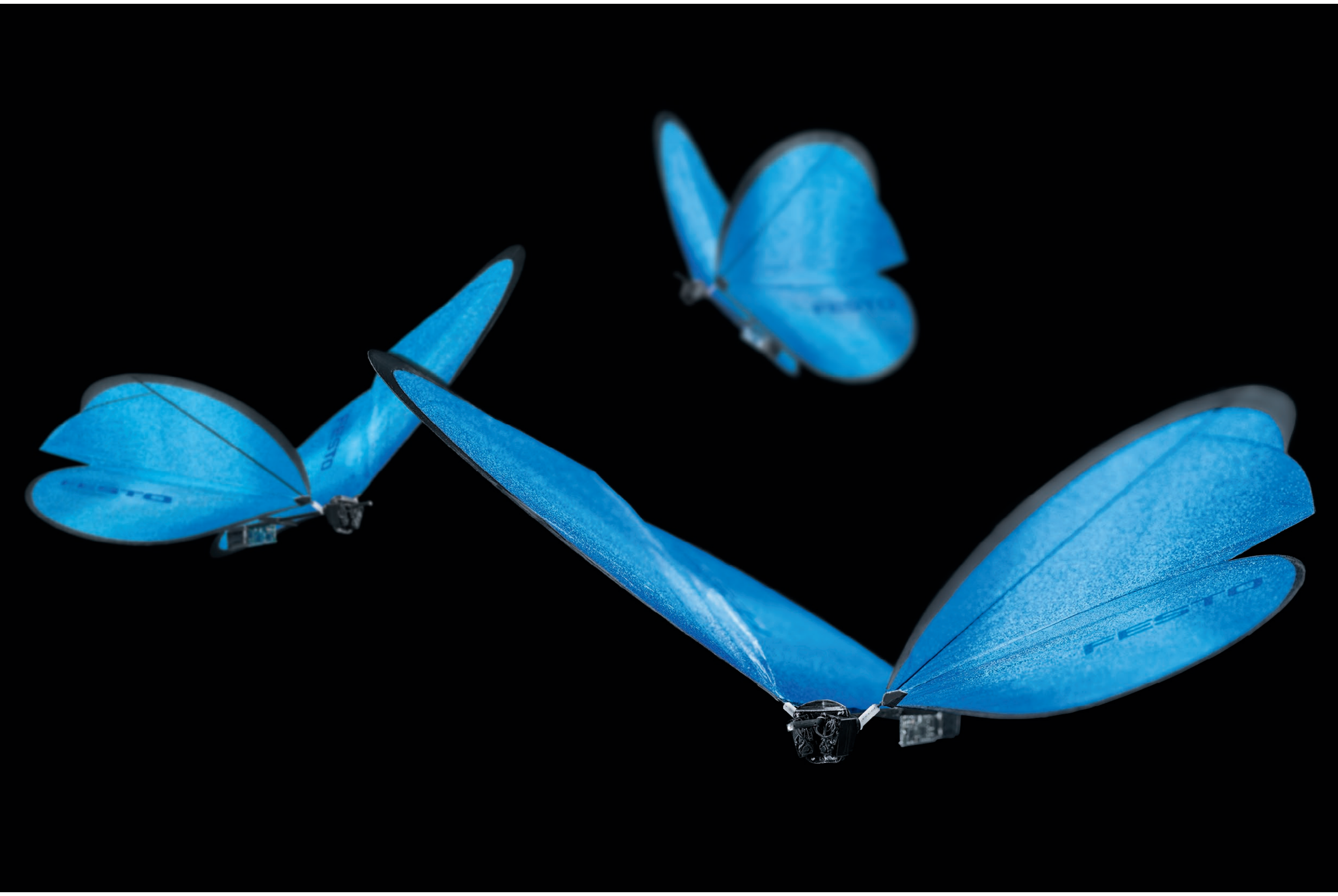
eMotionButterflies

Ultralight flying objects with collective behaviour



eMotionButterflies
Coordinated flying thanks to indoor GPS

Flying is not only one of mankind's oldest dreams, but also a recurring theme in the Bionic Learning Network. In association with universities, institutes and development firms, for years now Festo has been developing research platforms whose basic technical principles are derived from nature.

Although the first bionic flying objects developed by Festo were filled with helium, the SmartBird, with its beating wings, was able to provide the necessary uplift by itself. As a result, the developers technically implemented the flight of the dragonfly with the BionicOpter and, with the eMotionSpheres, showed how several autonomous flying objects can move in an enclosed space without colliding. With the eMotionButterflies, Festo now combines the ultralight construction of artificial insects with coordinated flying behaviour in a collective.

