The Science of "Fingerprinting" Bees

The ABIS system allows the rapid and accurate identification of bee species. This process is based on automatic image analysis of the bee's wings and enables the development of new, computer-aided methods to identify the bee species

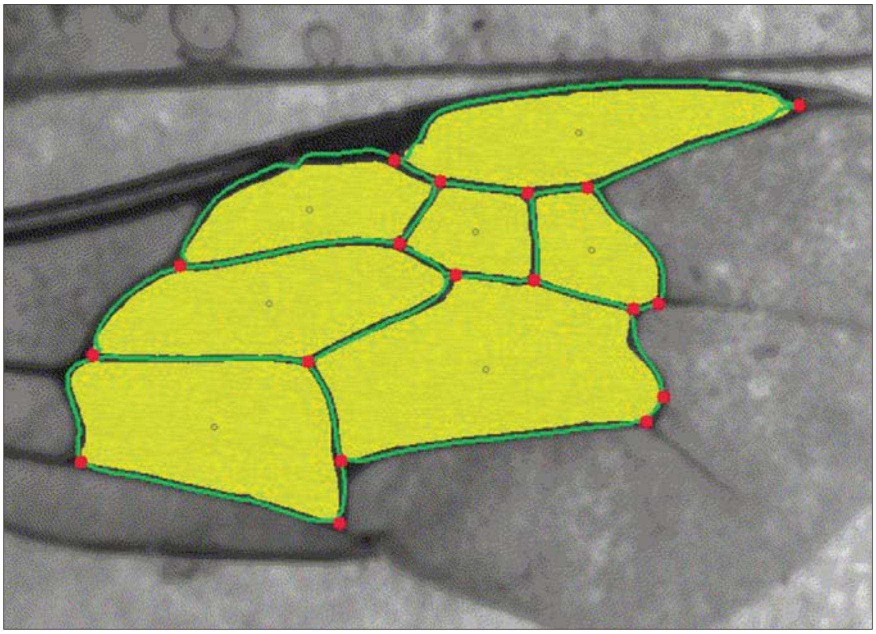
Biological systematics has been gaining in international significance since the Convention on Biological Diversity (CBD) held in Rio in 1992. In biology, the term "systematics" denotes the description of individual animal and plant species and their classification within an evolutionary tree that describes their evolutionary history. A specialised domain within systematics is biodiversity research, which investigates species diversity of a specific region. Cataloguing the dwindling number of species on the Earth for conservation purposes and securing the economic utilisation of animal and plant species in agriculture, chemistry and pharmacology has become a race against time. Owing to the urgency of these tasks, recording, processing and archiving species inventories without the aid of computers is no longer possible. This has led to a new field of research: biodiversity informatics.

A key issue in conserving natural landscapes and securing crop yields is the identification of the species that pollinate these plants. Due to the large number of species and their very narrow food specialisation, bees are some of the most important pollinators of our wild plants and crops.

The Automated Bee Identification System, or "ABIS" for short, was developed as part of an interdisciplinary research project involving zoologists and computer scientists and enables the rapid and reliable identification of bee species. ABIS can also be used to indicate the properties of natural landscapes and their state of preservation because, on account of their specialisation, bees can be used to identify very characteristic features of their habitat, such as types of vegetation and soil. The fact that ABIS is mobile and can be used to identify live specimens in the field also opens up new opportunities for carrying out monitoring studies to identify and monitor the number of animals living in a specific area over a specific period of time. The advantages of ABIS include the relatively low amount of equipment required compared to biochemical and molecular genetics methods and the possibility of mobile field

A mounted wing: The bee is anaesthetised before it is mounted in a holding clip. The wing can now be photographed for identification of the species. This is carried out with the Automated Bee Identification System, ABIS, a system that reliably identifies bee species.

After photography and analysis of the wing image using the ABIS system, the characteristic wing features can be seen: The green lines represent the veins, the red dots the vein junctions and the yellow areas the skin cells. Adjacent picture: The species is determined using a family-specific specimen wing.

