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Automated Identification of Insects in Flight

A. MOORE[1]

Agricultural Development in the American Pacific Project
Agricultural Experiment Station, University of Guam,
Mangilao, Guam 96923

Abstract—Insect wingbeat frequency has been used as a taxonomic character. To test the feasibility of developing instrumentation which monitors the identity and population density of flying insects, wingbeat frequencies of the mosquitoes, *Aedes aegypti* (L.) and *A. triseriatus* Say, were recorded using a microcomputer-based instrument which measured light reflected off the wings of individuals in flight. The wingbeat frequency and other spectral components from 403 individual recordings were used to train an artificial neural network. The trained network correctly identified the species and sex of mosquitoes in an independently recorded group of 57 mosquitoes. This technology has potential use for detecting and monitoring a wide range of flying insects.

Interspecific and intraspecific differences in wingbeat frequencies have been used to identify insects in flight (Reed et al. 1942, Sotavalta 1947, Sawedal & Hall 1979, Greenbank et al. 1980, Farmery 1982, Riley et al. 1983, Schaefer & Bent 1984, Unwin & Corbet 1984, Rose et al. 1985). To assess the feasibility of developing instrumentation which monitors the identity and population density of flying insects, Moore et al. (1986) measured wingbeat frequencies for individuals from two species of mosquitoes, *Aedes aegypti* (L.) and *A. triseriatus* Say. by recording changes in the intensity of light reflected off wings during free flight (Fig. 1). Spectral analysis showed that each recording contained the wingbeat frequency plus several harmonics (Fig, 2). A univariate discriminant function calculated using wingbeat frequencies from one group of mosquitoes (which will be referred to as the 'training set') was used to identify the species and sex of individuals from a second, independently reared group ('test set') with an accuracy of 84%. Multivariate discriminant functions calculated using wingbeat frequencies and amplitudes of the first four harmonics did not improve accuracy, implying that characteristics of the frequency spectrum, other than the wingbeat frequency, were not useful for identification. However, recent analysis of data from this experiment using a new pattern recognition technique from the field of artificial intelligence shows that the frequency spectra are rich in information useful for identification. An artificial neural network (Stanley 1989) was trained using the

[1] Present address: Department of Entomology, CTAHR-Maui Research, University of Hawaii, P. O. Box 269, Hawaii 96790.

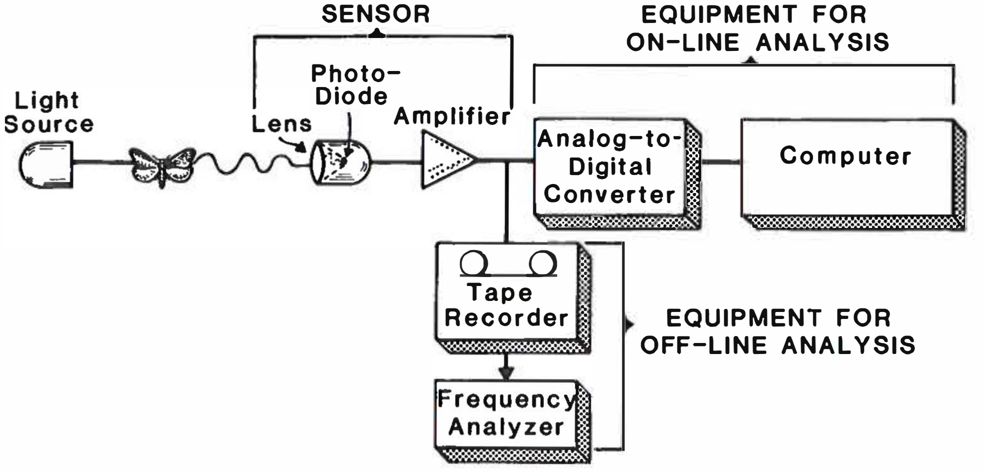

Figure 1. Schematic diagram of equipment for recording and analyzing insect wingbeat frequencies.

training set and correctly identified the species and sex of every mosquito in the test set with a high degree of confidence. This new technology may be useful in developing a remote sensing monitoring system which automatically counts and identifies insects in flight.

