Niilo Saranummi

VTT Information Technology,
Tampere, Finland

# Synopsis

## *Image and Signal Processing*

Image and signal processing techniques abstract and interpret data for diagnostic, therapeutic and monitoring purposes. Before they diffuse into clinical practice a thorough evaluation must be passed. First a new algorithm must be shown to work in laboratory conditions with a limited patient sample. After feasibility has been demonstrated the algorithm must be validated against a more comprehensive set of patient cases. This normally leads to changes in the algorithm requiring a new validation cycle. Once the algorithm has been "tuned" with the available patient cases it must be validated against a new independent set of patient cases to rule out bias in performance. Unfortunately, there are only a few of such reference signal and image libraries available.

Parallel to algorithm validation the procedure in which the algorithm is embedded must be evaluated. Typical questions for this stage comprise: will the algorithm improve diagnostic accuracy, can treatment plans be generated and executed with greater accuracy, will the algorithm reduce false positive alarms in monitoring tasks, what are the implications to manpower and other resource requirements, will the procedure replace an existing procedure or is this a new procedure, is it effective, and do users accept it? The value of the algorithm must be proven not only in the technical dimension but also in the dimensions of clinical outcomes and resource utilization.

The seven papers introduced here are at different stages of their respective diffusion curves. One of them explores an application of fractals to characterize cell profiles. Two papers present proof of principle, namely brain-computer communication and robotic assistance in orthopedic surgery. Two papers show that signal and image processing techniques can make difference in explaining cardiomyoplasty and measuring skeletal growth. One paper addresses ECG compression, and the last paper reviews the application of 3-D imaging techniques in medicine.

The first paper *Digital image analysis of self-similar cell profiles* by Nonnenmacher and co-authors [1] suggests fractal dimension (D) as a classifier of cell profiles. Three techniques for measuring the fractal dimension are described and evaluated. The cells used in this test are human T-lymphocytes and hairy leukemic cells. A set of cells is used to provide a statistical estimate of the cellular profiles of these cells. The measurements are carried out using scanned electron micrographs. The use of yardstick, box counting and probabilistic methods was tested in measuring D. If minimising the error is the main criterion then the probabilistic method is the best. However, it requires much more computing time than the others. The yardstick method is the quickest but it is also the most inaccurate of these three methods. Therefore the authors suggest the use of the box counting method because that is able to detect self-similarity over a domain which is two orders of magnitude larger than that obtainable with the yardstick method. The paper concludes by suggesting fractal dimension as one of the quantifiers for cell shapes.

Wolpaw and McFarland show in their paper *Multichannel EEG-based brain-computer communication* [2] that 2-channel EEG can be used to control the movement of a cursor on a computer screen in two dimensions. All individuals have a need to communicate with and control their environments. In certain disabilities these skills have been lost. Alternative means are then required to compensate for the loss of speech and motor movements. Many strategies have been explored and shown to function for cases where control of movements of some body parts still exists. In this paper, a method based on EEG is investigated which could, if successful, be used by people with no motor movements at all. It is based on two electrode pairs placed on the skull. A narrow frequency band of 5 Hz centered around 10 Hz is extracted from the EEG signal. These signals are used to generate the control signals for moving the cursor in the vertical and horizontal directions. Five normal adults participated into the study in which they gradually learned to use their EEG to control the movements of the cursor. The best score was 70% whereas if left to chance the score would only be 25%. One individual, on the other hand, was only able to control in one dimension. It would have been interesting to know what the learning curve is, i.e., how quickly people can be trained and whether the scores can reach 100%. It appeared that the test subjects used slightly different frequencies to control the movement in the two directions (10 Hz and 11 Hz respectively). However, the authors do not tell whether the use of control signals derived from these narrower frequency bands would give better separation and better scores. Could it be that the control frequencies are individually determined and that therefore the signal filters need to be adapted case by case? Anyhow, the results are very promising. Future work will show whether the method can really be made to work with an acceptable speed, spatial resolution and accuracy.

The paper *Robotic assistance in orthopaedic surgery* by Matsen and co-authors [3] is also about a proof of principle. A robotic arm has been used to assist the surgeon in planning, positioning and orientation of cuts and holes of the femur in total knee arthroplasty. The rationale for using robotic assistance lies in the fact that the procedure is very complex and requires a highly skilled surgeon for the knee replacement to be attached to the femur in an optimal way. The robotic approach is based on templates in the planning phase. The surgeon selects a template that meets the requirements best. This approach is based on complete 3-D geometrical plans stored as templates which the robot then translates into orientation and positioning instructions of the actual surgery. The use of templates and the subsequent guidance in positioning and orientation of holes and cuts improves accuracy and precision. In a sense the robotic assistance system is a knowledge system, in which the templates are the high-level representations of allowed procedures which can be translated into instructions on how to carry out such a procedure. The surgical procedure is carried out by the surgeon. The robot only shows the positions and orientations of the drill and saw with respect to the distal part of the femur. The method has been tested in laboratory conditions for accuracy and precision. It was also compared against a group of five practising orthopedic surgeons using plastic femurs and finally in a full operating room environment with a cadaver. The overall results are very promising. The accuracy of the fit is much better when using robotic assistance. The time to carry out the procedure is roughly the same although the authors make suggestions on how the time can be reduced. In highly complex surgical procedures robotic assistance can clearly be of help outweighing the extra cost of the system.

