Selling the ambience of your living over the web

Hidden particles reveal flow in embryo hearts

Lopsided swirl in the pizza oven

Micro satellite in swarms with adaptive electronics

Chips in vains & magnetic field navigation for catheters

2004•1

DELFT OUTLOOK

RESEARCH & EDUCATION AT DELFT UNIVERSITY

TU Delft

Delft University of Technology

CONTENTS

COVER: A mix of ambiences at the Studio Home Lab at the Faculty of Industrial Design Engineering.

COLOFON

Volume 21, № 1
DELFT OUTLOOK IS PUBLISHED FOUR TIMES A YEAR
BY DELFT UNIVERSITY OF TECHNOLOGY
ISSN 0926-7212

EDITOR
Philip Broos (editor-in-chief)
Piet Musters (picture editor / photographer)
Maarten van der Sanden

CONTRIBUTING WRITERS
Astrid van de Graaf
Joost van Kasteren
Bennie Mols
Bruno van Wayenburg

EDITORIAL OFFICE DELFT OUTLOOK
P.O. Box 5
NL 2600 AA Delft,
The Netherlands
Telephone +31 15 278 5860
Telefax +31 15 278 1855
E-mail : delftoutlook@tudelft.nl

DESIGN & LAY-OUT
RAM Design, Asperen, The Netherlands

PHOTOGRAPHY
Delft TU, unless mentioned otherwise

TRANSLATIONS
Marcus de Geus, Delft
Mrs. Drs. Margaret Clegg BA, The Hague

PRINTING
DeltaHage BV, The Hague, The Netherlands

EDITORIAL COUNCIL
Prof.Dr.ir. J.H.T.H. Andriessen (PSYCHOLOGY OF WORK & ORGANISATION)
Prof.Dr.Ir. C. van den Akker (CIVIL ENGINEERING)
Prof.Dr. J. Dankelman (MECHANICAL ENGINEERING)
Prof.Dr. J.W. Drukker (INDUSTRIAL DESIGN ENGINEERING)
Prof.Dr.Ir. J.T. Fokkema (APPLIED EARTH SCIENCES)
Prof.Dr. P.J. French (ELECTRICAL ENGINEERING)
Prof.Dr.Ir. T. van der Hagen (INTERFACULTY REACTOR INSTITUTE)
Mrs. Drs. M.A.M. Heijne (LIBRARY TU DELFT)
Prof.Dr.Ir. P.M.J. van den Hof (APPLIED PHYSICS)
Prof.Dr.Ir. T.M. de Jong (ARCHITECTURE)
Prof.Dr.Ir. U. Nienhuis (MARINE ENGINEERING)
Prof.Dr. H. Koppelaar (TECHNICAL INFORMATICS)
Prof.Dr. J.G. Kuenen (CHEMICAL ENGINEERING)
Prof.Dr.Ir. H. Priemus (POLICY ANALYSIS)
Prof.Dr. H.G. Sol (SYSTEMS ENGINEERING)
Prof.Dr. G.J. Olsder (APPLIED MATHEMATICS)
Prof.Ir. M.G. Vosselman (GEODESY)

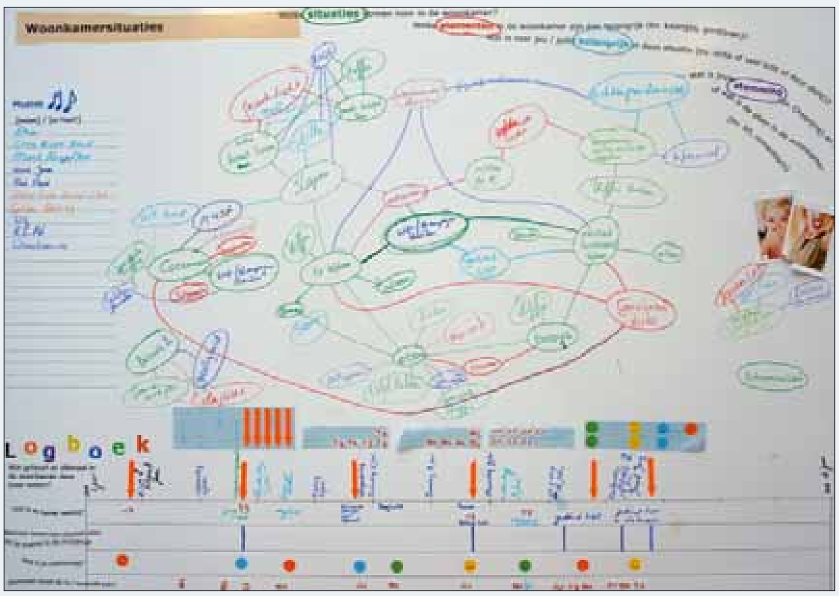
For sale: Mood Tuscany for your living room

