Sketch of an automatic image based pollen detection system

Gildardo Lozano Vega, Yannick Benezeth, Matthias Uhler, Frank Boochs, Franck Marzani

Sketch of an automatic image based pollen detection system

GILDARDO LOZANO-VEGA[1,2,3], YANNICK BENEZETH[2], MATTHIAS UHLER[1], FRANK BOOCHS[1], FRANCK MARZANI[2]

Abstract: The ability of measuring accurately airborne pollen concentration in the environment is an important goal for palynology. It has been unsatisfactory for agile usage to date. Huge volumes of airborne particles prevent palynologists from opportunely processing statistically suitable information. Additionally, measurements from stationary pollen monitors cannot be accurately associated to individuals.
In the context of computer vision, this paper presents the outline for the structure of an image based pollen detection system, under the framework of the Personalized Pollen Profiling and Geospatial Mapping project based on individual information of allergic patient profile measured at multiple points from personal mobile wearable devices. With features from classical geometric and optical measures to specialised palynological information, it is feasible to characterise different pollen taxa images. Optimal selection of features allows a pattern detection system to split and recognise each taxon exactly. Gathering such accurate individual pollen concentration data in a geo-spatial context will benefit not only to patients through more precise medication but also to the improvement of pollen distribution models and forecasting.

1 Introduction

The proportion of people in the world that suffer from allergic rhinitis is considerably high; estimations indicate from 10% to 20% (DYKEWICZ & HAMILOS 2009). For diagnosis purposes, it is necessary to understand the sort of airborne pollen taxa and the amount the sufferer was exposed to. Moreover, in order to avoid contact to risky environments, it is also beneficial to forecast pollen concentration by geographic regions. For instance, the allergen distribution in Europe changes every year (D'AMATO et al. 2007). This makes the creation of prediction models more difficult due to requirements of more precise data. Thus, the ability of measuring accurately airborne pollen concentration in the environment has become an important purpose for palynology.
Traditional counting methods consist of trapping airborne samples and counting particles manually. This is time consuming, involves costly labour and requires long-trained palynologists. Additionally, it is highly susceptible to human error due to fatigue or inexperience. These factors limit the processing of huge volumes of airborne samples and the necessary information to perform analysis with geographical accuracy in timely manner.
The advent of computer vision had brought plausible possibilities of improving counting methods to palynology. Microscopic object identification is becoming faster and more robust, although a satisfactory automatic pollen detection system has not been found yet. Such system need to be able to estimate the pollen concentration accurately in time and to gather information from multiple geographic points still being affordable.

1) i3mainz, Fachhochschule Mainz, Lucy-Hillebrand-Strasse 2, 55128 Mainz, Germany.
2) Le2i, Université de Bourgogne, B.P. 47870, 21078 Dijon Cedex, France.
3) E-Mail: gildardo.lozano@fh-mainz.de

2 Scheme of the 3P-GM project

The present work aims to outline the structure of an image based pollen detection system, under the framework of the Personalized Pollen Profiling and Geospatial Mapping project (3P-GM). The aim of 3P-GM project is to create an allergic patient profile based on reliable information of most allergenic pollen taxa concentration in the vicinity of a patient, measured on an individual basis at multiple points from personal and mobile devices.
Whereas stationary pollen monitors are capable of sampling just a single location and representing extensive regions, the proposed individual mobile pollen trap will gather airborne particles in the vicinity of the patient, and therefore with a closer relationship to the concentration of his exposure. The device will be able to gather information of the environmental conditions, geo-position and sampling time. Together with the symptomatic framework, this information will bring the analysis of pollen concentration to a new level. For example, it can be analysed by geo-statistical scientists, for example, to improve pollen distribution models and forecasting or by doctors for more precise and personalised treatment and medication.
In the following section, a description of relevant approaches according their function in the image based pollen detection system is given: imaging technologies, pollen localisation and segmentation techniques, modelling of pollen according to discriminating characteristics and machine learning schemes.

