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INTERNAL WOOD INSPECTION WITH ACTIVE CONTOUR USING DATA FROM CT-SCANNING

Cristhian Aguilera
Depto. de Ing. Eléctrica y Electrónica, Universidad del Bio-Bio, Casilla 5-C, Concepción, Chile

Richardo Sanchez
Depto. Ing. Eléctrica, Universidad de Concepción, Casilla 160-C, Concepción, Chile

Erik Baradit
Depto. de Física, Universidad del Bio-Bio, Casilla 5-C, Concepción, Chile

ABSTRACT

The segmentation of objects coming from digital images is an area that is increasingly being addressed with greater emphasis. Diverse techniques have been applied to segment images obtained by Computer Tomography (CT). One of the principal problems is that the majority of these images are guided, principally by image intensity, creating complications when images possess noisy information. This work proposes an automatic segmentation method for images obtained by CT. It proposes the use of active contour with an energy function that weights the image's potential with object information known a priori to segmentation. To validate the proposed technique, wood pieces, saturated in water and noise, were inspected to isolate knots and other defects. The results have been surprising, obtaining very acceptable degrees of certainty, greater than those obtained with traditional techniques.

KEY WORDS: image processing, X-rays, wood

INTRODUCTION

Exact knowledge of a material's internal structures is important information that acquires great relevance when the final product needs to be optimized or the quality indexes need to be improved. For example, in the case of the lumber industry, the internal structure of a piece or log as well as its density and the location of its internal defects result in an important economic advantage. The same occurs in other productive processes, such as the textile, metal, mechanical, or plastic industry. Consequently, to optimize prime material use, information on its form and internal quality is fundamental prior to its utilization. Many studies support this declaration (Sarigul et al. 2001, Schmoldt et al. 2000a), and is especially important in the lumber industry, where the situation of some products is very sensitive. For example, internal knowledge of a material allows the identification of a better cutting pattern, adapted to its internal structure, notably increasing efficiency in raw material use. Some researchers like Öhman (Öhman 1999) demonstrated that in the case of the lumber industry, the value of sawed wood can increase by 10 % when the internal structure of the piece is known. Others have estimated improvement percentages due to cutting optimization between 3% and 28% (Schmoldt et al. 2000a). The incorporation of automatic inspection systems, both internal and external detection, has enormously increased in these last few years. Additionally, this system can be extended to other manufacturing industries as mentioned earlier.

In the study to internally characterize materials, several non-destructive techniques have been used including: Ultrasound, microwave, gamma rays, nuclear magnetic resonance (NMR) and X-rays. The ultrasound technique is based in the propagation of mechanical waves through wood (Bucur 1995, 1996). Based in this phenomenon, ultrasound has been studied to measure the humidity content effect and temperature on the mechanical properties and to evaluate and classify wood for structural use (Sandoz 1996, Sandoz 1993). Another technique used is microwaves, where a microwave sensor is capable of detecting a void in a piece of wood, plastic, or in any material. Even though some consider that the use of microwave studies is limited with respect to exploration depth and low penetration for internal defect detection, the present technological advances suggest greater potential to this technique. For example, in wood, some properties are dependent on humidity, density, and fiber angle (Torgovnikov 1994). The principal microwave sensors have successfully estimated fiber angle, detected knots, measured density and humidity, and classified according to mechanical resistance (Martin 1987, King 1991).

The application of gamma rays, X-rays, and NMR has been validated for the internal morphological description of wood and other materials. However, the majority of the studies developed have centered in treating the data obtained by computerized X-ray tomography since this technique provides the security, exploration velocity, and information quality characteristics required for real-time industrial implementation. Additionally, NMR is limited by the presence of objects that perturb the scene such as metallic objects inside the explored pieces (Karsulovic and Leon, T. 1996).

X-rays have been used to examine internal characteristics of many materials (Benson et al. 1982, Taylor et al. 1984, Wagner et al. 1989, Zhu et al. 1996). A computerized X-ray tomography reflects variations in the density of an object or body. The areas of higher density can be represented as an image with more brilliant or clearer points, while the lower density areas appear in the image as darker points. Thanks to this property and the subsequent image generation, internal defects in the materials, such as cracks, can be isolated. Using X-rays in the lumber ambit, Öhman (Öhman 1999) demonstrated that the internal structure of a piece of lumber can be identified with a precision between 74 and 81 % (95 % of confidence for the average interval).

