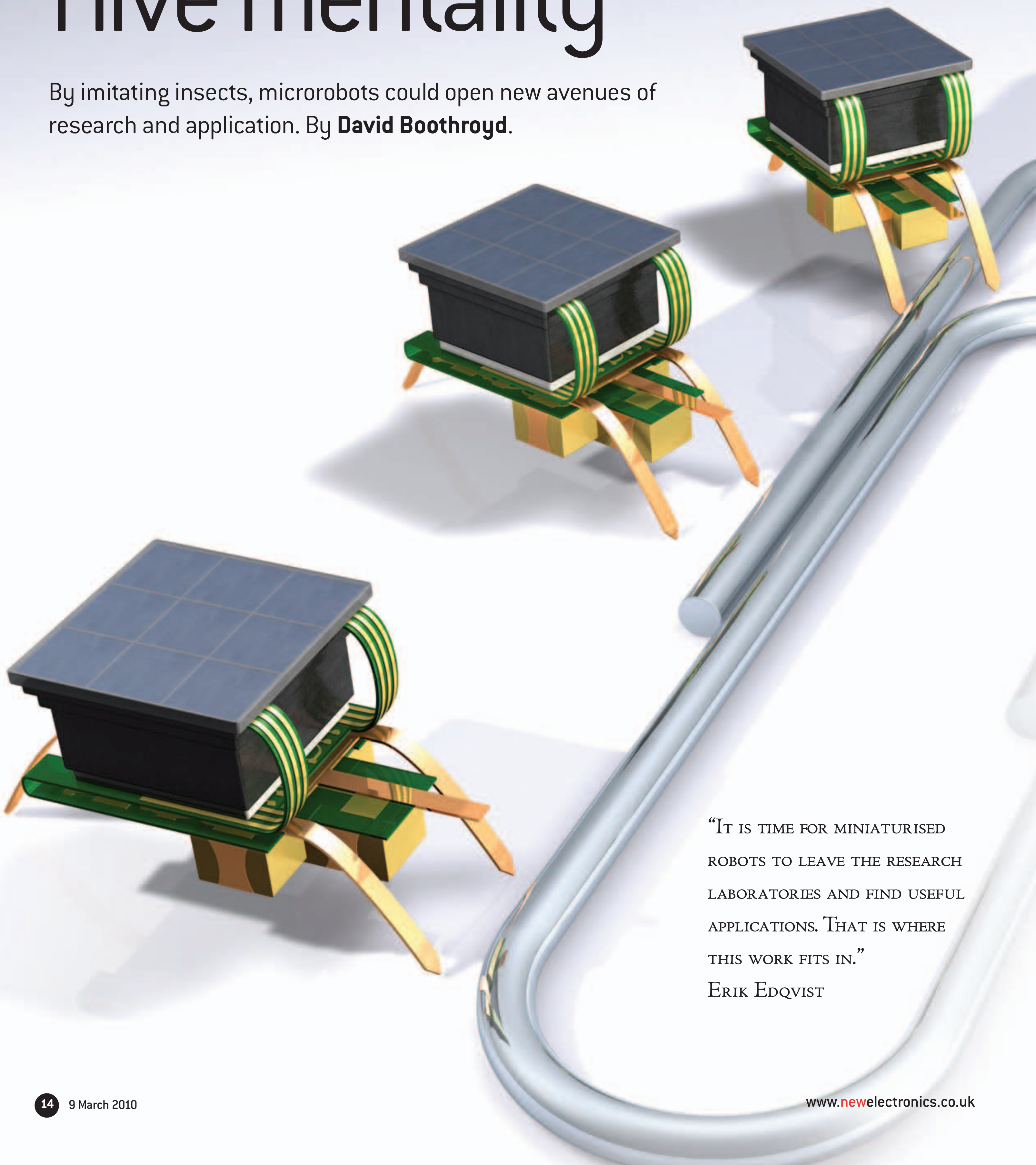
Hive mentality

By imitating insects, microrobots could open new avenues of research and application. By **David Boothroyd**.