When people furnish a living room they can create a single atmosphere with some scope for slight variations during the evening when lights can be added. Music also plays a major role in creating the right mood, and so will a painting or a photograph on the wall. Of course things can be changed, but it takes a bit more effort than the method proposed by researchers at TU Delft, who can instantly change everything at the touch of a button. This is what the Melancholy mood looks like.

Romantic, snug, cosy, or chaotic – your integrated ambience control will automatically fill the room with your personal choice of music, lighting, and art

by BENNIE MOLS

Most consumer products are designed with the average user in mind. Wallpaper, stereo, lighting equipment, none of them contain any knowledge about the specific, changing wishes of their owner. Once bought, they never change. At the Studio Home Lab of the Delft faculty of Industrial Design, researchers are investigating how music, lighting and art can instantly change the atmosphere in your living room. They have developed models of moods such as romantic, quiet, snug, cosy, chaotic, and business-like. The result is an integrated atmosphere control unique in the world. The system can be operated by anything from a mobile display on which users click to make their selections to voice-operated control. One of the innovative controls devised by the Delft researchers is a small wooden work of art that the user can shape to express his personal mood. In addition to choosing their type of control, they may one day be able to exchange living room moods in digital form with Internet users all over the world.



Researchers Julie Beusmans and Liliane Hoyng visited a number of households (most of them couples). In a two-hour interview, the test subjects were informed about the exact purpose of the research. They were then asked to create a so-called mind map over the next fortnight to illustrate a number of situations that occurred in their living room, such as turning down a certain lamp when visitors come in, or what they would do when working in the living room, or when having a dinner party. The express purpose of the exercise was to make the couples more aware of their surroundings.

If you're fed up with your current living room decor all you can do is repaint the walls in a more stylish colour, change the lighting systems, and hang a new work of art. Rather cumbersome, and impractical for those restless souls who feel like changing their living environment once a month. Even so, we all feel the need from time to time for a change of atmosphere. One day we may be looking for a practical, business-like setting, the next we may want a warm, romantic ambience, or simple, relaxing surroundings. We turn off electric lamps and light candles, put on mood music, but the walls themselves don't change as easily. Whatever we do it's no easy task to quickly transform the atmosphere of a living room.

Researchers at the faculty of Industrial Design are conducting experiments at their Industrial Design Studio Home Lab with an atmosphere control system that automatically changes our environment. At the press of a button, a spoken command, or, in the most advanced configuration, by changing the shape of a work of art, the device will instantly change the look and feel of your living room. From quiet to crazy, from romantic to severe, the occupants should be able to fit everything to their individual requirements. The system simultaneously changes the lighting, music, and even an image, still or moving, projected onto a wall.

Associate professor Dr David Keyson heads the Intelligence in Products research group of the Human Information Communication Design section at the faculty of Industrial Design. He is also the project leader of the Studio Home Lab. Previous products developed by the group included an intelligent, voice-operated thermostat (see Delft Outlook 2001·4).

'We are looking for ways to incorporate knowledge about the user in different products, in this case an atmosphere control system. In addition to looking at the technical interface between the user and a product, we are also investigating the way in which the product is used. Instead of simply looking at the end product, we consider various intermediate stages on the way to the finished product.

For this project, the TU Delft researchers are collaborating with researchers, Liliane Hoyng and Nicole de Koning of TNO Telecom (formerly the well-known Dr. Neher Laboratory / KPN Research).