3 Sketch of a pollen detection system

Almost all works and projects in automatic and semi-automatic pollen recognition have followed the process described in Fig.1. The goal is to optimally adapt processing to the real characteristics of the pollen, which are most suitable and reliable for robust image based detection. However, available technical resources limit the system for instance, microscopy hardware, cost and computational power (including processing time and data storage). A trade-off between accuracy and resources needs to be considered. Below, most representative approaches are described as function of their contribution to tackle the recognition problem.

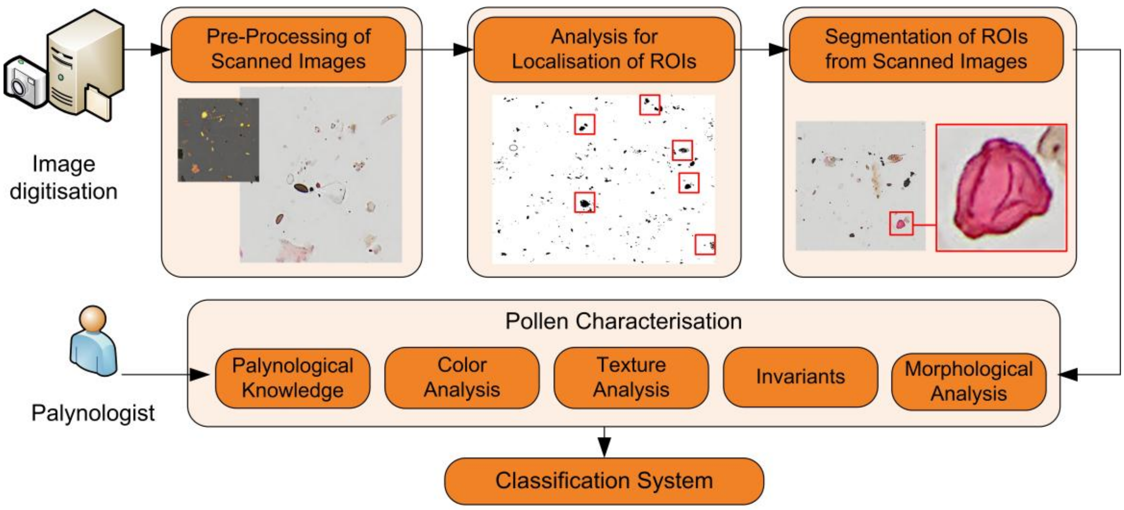

Fig.1 Typical pollen detection system: Image digitalisation, pre-processing, ROI localization. ROI segmentation, pollen characterisation and classification.

3.1 Image digitisation

Pollen grains have typical size between 10 and 100 microns depending on the taxa and almost all allergenic sorts have near spherical shape. Additional important characteristics are symmetry, apertures, ornamentation and internal structures. During the digitisation, it is sought to retain all these characteristics in the image. Also pollen grains usually acquire a purple-red dye after being prepared with fuchsine to enhance visibility of characteristics, previous to digitisation.
3P-GM project employs *airborne samples* as source that, unlike *manually prepared samples* are formed of a bulk of airborne pollen, debris and different biological particles stuck randomly in a sampling material.
One of the most employed microscopy techniques for pollen detection is transmitted light microscopy (TLM) due to its accessibility, simplicity and low cost. A drawback is the reduction of visibility of pollen characteristics after its projection in a 2D plane with magnification limited to 100X. Multiple-layer imaging at different heights is a technique that is used to gather volumetric information of the specimen. Higher-quality imaging methods such as electron beam based and confocal microscopy require specialised manipulation, high cost and long imaging time. Also fluorescence microscopy is useful to identify specimen's components that under typical TLM would not be possible. However, it requires high energy light sources, which usually have short lifetime (WU et al. 2008).

