetter, R. 2000. Growth periodicity and age of Amazonian tree species. Methods for their determination. In: F.A. Roig (ed.), Dendrocronología en América Latina: 135–155. EDIUNC, Mendoza.

Worbes, M., D. Klosa & S. Lewark. 1995. Rohdichtestruktur von Jahresringen tropischer Hölzer aus zentralamazonischen Überschwemmungswäldern. Holz Roh- u. Werkstoff 53: 63–67.