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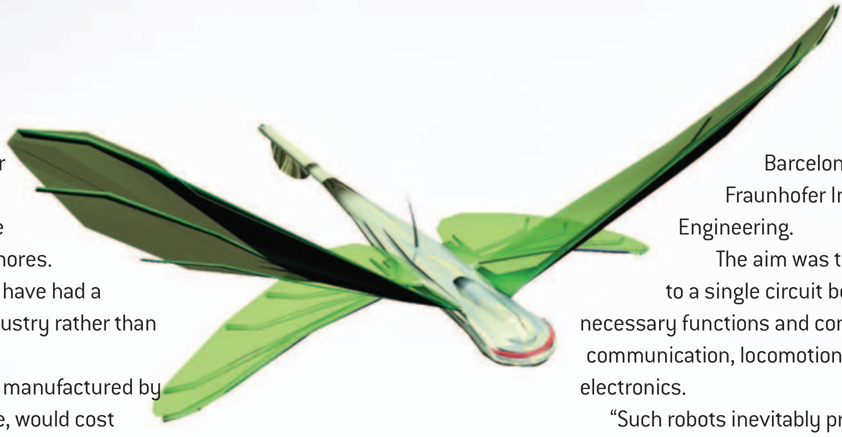


Fifty years ago, predictions for the future always included robots that would, by now, be doing most of our daily domestic chores. While that hasn't happened, robots have had a huge impact on our lives, but in industry rather than the home.

Vast numbers of goods are now manufactured by robot – the modern car, for example, would cost dramatically more to produce without the huge robots that automate large parts of the production process, and quality would be far worse. The same applies to many other industries. Quite simply, the world's manufacturing plants would be radically different – and less efficient – places without robots.

However, industrial robots – typically large, and fixed in place – are virtually a different concept to the smaller, moveable electronic servants beloved of futurists. A few have emerged, including vacuum cleaners such as Karcher's RoboCleaner, and lawn mowers like Friendly Robotics' Robomow. These are quite impressive – they can even dock and charge themselves automatically and follow a weekly programme and go to work at designated times.

Director of PC World, Simon Turner, has predicted robot servants for the home will become a reality within 10 years. Examples include the Spykee series developed by Meccano, Tribot and Rovio, from Wow wee, and iRobiQ, from Yujin Robots. Even so, don't hold your breath if you're looking for the ultimate robot servant that could stack the dishwasher, clean the car, then pop down to the supermarket.

Swarms bring intelligence

Potentially more exciting than medium sized robots are microrobots. Research into these tiny devices could have a massive impact in many areas. Such microrobots hold the prospect of so-called swarm robotics, in which scores, or even hundreds, of relatively simple robots could be combined to generate behaviour more complex than any individual device could achieve alone.

Swarm robotics has been inspired by the observation of social insects, like ants and termites, which demonstrate how simple individuals – in some cases many thousands – can interact to create an intelligent system, able to do things beyond the capabilities of a single individual: termites build large and complex mounds, for example, while army ants organise raids, and other ants can collectively carry large prey.

Potential application areas include the military, surveillance and monitoring, health, micromanufacturing and space exploration. One view of the last is that, ultimately, the only way we will truly explore the solar system and beyond is by building vast numbers of small robots that will be able to land on planetary bodies, then build copies of themselves as well as new vehicles, eventually generating millions of robots spread throughout the galaxy – not a scenario for the next decade, however.

Of course, to make huge numbers of robots, developing ways of mass producing them is vital and one swarm inspired project aimed to do just that by building a microrobot on a single circuit board. Part of the I-SWARM project – intelligent small-world autonomous robots for micro-manipulation – it involved researchers from across Europe, including Uppsala University, Barcelona University and the Fraunhofer Institute for Biomedical Engineering.

The aim was to integrate an entire robot on to a single circuit board, that would support all necessary functions and components including communication, locomotion, energy storage and electronics.

"Such robots inevitably present major challenges in terms of design and manufacturing," says Erik Edqvist, a leading researcher for the project at Uppsala. "I see them as pointing the way of manufacturing for future robots. There are experiments going on with flying insects, swimming robots and so on. But it is time for miniaturised robots to leave the research laboratories and find useful applications. That is where this work fits in. It is an attempt to build robots in a way that lends itself to mass fabrication techniques."