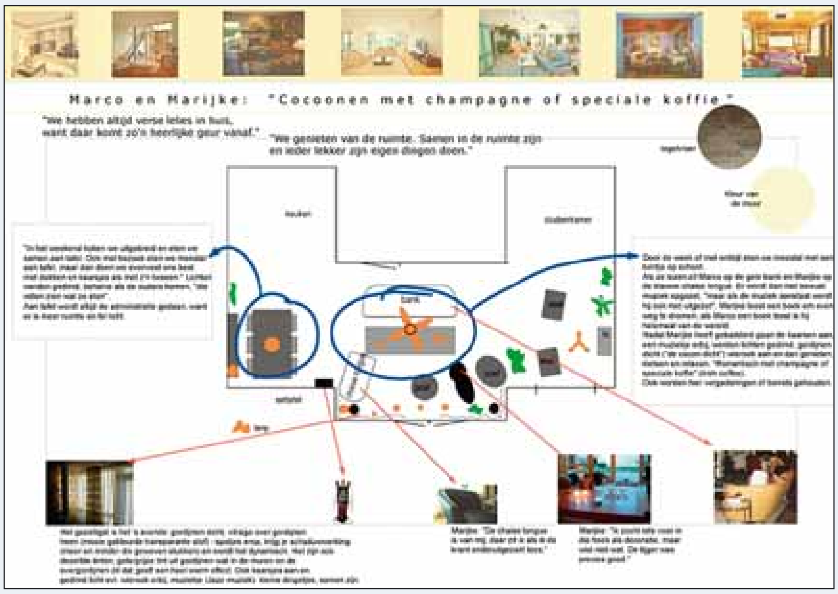
No complex electronics, please! ¶ We're in the Studio Home Lab, a living room complete with sofas, chairs, a coffee table, TV, pot plants, and bookshelves. Assistant researcher, Julie Beusmans hands me a prototype atmosphere control unit. It consists of a display, or tablet PC, the size of a book. The display shows a number of coloured icons each of which represents a certain mood. 'Here, you try it,' she says, and I press a stylus onto a red square on the display. At once, romantic music fills the room, the lighting changes to a nice warm shade of red, and a projector brings up a romantically inspiring moving image on a large wall. My next selection is a white square, and the atmosphere control system instantly changes the living room into a somewhat chilly, business-like environment. The underlying technology remains invisible, so itappears to happen by magic.

Basic Atmosphere Controller is the provisional name of the atmosphere control system. The device offers eight pre-programmed moods. Users can modify each of the basic moods to their own liking. The tablet PC is a wireless device, so users can sit back on the sofa and control everything from there. A computer program simultaneously controls music, lighting, and the art projected on the wall. In addition, the lights can still be switched on and off manually by the user. The system automatically stores the new settings. The techniques themselves are not new; the focus is on finding adequate models to create the different moods. The Basic Atmosphere Controller is the result of a long series of experiments with a number of test subjects.

'Technically, we can work wonders,' Beusmans says, 'but the main question we have to answer is whether users have any need for linked products. Do they want their lighting linked to their music and art? When I introduce our test subjects to the concept of atmosphere control, many of them respond by saying they don't want all that technology in the house.'

To find an answer to this question, Beusmans started by pasting up a number of collages which she showed to her test subjects. They were then asked to indicate the mood evoked by the collage. From the results of these experiments, Beusmans distilled eight basic atmospheres, including a number of negative atmospheres that people did not much care for. Together with Liliane Hoyng from TNO Telecom, she then visited six couples at home.

The couples were also given a sheet of cardboard on which to create a collage. This was intended to elaborate one of the situations, using felt-tip markers, images and text from magazines, photographs, and bits of material. Every three days, they would receive mail from Delft to keep them on their toes and to given them fresh ideas. On one occasion they might receive an envelope containing pictures of interiors, another time it would be a reminder to take photographs, or a postcard asking them if they would change anything depending on the season etc..



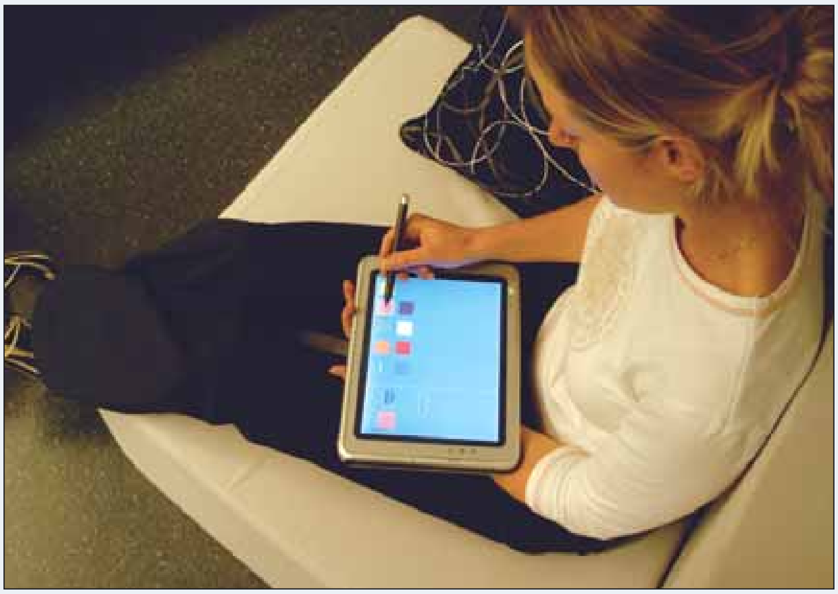
After two weeks the couples were visited again so that they could explain the mind map and the collage to the researchers. The material was then taken back to the university for analysis and to make so-called experience cards. These cards are an interpretation of the way in which the couples experienced the atmosphere in their living rooms. Two months later, the test subjects were invited to furnish Studio Home Lab, the department's living room laboratory, using the furniture provided as well as objects brought by the subjects, such as candles, paintings, CDs, cushions, drinks, snacks, etc. They were first asked to make the room their own and then to give it the right atmosphere for spending an evening in together on a cold winter's night. The lighting levels were changed, drinks were poured, snacks were put out, and mood music was put on. The researchers themselves stayed out of the picture, although the furnishing process was recorded using a video camera. Once the test couple were satisfied with the result, they were asked to sit on the red sofa to indicate that they had completed their assignment.