In order to replicate their natural role model as closely as possible, the artificial butterflies feature highly integrated on-board electronics. They are able to activate the wings individually with precision and thereby implement the fast movements.

To enable the butterflies to make the different flying manoeuvres with process reliability and stability, permanent communication is necessary. The localisation of the individual flying objects is ensured by the radio and sensor technology on board in combination with the installed guidance and monitoring system. An important part of the indoor GPS is a camera system, as could also be used in the factory of the future. Ten infrared cameras installed in the space record the butterflies using two active markers (infrared LEDs). The cameras transmit the position data to a central master computer, which acts like an air traffic controller and coordinates the butterflies from outside.

Clear behaviour patterns for collision-free movement
No human pilot is therefore required to control the eMotionButterflies. Preprogrammed routes, which specify the flight paths for the butterflies during their manoeuvres, are stored on the central computer. With the aid of additionally stored behaviour patterns, however, they can also move autonomously through the space. No direct communication takes place between the bionic flying objects in this respect.

01: **Consistent continuation:** ultralight construction and collective behaviour combined

02: **Networked overall system:** the merging of the virtual and real world

03: **Latest infrared technology:** precise localisation of the butterflies

04: **Safe handling:** harmless interaction between man and machine

01

02

03

04

Each butterfly receives its flight path wirelessly from the central master computer and tries to implement this as best it can. The wing movements necessary to do this are calculated on board the flying objects. If a butterfly leaves its path, this is corrected immediately. To do so, the camera system measures the exact actual position of all flying objects 160 times per second, upon which the computer readjusts each deviation. The planning of the flight paths is therefore constantly updated and the risk of collision is detected in good time. In order to prevent collision, the computer develops appropriate avoidance strategies based on defined rules.

Exact positioning thanks to infrared technology

The ten cameras are positioned so that they map out the space as a whole, and each butterfly is recorded by at least two cameras. Due to their special filters, they only capture infrared light and are not sensitive to other light. By means of the two infrared LEDS on the butterflies' torsos, they detect their position and orientation in the space and can also tell the optically identical flying objects apart.

Large spatial coverage due to active markers

Whilst passive reflectors first have to be illuminated, the two LEDs emit an infrared signal by themselves. The light only has to cover the distance between the butterfly and camera, meaning that the active markers help to record a larger space with the same number of cameras. The markers are not permanently lit in this case, but instead flash for only a millisecond. This makes them extremely long-lasting and energy-efficient. Synchronised with the flashing, the cameras record an image that they send to the master computer.

Fast calibration of the system

In order for the central master computer to know where the butterflies are located in the space, it must first know the positions of the cameras. The necessary calibration of the system can be carried out quickly and easily. To do so, an additional flying object with a measuring cross flies through the space freely for about 15 minutes and is recorded by the cameras whilst doing so. By means of the recorded flight data, the computer is able to determine the exact locations and alignments of all the cameras in the coordinate system.

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Special features of butterflies

Butterflies are known above all for coming into the world as caterpillars and later emerging as mostly colourful flying creatures. What is particularly striking about them are their large wings compared to their slim body. They are wafer-thin and consist of an elastic membrane, which gives the creatures their unique lightness and aerodynamics.

Technical benefits for Festo

With the eMotionButterflies, Festo has now technically implemented their extremely graceful and agile flight. So that the ultralight flying objects do not collide with each other, they are coordinated by an indoor GPS, which could also be used as a guidance and monitoring system in the production of the future.


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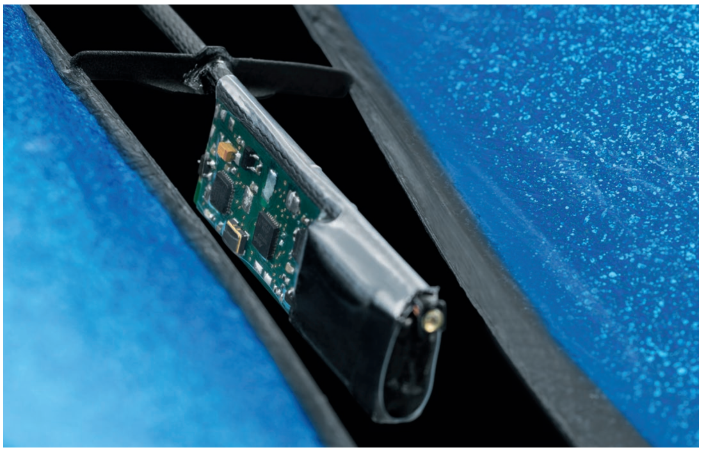
Highly integrated research platforms

01



02

The developers channelled their knowledge gained from the projects on the BionicOpter and the eMotionSpheres into the controls of the artificial butterflies. The indoor GPS was already used for the hovering balls and was developed further for the eMotionButterflies. The improved frame rate of the cameras gives the system an even higher level of precision, which was a basic requirement for exactly tracking the position of the eMotionButterflies. In comparison to the eMotionSpheres, the artificial butterflies are very agile and always on the move. Not only does that mean their autonomous behaviour is more complex, but also their coordination from outside.

