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Biodiversity Informatics in Action: Identification and Monitoring of Bee Species using ABIS

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Abstract

Bees, as the main pollinators of food crops, represent a critical natural resource which needs to be carefully exploited and managed. In recent years, however, destruction of bee's native habitats, infestations, and displacements of native bees by alien bee species have reduced and disturbed bee populations and this is already having considerable impact on global agriculture. A further concurrent problem is that there are probably fewer than 50 taxonomic experts worldwide able to identify bee species. ABIS (**A**utomatic **B**ee **I**dentification **S**ystem) is a suite of software tools created for the identification and monitoring of bees. Bee species are rapidly and reliably determined from images of the bees' wings by means of linear and non-linear statistics in conjunction with image processing. Work is currently in progress to couple the bee identification tools within a geographic information system and to make a bee recognition service available over the Internet.

Zusammenfassung

Bienen, die die Hauptbestäuber vieler Wild- und Nutzpflanzen sind, stellen eine kritische Ressource dar, zu deren Schutz zukünftig verstärkt Forschung und Management nötig sein wird. Viele Bienenarten gelten heute als gefährdet, da ihre Populationen durch die Zerstörung ihrer Lebensräume, durch Pestizide und durch Verdrängung angepaßter Bienenarten aufgrund von Importen faunenfremder Bienen stark reduziert wurden. Dies hat weltweit Auswirkungen auf die Erträge der Landwirtschaft. Einer intensiven Forschung steht entgegen, dass es weltweit weniger als 50 Experten gibt, die Bienen auf Artniveau bestimmen können. ABIS (**A**utomatic **B**ee **I**dentification **S**ystem) ist eine Software, die für die Identifikation und das Monitoring von Bienenarten entwickelt wurde. Auf der Basis einer Flügelaufnahme erfolgt durch Methoden der Bildverarbeitung und mittels linearer und nicht-linearer statistischer Klassifikationstechniken die Identifikation. Momentan

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wird die Erkennungssoftware in ein GIS integriert und einem Erkennungsservice per Internet verfügbar gemacht.

1. Goal and Scope

Animals pollinate two thirds of the 3000 species of agricultural crops, the annual value of this service being reported (Pimentel 1997) to be 65~70 billion US dollars.

Birds, wasps, beetles, butterflies, moths and flies are all pollinators (Buchmann 1996, Kevan 1999) but ~73% of world crops are pollinated by bees (Roubik 1995).

Bee populations throughout the world are in decline. Agro-chemicals, a pandemic disease spread by mite infestations, the destruction of their habitats (especially by deforestation), or competition for resources with commercially introduced bee species (Rathcke 1994) are all taking their toll on bee populations.

Bees clearly constitute a valuable ecological resource and monitoring, cataloguing and protection of bee species are necessary. This, indeed, is one conclusion being reported (Dias 1999) from the sequence of conferences resulting from the Convention on Biodiversity opened to signatories in Rio in 1992.

To monitor bee species, and therefore to protect and manage them, we must be able to identify them and therein lies a problem. There are 20 to 40 thousand bee species with 25,000 being perhaps a representative estimate. Worldwide, however, the number of taxonomists able to identify bee species can be numbered in tens with possibly around 50 acknowledged experts on bee taxonomy.

We therefore require a portable and inexpensive system capable of identifying bees, preferably without destroying the bee specimens in the process.

Coupling recognition results with geographical data and making such data and a recognition service publicly available would be of considerable utility. The system described in this paper (ABIS) provides such facilities.

2. Methods

We discuss the three topic areas – identification, Internet access, and monitoring – that correspond to the goals of the project.

2.1 Identification

The ABIS system's bee identification tool, partly developed as part of the *Automated Species Identification* project of the German Research Council (DFG), forms the core of the software suite. It employs image processing and a hierarchy of statistical techniques to provide a recognition result for an image of a bee's wing. In this section, we will describe the operation of this tool.

2.1.1 Recognition System

Recognition of a sample bee proceeds by acquiring an image of the bee's main wing. Live bees captured in the wild are cooled using an icebox: this renders them immobile for a time sufficient for the recognition image to be made without causing the bee long-term harm. Once the bee's wing has been clipped in a lightweight, transparent, plastic holder, it can be placed in a low-powered microscope and an image of the wing made with a commercial digital camera. (Figure 1.)

Figure 1: Experimental Apparatus

The key idea of the bee recognition system is to employ the venations present in the bees' wings, and the cells they enclose, to generate numerical feature vectors that we can then use for statistical recognition. (We could say that we are using the venations in the bees' wings almost as fingerprints.) The length of the feature vector obtained also means that conventional linear statistical techniques are insufficient for solving the recognition task and we must therefore turn to modern techniques such as Support Vector Machines (SVMs) or a non-linear statistical technique developed within this project: Kernel Discriminant Analysis (KDA) (Roth 1999b).