According to Skatter (Skatter 1998), gamma ray and X-ray sensors are the only ones that provide information on the form of the piece under the bark, being able to detect the wood's macroscopic and microscopic aspects. Skatter used X-rays to identify the exterior form of wood pieces. The results obtained by these researchers demonstrated that X-rays facilitate the measurement of the interior and exterior form, especially in small diameter pieces.

In conclusion, the processing velocity and the precision in the identification of the internal defects in a piece under inspection are very relevant in the use of X-rays as an exploration technique.

In the published literature, the application of the X-ray technique is fully justified with respect to the quality of the obtained information. The authors cited have centered their efforts in validating the technique as a tool applicable to wood and other materials (Sepulveda and Kline 2003, Rojas et al. 2005). A large volume of information provided by the tomographs, the processing velocity of the sensor part, the segmentation algorithms to be used to identify singularities, three-dimensional visualization, and finally the algorithms' great dependence on the material type and particularly in the singularities have significantly complicated automatic application and real time application. Up to now, these complications have been little addressed. In the next few years, an important challenge is precisely the adaptation and creation of appropriate segmentation algorithms for anomaly identification in pieces or materials in real time, and this is associated to the each one's processing velocity. Algorithm processing dependence makes the applications strongly dependent on the treated materials and the type of singularities to be detected.

An important number of visualization and segmentation techniques have been developed in these areas. They have had important success, which has permitted, for example, their incorporation into the latest generation of medical equipment. On the other hand, the development of segmentation techniques based in Artificial Neuronal Networks and their combinations have contributed to a great advance in the detection of singularities, presenting some knot recognition applications based in neuronal network techniques for 2D images. Other works (Schmoldt et al. 2000b) have developed techniques based in the combination of neuronal networks for the segmentation and classification, reporting very good results: 92 % of certainty over three-dimensional patterns. However, these studies, in addition to not improving substantially the certainty percentages, become complicated due to the material type and noise levels, in their distinct types, that can be handled by the technique.

In the ambit of deformable contours, several studies have been developed. These have been performed in different areas such as medicine, robotics, process industry, wood, etc. For example, (Ivins and Porril 1994) use deformable contours to segment medical images, (Sarigul 2001) use the same perspective to detect internal defects in hardwood logs, Heimann (Heimann 2004) propose the modification of the contour's energy forces to improve the detection characteristic.

Even though the authors have reported good results, in general the theme of noise or possible deformations, principally in those materials whose density can be affected by handling or treatment, such as is the case for wood, plastics and other materials. In this case, the relation between the X-ray and object density tremendously distorts X-ray tomography. Since humidity absorption, especially in the case of wood, is not homogenous, the problem is accentuated even more. The present work addresses this problem: the distortions produced by density variations in the objects and their effect on the Computerized Tomography. This study focuses on a solution considering a priori information in function of the energy of a deformable contour.

MATERIAL AND METHODS

A deformable contour or snake (Kass et al. 1988) is a parametric curve of the type

$$u(s) = (x(s), y(s)) \quad s \in [0,1] \tag{1}$$

Internal and external forces typically related to the image intensity gradient influence these contours. Such contours are generally situated near the object to be segmented in an image (Fig. 1), and attraction and repulsion forces, generated by the internal and external forces, deform the contour up to the point that this surrounds the object, obtaining an isolation of the object with respect to the entire image.

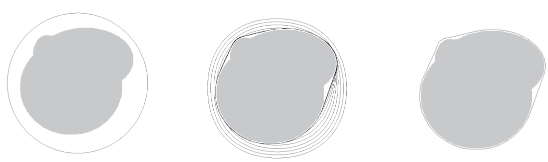


Fig. 1: Active Contour, a) Initial Contour, b) Contour Evolution c) Final Contour

As can be observed in the Fig. 1, the contour situated near the object to be segmented is attracted and deformed principally by the force of the image up to the point that the contour completely surrounds the object. From that point, we can observe that this method can be strongly influenced by other objects in the image or by intensity points not related to the object. The classic strategies approach the problem as a minimization of the snake's global energy, given by:

$$E_{snake} = \int_0^1 \left[E_{\text{int}}(u(s)) + E_{ext}(u(s)) + E_{img}(u(s)) \right] ds \qquad (2)$$

The forces involved are:

Internal forces: Internal constraints give the model tension and stiffness.
External forces: External constraints come from high-level sources, such as human operators or automatic initialization procedures.
Image forces: Image energy is used to drive the model towards salient features such as light and dark regions, edges, and terminations.