Highly complex system with reduced use of materials

With the butterflies themselves, Festo is taking another step into the areas of miniaturisation, lightweight construction and functional integration. Attempts are often made to counter complexity with a correspondingly high level of technical equipment. The eMotionButterflies impress, in contrast, with an intelligently employed mechanical system and the smallest possible power units in the tightest space, as well as a highly reduced use of materials.

Smallest possible space in the body

The engineering design of the eMotionButterflies is limited to the essential and only depicts the necessary fixing points for the components. Their design not only saves the necessary weight but also enables them to be assembled quickly and easily. The artificial butterflies therefore consist simply of a laser-sintered torso that houses all the necessary units. The electronics, the battery and two servomotors are installed here in the tightest space.

A wing root is attached to each motor, on which both front and rear wings are fastened. The rear wing is also fixed on the torso using a hinge and thus essentially acts as a control unit.

Consistent lightweight design in the wings

In order to fly true to nature, a weight as low as possible and a relatively large wingspan are particularly important. The wings are therefore curved out of wafer-thin carbon rods and covered with an elastic capacitor film. As the wings slightly overlap, an air gap is created between them when they beat, which gives the butterflies their special aerodynamics.

01: **Minimum net weight:** consistent lightweight construction due to low material use

02: **Aerodynamic split wing:** biggest possible wingspan with the smallest possible weight

03: **Unique flying behaviour:** moving freely like its natural role model

04: **Ultimate process stability:** collision-free manoeuvring due to permanent communication

03

04

The on-board electronics allow the two pairs of wings to be precisely activated and contain their own inertial sensor system to control the flying behaviour. Using the two servomotors, the beat amplitude, beat speed and the respective turning points can be freely and individually selected. In this way, the eMotionButterflies are fully manoeuvrable, very agile and come extremely close to their biological role model.

New approaches for the factory of the future
Within the framework of the Bionic Learning Network, however, Festo is not only concerned with the technical implementation of natural principles. The bionic projects also act as research platforms for technologies, applications and solutions in the production of the future. As a result, Festo has been testing the collective behaviour of networked components for several years already.

Yet the eMotionButterflies will not fly through the factory of tomorrow. Instead, the integrated technologies and the networked overall system are, in principle, possible solutions for future industrial logistics applications.

Merging of the real and virtual world
In thoughts about production of the future, the real and virtual worlds are continuing to grow together. The systems envisaged will consist of closely networked components and subsystems. The constant information exchange here guarantees the operational safety of the individual participants and hence the process stability of the entire system.

With the eMotionButterflies, Festo is already showing how several objects can be coordinated without colliding in a three-dimensional space thanks to multifaceted networking. The central computer controls the communication. It gathers all the information together, processes it and forwards it in real time to the individual participants.

The camera technology used enables large spatial coverage and impresses by precisely localising the extremely agile objects. The energy-efficient operating method of the markers and the fast start-up complete the indoor GPS, making it a graphic example for a potential guidance and monitoring system in the factory of the future.

Technical data

Installation:
10 infrared cameras
Frame rate: .... 160 images per second
Exposure time: .... 250 µs

1 central master computer
Analysed pixels: .... 3.7 billion pixels per second

Flying object:
Wingspan: .... 50 cm
Weight: .... 32 g
Wing beat frequency: .... approx. 1–2 Hz
Flying speed: .... 1–2.5 m/s
Flying time: .... 3–4 min.
Recharging time: .... 15 min.

Integrated components:
1 ATxmega32E5 microcontroller , 1 ATmega328 microcontroller, 2 servo motors made by MARK STAR Servo-tech Co., Ltd. to activate the wings, 1 inertial sensor (inertial measurement unit, IMU) MPU-9150 with gyroscope, accelerometer and compass, 2 radio modules, 2 LiPo cells 7.4 V 90 mAh, 2 infrared LEDs as active markers

Project participants

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