3.2 Localisation and Segmentation

The localisation problem consists in identifying particles of interest in images of airborne samples. Segmentation is performed to compute the detailed contour of the region of interest and extract it. The near-circular shape of the most allergenic taxa is the base of the processing. Modelling pollen as circular objects helps with the identification in airborne samples. Also, the roundness of the pollen contour is an advantage in the segmentation stage. It can be used for parameterising energy minimization methods as well as for the application of morphological operations. Colour, combined with shape characteristics, is also functional for segmenting and localising pollen in one step.
Commonly, the Hough transform has been used successfully to identify circular objects as done by RODRIGUEZ-DAMIAN et al. (2003) AND LANDSMEER et al. (2009). Furthermore, RONNEBERGER et al. (2007) used the so called voxel-wise vector based gray-scale invariants in order to extend circular to spherical object detection for 3D objects.
For segmenting manually prepared samples, ALLEN (2006) employed a classical edge detector, combined with morphological operations. Furthermore, BOUCHER et al. (2002) combined classical morphological operations with enhanced colour information and proposed a segmentation method without previous localisation on airborne samples. Results showed a localisation/segmentation rate over 90%.
Techniques based on energy minimization have been widely employed. RONNEBERGER et al. (2007) employed a fast version of graph-cut on confocal manually prepared samples. Similarly, the “snakes” approach aims to find the contour by balancing external and internal forces. Trade-off between accuracy and smoothness can be also achieved by tuning initial parameters. However, the wrong selection of these parameters makes snakes method susceptible to local minima. Examples of successful contour segmentation using snakes are FRANCE et al. (1997), RODRIGUEZ-DAMIAN et al. (2003) and RONNEBERGER et al. (2007) on their airborne samples.

3.3 Characterisation of pollen taxa

The extraction of particular information that describes pollen grains, such that depicted in Fig. 2, is critical for the success of the detection system. Some information can be enclosed in pollen characteristics such as morphological structure, texture, colour and spectral reflectance while some other can be enclosed in pixel properties measured by local features. In order to achieve a robust system, the information must be discriminant enough to distinguish uniquely different pollen taxa and discard non-pollen grains as well as insensitive enough not to take into consideration intra-class variability. Thus a compromise must be found. There exist no single feature that can characterise pollen taxa with the aforementioned considerations completely; therefore an optimal mix is desired. In this section, most promising features for characterisation found in the field are described.

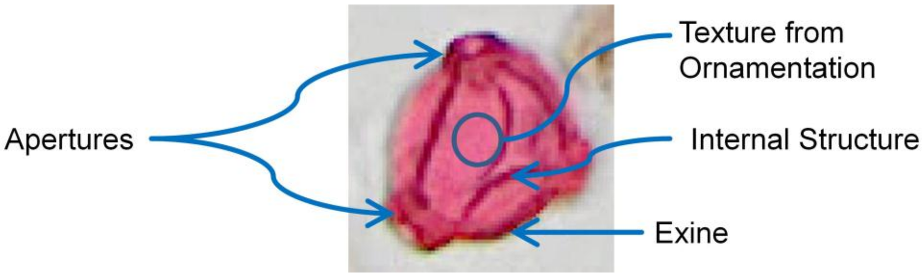

Fig.2 General characteristics of a pollen grain previously stained with fuchsin. Unknown taxon.

3.3.1 Morphological features

Geometric features. Geometrical structure is widely used in all sorts of applications and is one of the most common measures tested in pollen recognition due to its discriminating capability. RODRIGUEZ-DAMIAN et al. (2003) and BOUCHER et al. (2002) have tested more than 14 geometric features in total.

Second order moments. BOUCHER et al. (2002) and ZHANG et al. (2004) have employed parameters from central moments up to order three. These are known to be invariant to translation, rotation and scaling.

RODRIGUEZ-DAMIAN et al. (2003) are the only ones who used exclusively morphological features. An optimal search yielded to a recognition rate of 85.6% for just 3 taxa. BOUCHER et al. (2002) combined this sort of features with palynological information and reached a recognition rate of 77% for 30 taxa. Results indicate some weakness in morphological features, despite the amount of different measures. This fact was noticed by The Massey University (LI et al. 2004, HOLT et al. 2011) by considering additional features as improvement, as described in the following section.