The mechanical properties are specified by (Ivins and Porril, 1994):

$$E = \frac{\alpha}{2}\oint\left[\frac{\partial u}{\partial s}\right]^2 ds + \frac{\beta}{2}\oint\left[\frac{\partial^2 u}{\partial s^2}\right] ds + \frac{\rho}{2}\oint\frac{\partial u}{\partial s}x\ uds + \oint \mathrm{P}(\mathrm{I}(u))\, ds \qquad (3)$$

Tension *Stiffness* *Pressure* *Potencial*

Internal and External Energy are specified in discrete terms as:

$$E_{intern}(x) = a(s)\left|x_s(s)\right|^2 + \beta(s)\left|x_{ss}(s)\right|^2$$

Tension *Stiffness*

$$E_{extern1}(x) = k\left|i - x\right|^2$$

$$E_{extern2}(x) = \frac{k}{\left|i - x\right|^2}$$

Image Energy Functional

$$P = E_{img} = E(Line, Egde, Term)$$

Line Functional

$$E_{line} = \int_0^1 I(x(s))\ ds$$

Edge Functional

$$E_{edge} = -\int_0^1 \left|\frac{\partial I}{\partial X}\right|^2 ds$$

Termination Functional

$$E_{term} = \int_0^1 \frac{\partial \theta}{\partial n_\perp} ds = \int_0^1 \frac{\partial^2 C / \partial n_\perp^2}{\partial C / \partial n} ds$$

$$E_{term} = \int_0^1 \frac{C_{yy} C_x^2 + C_{xx} C_y^2 - 2 C_{xy} C_x C_y}{(C_x^2 + C_y^2)^{3/2}} ds$$

Considering the forces of a contour in situations where there is noise or distracter points, the situation will be distorted by the attraction or repulsion of these distracter points (Fig. 2).

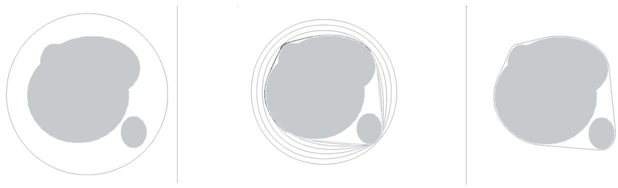


Fig. 2: Active Contour and distraction points, a) Initial Contour, b) Contour Evolution, c) Final Contour

This is the case of tomography X-ray images in which other objects or variation in object density (e.g., water saturation in wood pieces, X-Ray cut point) artificially loses the form of the objects to detect, provoking a large error in segmentation due to this influence.

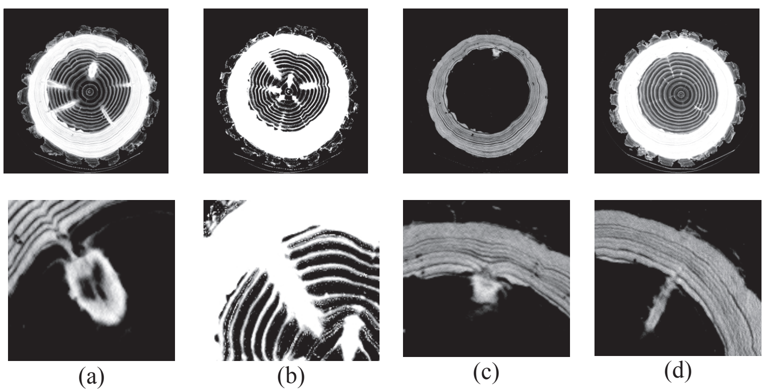


Fig. 3: Knots in image CT, a) Isolated knot and good geometry, b) Moisture and distraction points, c) y d) distortion by cut X-Ray

For example in the Fig. 3, a tomography image with distinct singularities or objects to detect can be appreciated in the piece being inspected. In a), the tomography of a piece with humidity under 8% is presented, and results in a very clear and easy-to-segment images; however, in b) an image of a wood piece with a lot of distortion due to high humidity content, in c) and d) distortion by X-Ray cut point, which as can be appreciated, is not necessarily distributed homogenously in the piece and can provoke deformations in the objects to be segmented.