'The first thing we wanted to find out was what they thought of the technology and about atmospheres in general,' the researcher explains. 'After the initial home interviews we left them some material to make them more aware of their own behaviour and situations at home. In two weeks, they had to create a «mind map» about different situations that occur in the living room, and a collage in which they elaborated one specific situation.' After two weeks, Beusmans returned to the couple to continue the interview. By that time, most couples had a clear idea about the various living room atmospheres they would like to have.

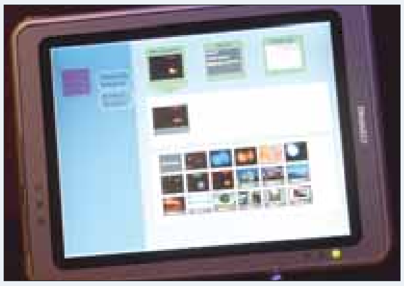
Presets preferred ¶ Eight couples then visited the Studio Home Lab. They were allowed to bring along anything of their own to give the room a personal touch. They brought books, art, cushions, and wine. They moved sofas, chairs, and cupboards around to their liking. When all was done, they were given free rein with the atmosphere control. Beusmans gave half of the couples a set of predefined atmospheres which they could modify as they saw fit, while the other half had to create their own atmospheres from scratch.
'The experiment clearly demonstrated that people like to have a predefined atmosphere, otherwise they are unable to see what all their options are, and they lose interest,' Beusmans says. 'Ask them to create an atmosphere of their own, and they will simply copy what they have at home. We call it the cold start problem. The only way to really get them going with designing atmospheres is to show them first what the possibilities are. At that point, most of then go «Wow! I'd like one of those at home!» even though at first they didn't think much of the idea.'

Staying in control ¶ Another major conclusion is that people like to stay in control. They want to be able to modify predefined moods.
Beusmans: 'I asked them what would be the first thing they would do if they had this technology at home. Most of them replied that they would like to create different atmospheres for different types of visitors. They also wanted to be able to give their own, personal names or images to each atmosphere.'
Ultimately, users should be able to load the atmosphere control with their own music collection and their own collection of art or photographs to create a personal digital mood file. Of course, the projector that displays art on a wall could equally well be used to show a movie or a favourite view of New York or the Grand Canyon.
Project leader David Keyson would like to take the atmosphere control concept one step further still. 'What we are heading for is a central computer in the home connected to the rest of the world through the Internet. It will enable you to send your custom-made atmosphere to a friend in the U.S. or download a new atmosphere from the Net. What we will have is a worldwide mood exchange network.'

Voice-operated atmosphere control ¶ Keyson's research group also conducts research into the way in which people would like to operate the atmosphere control system. Will it be enough to have a tablet PC on which users can click to make their selections, or will people prefer to change the mood of their living room by voice control, so they can simply call for «romantic», or «snug»? Marc de Hoogh is the group's software developer. He created the software that enables users to talk to the atmosphere control. The speech recognition software itself, which is speaker-independent, comes from Philips Electronics. Thousands of different voices form the basis for the acoustic model. The speech recognition module works well. 'It even works for me, in spite of my accent,' says Keyson, who is a Dutch-speaking American.
De Hoogh gives a demonstration. The current system still uses a normal telephone routed through telephone server software running on a PC on loan from TNO Telecom, but it could equally well use a box on the living room wall. Through the telephone, I can give commands to change the atmosphere. I have a choice of active, snug, romantic, serious, cosy, crazy, and quiet. I say «crazy», and the system immediately recognises my command. At present the only way to view the result is on a computer display, but direct control of the living room atmosphere is easily done. My next assignment is to tell the system how much I want of the selected atmosphere. Could we have things slightly more active, or a bit less cosy?