The robots are truly tiny, measuring less than 4 x 4 x 4mm. They are powered by a solar cell on top and move about via three vibrating legs, with a fourth vibrating leg used as a contact sensor. A flexible pcb acts as the robot's backbone, connecting the modules, which comprise the solar cell, capacitors for energy storage, an infrared communication (IR) module, an asic and a locomotion module that includes the vibrating contact sensor (VCS).

Mass production

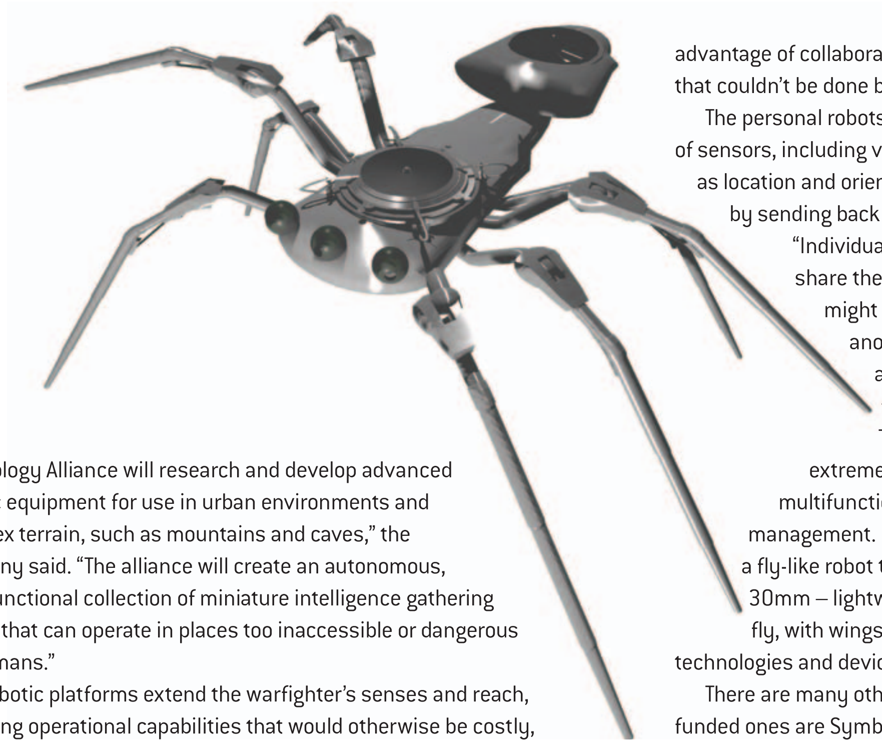
The asic is fabricated using a 0.13μm ultra low leakage SiGe cmos process provided by STMicroelectronics. It includes a microcontroller to manage the locomotion module, the VCS and the IR module. The asic has two voltage levels, 3.6V at the I/Os to drive the modules, and 1.2V in the core to save energy.

Conductive adhesive is used to attach the components to the double sided flexible pcb using surface mount technology. The circuit board is then folded to create a three dimensional robot. Initially, the robots were folded manually, but the aim would be to design a tool to do this automatically, making the process faster and increasing alignment accuracy.

"The important result is that the microrobots can be assembled using a surface mounting machine, whereas previous robots have usually been assembled manually with a soldering iron," Edqvist says. "One great benefit of mass producing swarms of robots is that the loss of some robotic units will be negligible in terms of cost, functionality and time, yet you can still achieve a high level of performance. Even though each microrobot is a physically simple individual, many robots communicating via the infrared sensors and interacting with their environment can form a group that can establish swarm intelligence to generate more complex behaviour."

One application of microrobots that is well on the way to serious use is in the military world. Here, the potential for surveillance and monitoring in dangerous environments is obvious and has prompted what is probably the largest microrobot project yet, led by BAE Systems. About two years ago, the company signed a $38m agreement with the US Army Research Laboratory to lead an alliance of researchers from the army, academia and industry to develop miniature robots to improve what it calls 'military situational awareness'.