Several techniques have been employed to improve these aspects, from characteristic extraction techniques up to improvements in the energy function utilized. However, even when information about the objects to be detected is known a priori, such as in the case of well-defined objects and with known forms and characteristics, this information has not been incorporated into the energy function. Some approaches, like Deformable Templates, use a priori defined Templates and transform the problem into how to best adjust this Template with the image considering contour forces. Still, even though this produces good results, it suffers from the rigidity due to the templates. If the energy function is modified to incorporate this a priori information (object knowledge), then it could be weighted against the image's energy. In mathematical terms, a new term is incorporated into the image's energy function, which weights the image information as well as the a priori information of the objects to detect:

$$E = \frac{\alpha}{2}\oint\left[\frac{\partial u}{\partial s}\right]^2 ds + \frac{\beta}{2}\oint\left[\frac{\partial^2 u}{\partial s^2}\right] ds + \frac{\rho}{2}\oint\frac{\partial u}{\partial s} x\ uds + \oint \mathrm{P}\left(\mathrm{I}(u), Inf\right) ds$$

$$\begin{aligned}&Where:\\&Inf: A\ priori\ Information\end{aligned}$$

In the case of CT images, this information can be incorporated, for example, in relation to the objects' morphological information, distribution, likely appearance locations, special characteristics, etc. For example, in the case of wood, to segment knots and other defects, geometric information of these could be used when it's most common forms are known.

$$E_{\inf} = \left\| C_{i-1} - 2C_i + C_{i+1} \right\|^2$$

$$\begin{aligned}&with:\\&\quad C_i = P_i - M_i\\&\quad P_i = \ Imagen\ Pixel\\&\quad Mi = ModelPixel\end{aligned}$$

One form of energy used can be modeled by equation 3, which describes in normalized terms the object's expected form near the minimization points in strict terms. Therefore, the energy function of the image is transformed in:

$$E_{imag} = -\alpha\left\|\nabla I\right\|^2 + \beta E_{\inf}$$

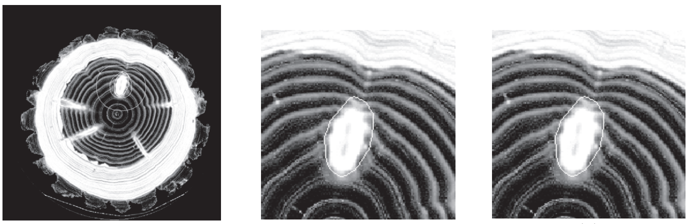
With α , β weighted constants.

RESULTS AND DISCUSSION

Following the method described above, using the modified energy functions incorporating information of knot geometry in pinewood, the images obtained from X-ray computerized tomography of wood pieces with the following characteristics were analyzed: a) images of wood with good geometrics and without excess humidity, b) images of wood with water saturation, and c) images with artificially generated noise, in this case, images with a normal distribution of artificially generated noise could be distinguished. In all the cases, analysis by means of a traditional energy function (method 1), and analysis by means of an energy function that considers knot geometry (method 2) were used.

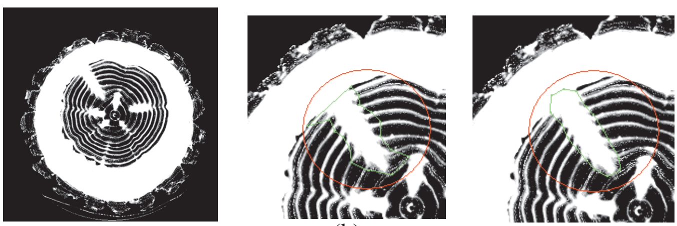
The first case of wood without water saturation (without excess water, Fig. 4) is considered. In this case, wood density is not altered externally, and consequently the images obtained from the X-Ray tomography perfectly represent its properties. Ten images were analyzed considering the distinct energy functions proposed.

The second case considered a piece of wood saturated with water, a real condition obtained in industrial processes, which means that there are density variations inside the wood that induce distortions into the images obtained by tomography. Ten images were analyzed. In Fig. 5, the location where there is water saturation can be observed in the tomography images, which as mentioned is a real situation in industrial inspection systems. In this case, the first method is very influenced by image intensity and especially by the intensities produced by water saturation (Fig. 5b). This result was expected because the energy function only weights image intensity without considering what it is trying to identify. In the second method (Fig. 5c), a well-behaving system is observed considering the attractions provoked by the intensity of water accumulations or saturations. In this case, when the image is weighted with the morphology of the object to identify, the system prohibits the contour from moving to locations unjustified by the object's nature.