3-D image processing can be used to shed new light on clinical questions as shown in the paper *New method for mechanistic studies of cardiomyoplasty: Three-dimensional MRI reconstructions*, by Cho and co-authors [4]. Cardiomyoplasty is intended to provide systolic augmentation of cardiac pump function as a result of a synchronously stimulated contraction of a latissimus muscle craft placed around the heart. The optimization of the orientation and conditioning protocols of the muscle wrap is, however, at the present time speculative. The authors have used radio frequency-tagged magnetic resonance imaging to generate 3-D reconstructions of the left ventricle throughout the cardiac cycle, both when the wrap was stimulated and without it. Contrary to techniques like ultrasound and nuclear medicine this method is able to show the marked translation, rotation and displacement of the left ventricle in the three-dimensions when the wrap is stimulated. The results were obtained using two dogs as test material. 3-D reconstructions are used to explain the cardiac function and phenomena during the stimulation of the cardiac wrap. The technique can also be used to optimise wrap orientation and conditioning. However, as MRI cannot be used in the presence of ferromagnetic devices (such as the implanted wrap stimulator) its usage is restricted to occasions where these are implanted and changed (for battery life).

Sun and co-authors present in the paper *A computer system for skeletal growth measurement* [5] how image processing can improve the accuracy and reproducibility of measuring skeletal growth in pediatric radiology. Current methods depend primarily on human observation and the skills of the observer. The method proposed in this paper is based on image processing algorithms to detect selected phalanges and to classify them using geometrical parameters associated with skeletal growth. These parameters are then used as a look-up-table to determine skeletal age. The original images are 512 x 512 matrices with 256 gray levels providing a resolution of 0.45 mm/pixel and 0.35 mm/pixel in the horizontal and vertical directions. First the gray scale of the image is equalized. The pixels are sorted according to their value into a trimodal histogram (the peaks representing bone, soft tissue and background). Threshold values are then selected and the three groups are each equalized. The image is then segmented to identify phalangeal regions of interest. Once the phalanges have been identified the geometrical parameters are measured. These are used as a look-up table to determine the age of that phalange. The global skeletal age of the subject is determined by averaging the ages of all measured phalanges. The system was tested with 12 test subjects against a trained radiologist. The results agree very well. The advantage of this system is its accuracy and speed compared to conventional methods based on human observation. The processing algorithms, however, cannot cope with bones that are close to one another (e.g., metacarpal and carpal bones) and this must be improved before this can become a clinical tool.

ECG compression has been a topic of research for many years. The paper by Nave and Cohen *ECG compression using long-term prediction* [6] presents a unifying view on the different approaches and proposes a new method which combines features of several compression techniques. Uncompressed ECGs require much storage space and a large bandwidth and/or a long time for transmission. Compression is a way to cope with these two limiting conditions. Over the years a large number of compression methods have been suggested and used. If some reconstruction error can be tolerated the compression factor can be quite large. As the authors point out, the main obstacles in deciding which compression algorithms are best, are the lack of one universally accepted ECG database and the lack of agreement on how to declare the errors in reconstruction. The method proposed in this paper is a parameter extraction method based on linear prediction coding. To enhance the performance of the method a codebook is used to match ECG complexes. An in-house ECG database was used to test the algorithm. It comprised 40 ICU patients representing a variety of pathologies. Each record was 20-30 s in duration. The method can reach a bit rate of 70 b/s with a reconstruction error of less than 10% (percent rms difference).

The last paper *A decade of clinical three-dimensional imaging* by Zonneveld and Fukuta [7] presents a review of 3-D imaging algorithms that have found their way into clinical routine. The paper spans a wide range of applications for 3-D imaging techniques: cranio-maxillo-facial complex, musculoskeletal, central nervous, cardiovascular, pulmonary, gastrointestinal and genito-urinary systems, and radiation therapy. The methods discussed cover all imaging modalities. However, the current limitations of 3-D imaging and processing are a barrier to further progress. Examples of areas where controversy exists and where improvements are needed are, for instance, quality of image rendering, preference for volume or surface rendering techniques, user-interface technologies, more sophisticated segmentation techniques to free physician time to the patient case, multimodality matching (including a 3-D anatomical atlas), surgical planning and simulation techniques, computer-assisted surgery and implant design, and, finally, pricing of advanced image workstations. There is still much work to be done but much has already been achieved. 3-D imaging is already a clinical tool.

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Address of the author:
Niilo Saranummi, D.Tech.,
VTT Information Technology,
PO Box 1206,
FIN-33101 Tampere,
Finland