3.3.2 Texture features

The Massey University is the only group that has deeply studied and tested texture features for pollen characterisation. In the last prototype a set of 31 parameters are used (HOLT et al. 2011). Combined with geometric features, their system achieved recognition rates from 88 to 100% for 6 different taxa. Mainly employed texture features are:

a) Grey-level co-occurrence matrix measures. From Haralick's statistics, LI et al. (2004) computed contrast of grey-levels, variance, homogeneity, inverse local homogeneity and entropy. ALLEN (2006) describes additionally the use of 12 measures from the grey gradient co-occurrence matrix.

b) Gabor features. Mean and standard deviation of a family of Gabor filters and

c) Wavelet features. Gabor and Orthogonal Wavelet transforms.

Texture analysis is a powerful approach, especially robust to low image resolution. For instance, The Massey University group had reached its results with a 20X maximum magnification system (HOLT et al. 2011).

3.3.3 Palynological knowledge

The traditional method of manual pollen classification is the identification and qualification of a set of distinctive structures belonging to each pollen taxa. The idea is to transmit palynological knowledge into the pollen detection. In a first approach, FRANCE et al. (1997) designed a method to identify a single taxon only by means of identifying its exine. Although they achieved a recognition rate of 90%, the false positive rate reached 35%. Moreover, BOUCHER et al. (2002) incorporated algorithms to find pollen structures like cytoplasm, exine ornamentation, exine thickness, pore and reticulum.

3.3.4 Colour features

BOUCHER et al. (2002) used colour information not only for segmentation but also included mean colour to the feature vector together with morphological features. Furthermore, LANDSMEER et al. (2009) designed a more complex colour-based discrimination system to distinguish pollen grains from debris, in which the colour of each pixel of the studied particle is compared to the previously determined typical colour of pollen. Best results showed a recall of 86% and a precision of 61%. Closely related, MITTSUMOTO et al. (2009) found Blue to Red (B/R) ratio suitable for recognition of 9 taxa by means of their autoflorescence images.

3.3.5 Local Invariant Features

Specific local features have been developed to address specific invariance by RONNEBERGER et al. (2007) and RANZATO et al. (2007). The best performance was reached by RONNEBERGER et al. (2007) who developed a set of 3D features from Haar integral framework: invariant to translation, rotation and global radiation deformation and robust to local deformations and gray-value transformations. They studied the performance of the features on airborne samples containing 22.700 particles of 33 pollen taxa and obtained a precision of 98.5% and recall of 86.5% with a rejection scheme.

3.3.6 Multispectral reflectance.

MITTSUMOTO et al. (2009) studied the fluorescence spectrum measured in 10nm wavelength intervals of 9 taxa. Unfortunately, only the B/R ratio was computed to compare it with the rest of the experiments. No-image-based techniques have confirmed that spectral reflectance of some pollen varies from taxon to taxon as explored by GOTTARDINI et al. (2007) and DELL'ANNA et al. (2009) with Fourier-Transform Infra-Red (FT-IR) spectral patterns.

4 Classification Algorithms

The choice of the classification method is vital for satisfactory results. Simple discriminating algorithms, e.g. one nearest neighbour, have been used for clustering due to their easy implementation and sometimes the low computational expense. For instance, RODRIGUEZ-DAMIAN et al. (2003) chose a minimum distance classifier. In order to select the most critical feature, a Floating Search Method was performed, reducing the vector size from 14 to 5 in the optimal case. BOUCHER et al. (2002) applied also the minimum distance idea to assign probabilities to shape feature vectors. The class decision was taken by confirming hypothesis probabilities by palynological features.

In a more sophisticated approach, RONNEBERGER et al. (2007) used a Support Vector Machine (SVM) technique together with one-versus-rest multi-class optimisation to get the aforementioned classification results on high-dimension vectors from 3D invariants.