Following is a brief description of the experimental methods. Details can be found in Moore et al. (1986). An instrumentation system for recording and analyzing insect wingbeat frequencies was constructed (Fig. 1). The photosensor, consisting of a photodiode and amplifier (Unwin & Ellington 1979), detected fluctuations in light intensity caused by reflections off individual mosquitoes flying through a light beam. Digital recordings of the signals were made with a microcomputer (IBM PC) equipped with an analog-to-digital converter (Lab-Tender, Tecmar Inc., Solon, Ohio) under the control of a program which simulates a digital oscilloscope (SCOPE2, Moore Scientific, Kula, HI). A change in light intensity caused by a mosquito flying in front of the sensor triggered storage of 512 samples at a rate of 10 kHz (Fig. 2A). Each signal was converted to a 256 cell frequency spectrum using the fast Fourier transform (Cooper 1981). The frequency spectrum for each signal contained a harmonic series with the fundamental at the wingbeat frequency (Fig. 2B).

In the original analysis, the wingbeat frequency and amplitudes of the first four harmonics were extracted from each signal in the training set (n = 403; approximately 100 signals for each species-sex combination). Discriminant functions based on several combinations of these variables were calculated and were tested by using them to identify signals from the test set (n = 57; approximately 15 signals for each species-sex combination). The function based on wingbeat frequency alone identified the correct species and sex 84% of the time. Accuracy did not improve when the amplitudes of the harmonics were used in the calculations.

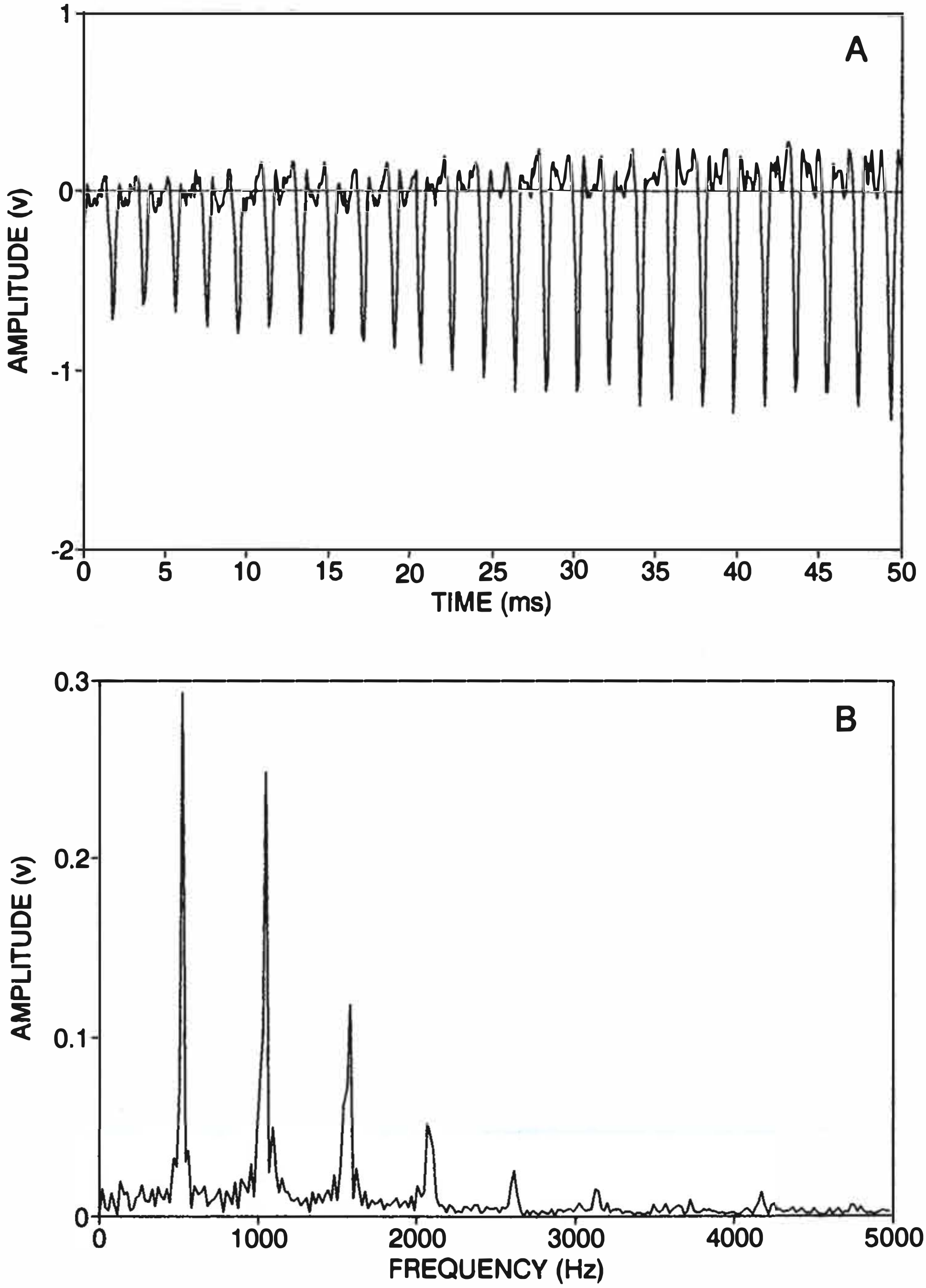

Figure 2. (A) Signal produced by the flight movements of a female *Aedes aegypti* mosquito. (B) Frequency spectrum.