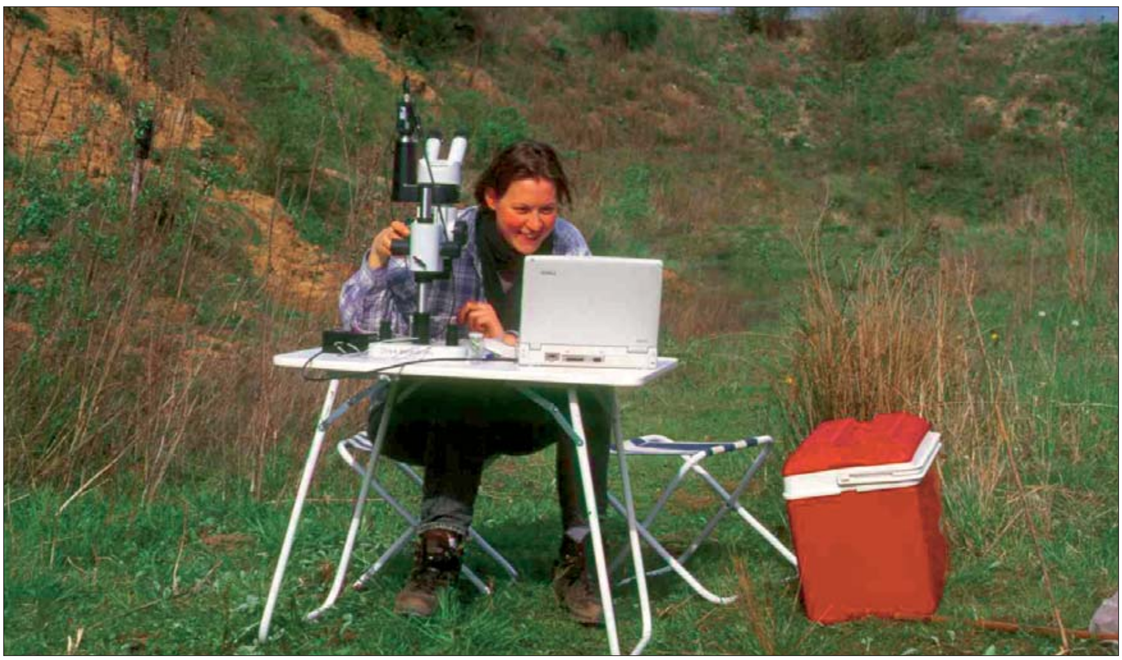


investigations, as well as the identification of live bees.

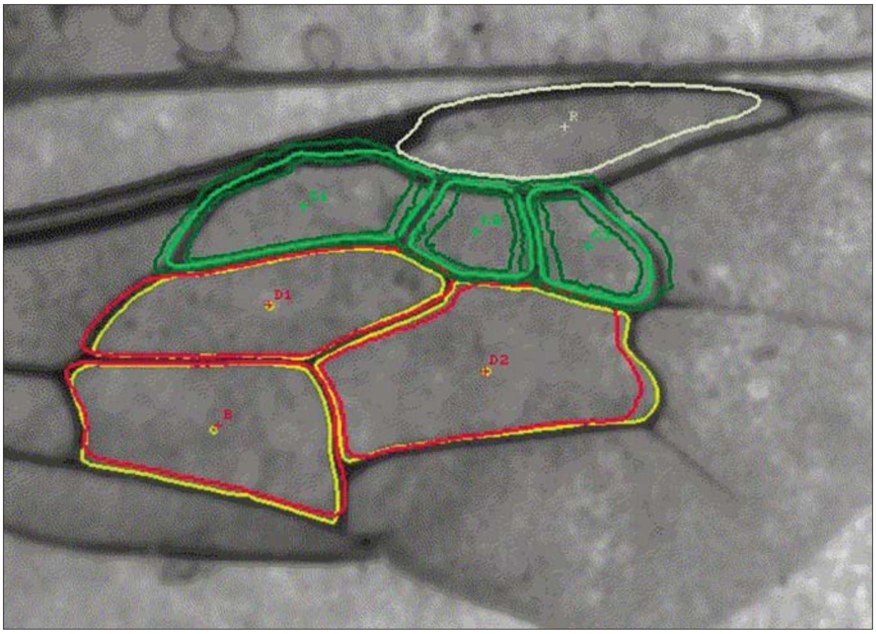
What, though, is the most efficient approach to identify bee species automatically? Taxonomists identify species on the basis of visible differences between various morphological characteristics, such as shapes and colours of the body, head, antennae, legs and wings. This time-consuming process is not viable for automatic species identification. Instead, an automated, computer-aided identification of the species should be based on just a few, easily perceptible physical characteristics.