Neural Networks have become very popular due to its relative simple configuration, flexibility and favourable results. For example, ZHANG et al. (2004) employed a supervised multilayer perceptron to classify a 6-dimension vector. Currently, HOLT et al. (2011) still relay in Neural Networks to classify the pollen types.

Then again, other classification methods have not been successful. RANZATO et al. (2007) used a Bayes classifier for a recognition rate of 64.9%. LANDSMEER et al. (2009) used Quadratic Discriminant Classifier and obtained the aforementioned recall of 86% and precision of 61%. These results put the method's suitability in this task into question.

5 Discussion

3P-GM project demands multiple point pollen monitoring, which implies massive analysis and agile concentration estimation. This fact discards complex and costly technologies like confocal or electron based microscopy and TLM is left as the most suitable. To overcome the reduction of pollen information, fluorescence and multiple-layer images are a clear option.

In the context of the project, the selection of techniques must focus on the localisation and segmentation of airborne samples from mobile pollen traps. Circular locators have been effectively tested on airborne samples even though some problem could arise with overlapped particles. Thus, its combination with supporting approaches may be recommendable, for example with colour features, whose information is useful not only for localisation but also for segmentation and characterisation. Moreover, airborne samples are susceptible to pollen cluttering and cropping. This problem has not been fully addressed yet and most approaches just reject particles in such cases. Multiple-layer images own the volumetric information needed for recognising overlapping particles, but constrains must carefully considered when using stacks of TLM images.

Pure morphological operations look unsatisfactory for segmenting airborne samples due to the random disposition of particle clutters. To overcome this problem, energy-minimisation-based approaches seem to have a reasonable trade-off between performance and computational cost.

The 3P-GM project requires a robust pollen characterisation to cope with most allergenic taxa. Global features, such as morphology, texture and colour, are measured considering the whole image and can provide some robustness, for example to rotation. They are weak against occlusion and imprecise segmentation and the extracted information is not enough for

characterising pollen completely. However, global features can be used in an early rough classification of groups of similar taxa due to its simple implementation. Further classification would be needed.
Palynological knowledge has been employed for specific taxon characterisation. It turns the system more complex as the number of taxa increases. Moreover, previous works have shown difficulty to detect specific characteristics due to the random orientation of particles. Nevertheless, rich palynological information is available and it is not fully employed in automatic detection systems. Multiple-layer images are an advantage in the detection of palynological characteristics.
The use of local features has been barely explored for characterisation. Aforementioned invariants are computed locally, but they are used for describing the whole image in a global manner. Local approaches, like SIFT and local self-similarity, usually employed in object matching, are a potential area of study for robust pollen description.
Fluorescence and multispectral reflectance are properties that have not fully explored for the characterisation task and early results using these techniques are encouraging to keep investigating in that direction as important features.
A quantitative comparison of the aforementioned performances is not always possible because of the variety of used methods and because the studied pollen taxa with different levels of difficulty, is not the same in all the experiments. Results suggest that simple classification methods are not enough when considering complex or high-dimensional features. Thus, optimal dimensional reduction and more complex algorithm can help to improve classification rates. To date, best classification results have been reached by means of neural networks and SVM. We consider that the optimal classifier is a function of specific feature vectors. Once the structure and dimensionality of the feature vector is chosen, testing different classification schemes would be possible.

6 Conclusions

A practical and reliable automatic pollen detection system remains still unsolved. Several efforts have gotten closer, with respectable results and some prototypes are already working in the field. 3P-GM project is expected not only to short the distance to the goal of improving the accuracy of the pollen concentration measure, but also of the availability of the data to allergists focused on the relief of the patients. Future work will be the study of fluorescence, multiple-layer images and palynological knowledge as support of already established characterisation methods with focus on a practicable and robust implementation.

7 Bibliography

ALLEN, G., 2006: An Automated Pollen Recognition System (Master's thesis). Massey University.