Despite the problem's difficulty, our system offers a fully automated image processing and recognition engine able to classify the bees from only their wing images (Roth 1999a). The steps in the recognition process are as follows.

1. The system detects lines and intersections within the image and uses this information to generate hypotheses about the likely locations of cells.
2. It uses some initial general knowledge about bees' wings to guide it in its search for three basal cells which have proven to be stable against disturbances.

3. A best-first search of a tree of hypotheses generally permits the detection of the three cells. Once they are found, we calculate intermediate numerical features which are employed to guide the future search.
4. The features from the previous step are supplied to a linear classification algorithm (Linear Discriminant Analysis, LDA) which permits the loading of a deformable template particular to a family of bee species (figure 2)
5. Employing hints from the template, the remaining cells are found. The complete set of cells is then used to calculate a new set of feature vectors.
6. We extend the new feature vectors with intensity values obtained by averaging within a sampling window scaled such that it always has a particular orientation with respect to two particular wing cells.
7. We apply a non-linear statistical method such as SVM or KDA to carry out the final recognition phase with the extended vectors.

Training the system is by-and-large a generic process. The same tool can be used for many different genera or possibly even for different classes of organism. The main requirement is that the chosen body part of the organism should show a recognisable venation.

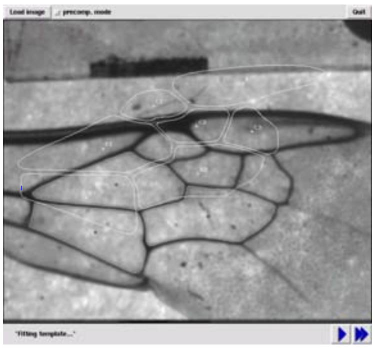

Figure 2: Deformable Template

2.2 Accessibility via the Internet

Our current ABIS website[3] explains the basic concepts of the recognition system as well as the overall context of the project. We are currently integrating a "bee-recognition service" into this ABIS website where interested parties can employ an applet within their Web-browsers to select and upload their own bee wing images to a bee-recognition server. This server automatically carries out the recognition of the

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bees' species, interacting with the remote applet to give the user some idea of the progress of the recognition task. Additional facilities for informing the user about the set of trained bee species and providing GIS information will be integrated within the website. Providing such a unique and important facility (freely accessible over the internet) serves the purposes of aiding workers in the field and of raising public awareness of the issues at hand. This new, enhanced, ABIS site will be available soon.

2.3 Monitoring using a GIS

If we are able to recognise bees, we are then able to monitor them. A recognition result can be combined with geographic and temporal data and made available within a bee monitoring system. An ideal end-product would be an environmental information system (EIS), which would provide conservationists, planners, politicians, and, hopefully, to an even greater extent, the general public, with geographically-based information concerning bee species.

We are currently making the initial steps towards the creation of such a GIS. The GIS database will store identification results together with the relevant meta-data to enable us to monitor the bee populations identified using our identification tool. This work will be reported in subsequent publications.

3. Results and Conclusion

We have carried out many experiments to establish the high performance of the recognition system. In one sequence of experiments, designed as an extreme test, we sought to separate the bees from the complex comprised of *Bombus lucorum*, *Bombus terrestris*, *Bombus cryptarum*, and *Bombus magnus* (Schröder 2001). These bees are very similar and it is extremely difficult even for an expert to be able to tell them apart. Employing images of the wings of 20 different members of each bee species to train the system, resulted in a successful recognition rate of over 95%. This is notable because it is likely to be higher than that achievable by a human expert when dealing with this extremely difficult task.

In further experiments including additional *Bombus* species such as *Bombus veteranus*, *Bombus sylvarum* and *Bombus ruderarius* employing 60 to 70 training images from each species, we again achieved recognition rates of over 95% and such high recognition results have also been repeated in subsequent experiments with bees from different genera (such as *Colletes*).

4. Recommendations and Outlook

The critical importance of bees to agriculture and, as a result, to human wellbeing is absolutely clear. As signatories to the Convention on Biological Diversity (opened at the United Nations Conference on Environment and Development (UNCED) in Rio, 1992), we are legally obliged to take all necessary steps to preserve diversity and to promote sustainable development. Moreover, current reports concerning diminishing bee populations and lower yields from pollinated food crops give cause for concern.

The ABIS project provides a tool for fulfilling our responsibilities, aiding conservationists, planners and agriculturalists, while at the same time preserving and protecting biodiversity. Exceptional recognition and discriminatory performance from a species-neutral software suite provides some hope for a solution to these problems. The ABIS project provides a world-class demonstration of biodiversity informatics in action. We will continue to report on its progress as its capabilities grow.

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