The bees' wings were chosen for this. The bee family belongs to the *Hymenoptera* order within the insect class. Bees have almost transparent, membranous wings that, on closer inspection, exhibit a distinctive network of veins. Can this network of veins be used as a "fingerprint" for the accurate identification of a species? Identification rates of up to 97 percent have been obtained with the ABIS system, providing impressive confirmation of the suitability of using this feature as a means of identification.

How does the ABIS system work? The starting point is an image of the bee's wings taken with an ordinary digital camera mounted on a microscope – a standard instrument used by taxonomists in species identification. The bee's wings are fixed in a transparent clip consisting of a glass prism and a glass slide, and are then lit from behind by white light-emitting diodes. This does not injure or damage the bee's wings, thus enabling ABIS to be used to examine valuable scientific collections and to identify species of live bees. During the identification of live specimens, the bees are stunned by cooling them with ice-water in a commercially available cold box or they can be anaesthetised with carbon dioxide. Fixation and imaging processes take less than a minute. The light reveals the well-defined structure of the wings, with the non-transparent veins forming a dark network of lines enclosing bright sections – the wing's transparent skin cells. Three categories of characteristic wing features are studied: veins,



ABIS is mobile and can thus be used in the field at any time. Above right: Having had its wing photographed, the liberated photographic model prepares for take-off.



vein junctions and transparent skin cells. So-called morphometric features are derived from these characteristics, and they are used to describe the shape of a wing by means of numerical values. Examples of these values include distances between vein junctions, area ratios of skin cells and length ratios of veins.

These morphometric characteristics of all the veins, vein junctions and skin cells of a wing thus form a comprehensive series of numbers, the so-called feature vector. The species is identified on the basis of a principle known as "supervised classification", which requires that an experienced taxonomist trains the ABIS system in a so-called training step. ABIS "learns" each species to be identified using a number of previously identified wing images. This means that ABIS learns a function which assigns feature vectors to a trained species.

Indeed, the identification of the veins, vein junctions and skin cells in the wing image and the assignment of the feature vectors to a single species of bee are such demanding processes that standard methods of image processing and classification are insufficient. Weak contrast levels in the image, soiling and pollen deposits on the wings and other forms of contamination necessitate a two-step image processing procedure. Experience has shown that robust identification of a certain subset of skin cells and the veins delimiting them is possible, and initial image processing and classification is therefore based solely on these wing characteristics. This is sufficient to identify the genus. In the second step, ABIS loads a genus-specific "wing template" from its knowledge base. The wing template was derived in the training step from all previously identified wing images of this genus.

> The ABIS system "knows", on the basis of a specimen wing, how many veins, cells and nodes to book for

This wing template predetermines the structure and approximate locations where ABIS will find the remaining elements in the subsequent image processing. In other words: the system "knows" the number of veins, cells and nodes that must be found in which neighbouring constellation. While these relationships and approximate geometries are the same for all species of a genus, the precise geometric shape of these predictions is based on the individual wing image and thus ultimately specifies the characteristic feature vector required for the identification of the bee species.

In addition, simple, linear classification methods cannot be successfully employed for the very difficult identification of the species on the basis of the feature vectors generated for each wing image. Instead, a new non-linear variant of the established linear discriminant analysis method was developed. Not only is this variant method capable of resolving very complex classification tasks, but it is also extremely useful for visualising the results of the identification process.

ABIS has been successfully used in Germany, Brazil and in the USA, and identification rates of almost 100 percent have been achieved. However, just like people, the system's success depends on its learning process: the more comprehensive and meaningful the training material, the better the results of the subsequent species identification from new wing images.

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