"The Micro Autonomous Systems and Technology (MAST) Collaborative



Technology Alliance will research and develop advanced robotic equipment for use in urban environments and complex terrain, such as mountains and caves," the company said. "The alliance will create an autonomous, multifunctional collection of miniature intelligence gathering robots that can operate in places too inaccessible or dangerous for humans."

"Robotic platforms extend the warfighter's senses and reach, providing operational capabilities that would otherwise be costly, impossible, or deadly to achieve," said Dr Joseph Mait, MAST cooperative agreement manager for the Army Research Laboratory.

MAST is aiming for significant innovations in several key areas for microrobotics including: small scale aeromechanics and ambulation; propulsion; sensing, processing and communications; navigation and control; microdevices and integration – led by BAE; platform packaging; and systems architectures. Other major players in the project are three US universities, Michigan, Maryland and Pennsylvania.

"The technologies that will be developed under MAST represent capabilities and techniques that will influence nearly all of the products that BAE Systems will develop and produce in the future," said Steve Scalera, MAST program manager for BAE Systems.

As with the I-SWARM project, BAE admits it will draw on our understanding of how animals and insects sense their surroundings, manoeuvre around, over and through obstacles and combine to perform complex behaviours. Potentially relevant examples it cites include how a bee find its way back to the same flower, how a gecko climbs a vertical wall and how ant colonies and packs of wolves work cooperatively to accomplish tasks that no one entity could accomplish alone. Also, how do you design a robot with legs that can also function as antennae, or whose body is also its power source?

"Our goal is to develop technologies that will give our soldiers another set of eyes and ears for use in urban environments and complex terrain, places where they cannot go or where it would be too dangerous," explained Bill Devine, Advanced Concepts Manager with BAE Systems. "Our goal is also to develop technologies that will take maximum advantage of collaboration between multiple robots to accomplish missions that couldn't be done by a single robot."

"Individual microrobots will collect different kinds of data and share the information with others. By integrating the different data and individual capabilities, the robots will create a fusion of knowledge of their environment."

The personal robots will be fully autonomous and equipped with a range of sensors, including visual, audio, thermal, magnetic and chemical, as well as location and orientation capabilities to improve awareness for troops by sending back vital, lifesaving information.

"Individual microrobots will collect different kinds of data and share the information with others," says BAE. "One microrobot might use cameras, another detect radio frequencies, and another use acoustics. By integrating the different data and individual capabilities, the robots will create a fusion of knowledge of their environment."

Three specific technical challenges for MAST are the extreme level of integration needed, the development of multifunction sensors and actuators, and micro power management. But prototypes have already been created, including a fly-like robot that weighs less than 25g and has a wing span of 30mm – lightweight carbon joints allow the robot to mimic a real fly, with wings that beat 110 times a second. BAE says some technologies and devices developed for MAST could be in use within a year.

There are many other microrobot projects underway. Two major EC-funded ones are Symbrion and Replicator, which stem from the I-SWARM programme, and involves researchers and universities across Europe, coordinated by the University of Stuttgart. These are aiming to develop new principles of adaptation and evolution for symbiotic multi robot 'organisms', again drawing on examples from biology. The aim is for them to manage their own hardware and software organisation autonomously, enabling them to configure, heal, optimise and protect themselves. One specific test application of Symbrion is the development of an artificial immune system, featuring an architecture capable of maintaining the internal state (homeostasis) for both the individual and collective Symbrion robot.

Another active research centre is the Autonomous Systems Lab at the Ecole Polytechnique Federale De Lausanne in Switzerland. This has produced several devices, one of the latest being Alice, a small (less than 1in3), inexpensive and simply constructed autonomous microrobot. Large swarms have been constructed, with more than 90 robots operating simultaneously.

Some innovative manufacturing techniques are being developed. For example, the University of Maryland is pioneering a method employing multistep photolithography via inkjet printed masks to build small polymer robots that move in the same way as insects.

Major challenges remain however, perhaps the most significant being power, because they cannot carry heavy batteries. Here, a tantalising prospect suggests itself: wireless power. If energy could be beamed to swarms of microrobots, it would remove at a stroke a major obstacle to their use.

Interestingly, wireless power is seen as a crucial future technology – by none other than Intel's chief technology officer Justin Rattner.