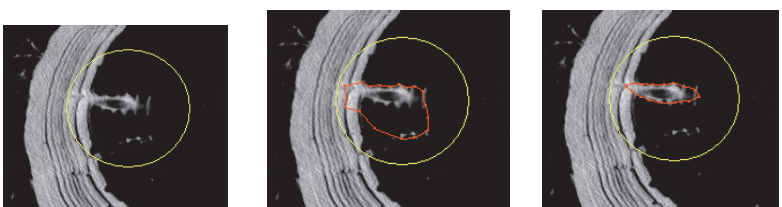
(a) (b) (c)

Fig. 4: Knots isolated in image CT, a) Original image, b) Segmentation without a priori information, (c) Segmentation with a priori information



(a) (b) (c)

Fig. 5: Knots in image CT with moisture, a) Original image, b) Segmentation without a priori information, (c) Segmentation with a priori information



(a) (b) (c)

Fig. 6: Knots in image CT with distortion, a) Original image, b) Segmentation without a priori information, (c) Segmentation with a priori information

The third case considered a piece of wood with distortion due to the X-Ray cut. In the Fig. 6, the location where there is distortion in the knot morphology can be observed. The first method is again very influenced by image intensity and especially by the intensities produced by isolated points (Fig. 6b). In the second method (Fig. 6c), the system that behaves very well is observed considering the attractions provoked by the intensity of isolated points. In this case, when the image is weighted with the morphology of the object to identify, the system once again prohibits the contour from moving to locations unjustified by the object's nature.

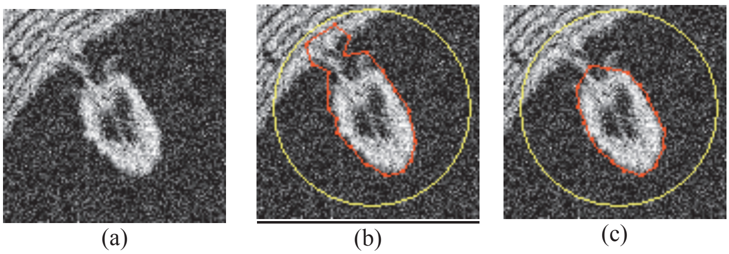


Fig. 7: Knots in image CT with noise, a) Original image, b) Segmentation without a priori information, (c) Segmentation with a priori information

To test system robustness, some images corrupted with noise as well as with artificially generated stains were created close to the objects to be detected. As can be appreciated in the Fig. 7, there is an initial image corrupted with noise (Fig. 7a) and one active contour around the knot (Fig. 7b). The results are very good because, despite the generated noise, the segmentation is performed very well (Fig. 7c), and the proposed energy function avoids the exaggerated deviations produced when considering the force of the contour related only with image intensity. Finally, as can be observed in the figures, when there is neither water saturation nor distortion in the topographic images, both systems behave well. However, it can already be appreciated that the system with the traditional energy function is more affected by moisture and distortion than the proposed energy system.

CONCLUSIONS

Based the results obtained, we can conclude that the active contours method presented is a good alternative in situations where information of the objects to be segmented is known a priori. In the case of active contours, the incorporation of this information in an energy function, and in particular in the function that describes the image's force, is a very good alternative for situations where the image is distorted by handling, environment, or treatment situations. The examined cases correspond to the case of segmentation by computational tomography for wood pieces where there are significant distortions principally due to the storing process, which provokes an increase in material density and the consequent effects on the tomographies. This case is of special interest for the lumber industry; however, this technique can be used in other situations, such as in the medical ambit where the morphology of known objects in the human body can help segment tumors using the known object segmentation perspective rather than the tumor segmentation. The authors are presently developing techniques in the 3D ambit as well as searching for ways to reduce the method's computational costs, which were not considered in this first study.