BOUCHER, A., HIDALGO, P. J., THONNAT, M., BELMONTE, J., GALAN, C., BONTON, P., & TOMCZAK, R., 2002: Development of a semi-automatic system for pollen recognition. Aerobiologia, **18**(3), pp. 195–201. Springer.

D'AMATO, G., CECCHI, L., BONINI, S., NUNES, C., ANNESI-MAESANO, I., BEHRENDT, H., LICCARDI, G., POPOV, T. & VAN CAUWENBERGE, P., 2007: Allergenic pollen and pollen allergy in Europe. Allergy, **62**(9) pp. 976–990.

DELL'ANNA, R., LAZZERI, P., FRISANCO, M., MONTI, F., MALVEZZI CAMPEGGI, F., GOTTARDINI, E., & BERSANI, M. , 2009: Pollen discrimination and classification by Fourier transform infrared (FT-IR) microspectroscopy and machine learning. Analytical and bioanalytical chemistry**,** **394**(5), pp.1443-52.

DYKEWICZ, M. & HAMILOS, D., 2010: Rhinitis and sinusitis. The Journal of allergy and clinical immunology. **125(**2) pp. S103-S115.

FRANCE, I., DULLER, A. W. G., LAMB, H. F.& DULLER A.W.G., 1997: A Comparative Study of Approaches to Automatic Pollen Identification. Proceedings of the British Machine Vision Conference, pp. 1-10.

GOTTARDINI, ELENA, ROSSI, S., CRISTOFOLINI, F., & BENEDETTI, L., 2007: Use of Fourier transform infrared (FT-IR) spectroscopy as a tool for pollen identification. Aerobiologia, **23**(3), pp. 211-219.

HOLT, K., ALLEN, G., HODGSON, R., MARSLAND, S., & FLENLEY, J., 2011: Progress towards an automated trainable pollen location and classifier system for use in the palynology laboratory. Review of Palaeobotany and Palynology**,** **167**(3-4), pp. 175-183. Elsevier B.V.

LANDSMEER, S. H., HENDRIKS, E. A, DE WEGER, L. A, REIBER, J. H. C., & STOEL, B. C., 2009: Detection of pollen grains in multifocal optical microscopy images of air samples. Microscopy research and technique, **72(**6), pp. 424-30.

LI, P., TRELOAR, W. J., FLENLEY, J. R., & EMPSON, L., 2004: Towards automation of palynology 2: the use of texture measures and neural network analysis for automated identification of optical images of pollen grains. Journal of Quaternary Science, **19**(8), pp. 755-762.

MITSUMOTO, K., YABUSAKI, K., & AOYAGI, H., 2009: Classification of pollen species using autofluorescence image analysis. Journal of bioscience and bioengineering, **107**(1), pp. 90-94.

RANZATO, M., TAYLOR, P., HOUSE, J., FLAGAN, R., LECUN, Y., & PERONA, P., 2007: Automatic recognition of biological particles in microscopic images. Pattern Recognition Letters, **28**(1), pp. 31-39.

RODRIGUEZ-DAMIAN, M., CERNADAS, E., FORMELLA, A., & GONZÁLEZ, A., 2003: Automatic identification and classification of pollen of the urticaceae family. Proceedings of Advanced Concepts for Intelligent Vision Systems (ACIVS 2003), pp. 38-45.

RONNEBERGER, O., WANG, Q., & BURKHARDT, H., 2007: 3D invariants with high robustness to local deformations for automated pollen recognition. Proceedings of the 29th DAGM conference on Pattern recognition. pp. 425–435. Springer.

WU, Q., MERCHANT, F. & CASTLEMAN, K., 2008: Microscope image processing. Academic Press.

ZHANG, Y., FOUNTAIN, D. W., HODGSON, R. M., FLENLEY, J. R., & GUNETILEKE, S., 2004: Towards automation of palynology 3: pollen pattern recognition using Gabor transforms and digital moments. Journal of Quaternary Science, **19**(8), pp. 763-768.