In the recent analysis, an artificial neural network in which the input layer contained 256 neurons (one for each cell in the frequency spectra), the hidden layer contained 127 neurons, and the output layer contained four neurons (one for each of the four species-sex combinations). Each fact in the training set consisted of 256 numbers representing the amplitude of each cell in the frequency spectrum plus one of four identifying codes corresponding to the species-sex combination of the mosquito which produced the signal.

After training to completion, the network was tested by using frequency spectra of signals in the test set as input. The species and sex of the mosquito causing each signal were identified correctly. Furthermore, each insect was identified with a high degree of confidence as indicated by the fact that the relative firing rate for the output neuron representing the correct species-sex combination ranged from 88% to 100% with a mean of 98%.

This study demonstrates the feasibility of developing instrumentation capable of counting and identifying insects in flight. Even though morphologically similar species were used in the experiment, each signal, lasting only one-twentieth of a second, contained information enabling identification of species and sex with a high degree of confidence. With further development, this type of instrumentation could become an important tool for research and pest control.

A flight monitor designed for the field could use either the sun or an appropriate artificial light source, such as a red or infra-red laser. Possible applications include continuous monitoring of several sympatric populations (useful for ecological and biological control studies), pollination studies, measurement of diurnal activity cycles, and evaluation of attractants and repellents. The system I envision will be able to count and identify several species flying through a defined volume of airspace. Such a monitor will be a useful entomological tool. A medical entomologist could use it to determine what species of mosquitos are present, how numerous they are, and when they are flying. A biocontrol specialist might monitor the flight activity of a host insect and several parasitoids and predators.

References

Cooper, J. W. 1981. Introduction to Pascal for Scientists, Wiley, New York.

Farmery, M. J. (1982). The effect of air temperature on wingbeat frequency of naturally flying armyworm moth (*Spodoptera exempta*). Ent. Exp. Appl. 32: 193–194.

Greenbank, D. O., G. W. Schaefer & R. C. Rainey. 1980. Spruce budworm (Lepidoptera: Tortricidae) moth flight and dispersal: new understanding from canopy observations, radar, and aircraft. Mem. Entomol. Soc. Can. 110.

Moore, A., J. R. Miller, B. E. Tabashnik & S. H. Gage. 1986. Automated identification of flying insects by analysis of wingbeat frequencies. J. Econ. Entomol. 79: 1703–1706.

Reed, S C., C. M Williams & L. E. Chadwick. 1942. Frequency of wing-beat as a character for separating species races and geographic varieties of *Drosophila*. Genetics 27: 349–361.

Riley, J. R., Reynolds, D. R., and Farmery, M. J. (1983). Observations of the flight behaviour of the armyworm moth, *Spodoptera exempta*, at an emergence site using radar and infra-red optical techniques. *Ecol. Entomol.* 8: 395–418.

Sawedal, L. & R. Hall. 1979. Flight tone as a taxonomic character in Chironomidae (Diptera). Entomol. Scand. Suppl. 10: 139–143.

Schaefer, G. W., & G. A. Bent. 1984. An infra-red remote sensing system for the active detection and automatic determination of insect flight trajectories (IRADIT). Bull. Entomol. Res. 74: 261–278.

Sotavalta, O. 1947. The flight-tone (wing-stroke frequency) of insects (Contributions to the problem of insect flight 1.). Acta Entomol. Fenn. 4: 1–114.

Stanley, J. 1989. Introduction to Neural Networks. California Scientific Software, Sierra Madre.

Unwin, D. M. & S. A. Corbet. 1984. Wingbeat frequency, temperature, and body size in bees and flies. Physiol. Entomol. 9: 115–121.

Unwin, D. M. & C. P. Ellington. 1979. An optical tachometer for measurement of the wing-beat frequency of free-flying insects. J. Exp. Biol. 82: 377–378.