REFERENCES

1. Benson, D., Knowles, K., Thompsom, F., Cown, D., 1982: Detection of defaults in logs, Report Nº 8 Forest Reserach Institute of New Zeland-Forest Service : 1-9
2. Bucur, V., 1995: Acoustic of wood, Springer, Pp. 400
3. Bucur, V., 1996: Acoustic of wood as a tool for non destructive testing, 10 th Int. Symp. On non destructif testing of wood. Laussanne: 53-59
4. Heimann, T., Thorn, M., Kunert, T., Meinzer, H., 2004: New methods for leak detection and contour correction in seeded region growing segmentation, the international archives of the photogrammetry, remote sensing and spatial information science, Vol. 34: 317-322
5. Ivins, J., Porril, J., 1994: Statistical snakes: active region models, fifth british machine vision conference (BMVC'94; York, England), Vol. 2: 377-386
6. Karsulovic, J., Leon, T., 1996: Aplicación de la radiación Gamma en la detección de Nudos en Piezas de Madera de Pino radiata, Revista de Ciencias Forestales Vol. 10 Nº 10: 1-6
7. Kass, M., Wikins, K., Terzopoulos, D., 1988: Snake: Active Contour Model, International Journal of Computer Vision, Vol 1: 321-331
8. King, R., 1991: Measurement of basic weight and moisture content of composite board using microwave. VIII th Int. Symp. On non-destructive testing of wood. Vancouver: 21-32
9. Martin, P., 1987: Evaluation of wood characteristics, Internal scanning of the material by microwaves, Wood Sciences Technology, N° 21 : 361-371
10. Öhman, M., 1999: Plank grade indicators in radiograph images of scots pine logs, Holz als Roh- und Werkstoff, Vol. 57 :359-363
11. Rojas, G., Hernández, R., Condal, A., Verret D., Beauregard, R., 2005: Exploration of the Physical Properties of Internal Characteristics of Sugar Maple Logs and Relationships with CT Images, Wood and Fiber Science, Vol. 37, Number 4: 591-604
12. Sarigul, E., Abbott, L., Schmoldt, D., 2001: Nondestructive rule-based defect detection and indentification system in CT images of hardwood logs, Review of Progress in Nondestructive Evaluation, Vol. 20: 1936-1943
13. Sandoz, J., 1993: Moisture content and temperature effect on ultrasound timber grading, Wood Science and Technology, Vol. 27: 373-380
14. Sandoz, J., 1996: Ultrasonic solid wood evaluation in industrial applications, 10 th Int. Symp. On non-destructive testing of wood. Lausanne: 313-321
15. Schmoldt, D., Scheinman, L., Rinnhofer, E., Occeña, L., 2000a: Internal Log Scanning: Research to Reality, Hardwood Symposium Proceedings: 103-114
16. Schmoldt, D., He, J., Abbort, A., 2000b: Autometed Labeling of log feature in CT imagery of multiple hardwood species, Wood and Fiber Science: 287-300
17. Sepulveda, P., Kline, D., 2003: Prediction of fiber orientation in Norway spruce logs using an X-Ray log scanner: A Preliminary Study, Wood and Fiber Science, Issue Vol. 35, Number 3: 421-428
18. Skatter, S., 1998: Determination of cross-sectional shape of softwood log from three x-ray projections using an elliptical model, Holz als Roh-und Werkstoff, Vol. 56: 179-186
19. Taylor, F., Wagner, F., McMillin, C., Morgan, I., Hopkins, F., 1984: Locating knots by industrial tomography, Forest Product Journal, Vol. 34, Number 5: 42-46
20. Torgovnikov, G., 1994: Dielectric Properties of wood and wood-based materials, Holz als Roh-und Werkstoff : Pp. 86
21. Wagner, F., Taylor, F., Ladd, D., McMillin, C., Roder, F., 1989: Ultrafast CT scanning of an oak log for internal defect. Technical note, Forest Product Journal, Vol. 39, Number 11/12: 62-64

22. Zhu, D., Conners, R., Schmoldt, D., Araman, P., 1996: A prototype vision system for analyzing CT imagery of hardwood logs. IEEE Transactions on Systems, Man and Cybernetics—Part B: Cybernetics, Vol. 26 Number 4: 522-532

Cristhian Aguilera
Depto. Ing. Eléctrica y Electrónica
Universidad del Bio-Bio
Av. Collao 1202
Casilla 5-C
Concepción
Chile

Richard Sanchez
Depto. Ing. Eléctrica
Universidad de Concepción
Victor Lamas 1290
Casilla 160-C
Concepción
Chile

Erik Baradit
Depto. de Física
Universidad del Bio-Bio
Av. Collao 1202
Casilla 5-C
Concepción
Chile