For the next scene, the test subjects were asked to take the atmosphere control unit (a handheld PC with a touch screen) and select from a number of predefined atmospheres the one they liked best for a cold winter's evening.



When the test couple had located the right atmosphere from among the predefined atmospheres, they were given the opportunity to change it to personalise it. They could change the music by clicking on one of the music tracks from a library containing their own music selection, and select from a collection of moving and still wall projections, including some of their own holiday snaps. Finally, the lighting was set. This could be done either by using the atmosphere control unit, or by getting up and operating a dimmer switch. Every action was recorded. Whereas at the start of the project the people were sceptical about using a central system to control devices around the house to create specific moods, after using the atmosphere control system they all wanted one. They were delighted about the ease with which they could sit back on the sofa while the room around them underwent a metamorphosis. What many didn't expect was that the atmosphere control system allowed them to create a better atmosphere than they would have done without it. However, having created each of their different atmospheres, they did not think they would continue to design additional atmospheres. All the test subjects agreed that they had to undergo the changes in atmosphere in order to appreciate them.

Intelligent atmosphere control

At Studio Home Lab, doctoral student Martijn Vastenburg is looking at ways to have the atmosphere control system actively adapt to the changing requirements of persons in the room. For example, a ringing telephone could cause the system to lower the music volume. Should the occupant fall asleep on the sofa, the system could switch off the music altogether and even lower the lighting level. Vastenburg will soon be inviting couples to the living room to find out how people would like to communicate with the atmosphere control system in their own living room. The idea is that one person will sit in the living room and will be presented with changing situations. The other person will be seated at a console from which he or she can operate the atmosphere control system. The occupant in the living room would then talk to the other person giving commands to change the atmosphere as the situation changes. By studying the dialogues that develop between the couples, Vastenburg hopes to lay the foundations for a personalised atmosphere control system. Initially, the communication will be voice only. In a subsequent phase, a video camera could visually monitor the changes in the living room situation. The atmosphere control system could then intervene, for example when it detects that the occupant has dozed off on the sofa.

According to Keyson, a recurring problem with voice-recognition systems is that people don't know what they can say to the system.
'In the living room a possible solution to this problem would be to start by projecting the options in the form of words onto the wall. After a while, the user will know the available options, and the projection can stop.'

Model-A-Mode ¶ Graduate student Philip Ross, who is also working with the Intelligence in Products group, is researching the most advanced means of operating the atmosphere control system: by modelling a flexible work of art. Touch as an emotional interface.
'When people talk with one another, in addition to using their heads, they use gestures and emotional expressions,' Ross explains. Current products such as video recorders tend to use only cognitive aspects of communication. To be able to program a VCR, you have to study all sorts of icons and menu structures. Ross is looking into methods of incorporating physical and emotional skills into tangible designs.
'People have an intuitive sense of atmosphere. My first question therefore was how I could project a specific sense onto a tangible object.'
Before he started designing, Ross asked a number of test subjects to use gestures to express atmospheres. He found a certain degree of consistency in the gestures people used for specific atmospheres. Happy atmospheres tended to result in faster, more open-handed, gestures. Ross designed his control to look like an attractive, wooden work of art. It consists of a rotating carousel with four flexibly hinged flags set close to each other along the edge. The whole thing as about the size of half a football. Each flag has two degrees of freedom, in the vertical plane, and round its own axis. In addition, each flag features a wooden side and a metal side. The carousel can turn faster or slower, depending on how hard the user swings it. Electronic intelligence linked to the electric motor then keeps the disc spinning at its new speed until the user decides to change the speed again.

Invisible ¶ The design called for the technology to remain invisible as much as possible, since the user's sense of atmosphere had to remain central.
Ross: 'As it turns out to create a more active atmosphere people will spin the carousel at higher speeds. The flags can be used to form patterns to express a specific emotion. A closed mood will correspond with the flags lying flat, whereas upright flags indicate an open atmosphere. With the wooden sides of the flags visible, the atmosphere will be warmer than when the metal sides are showing. A chaotic atmosphere will be created by pointing the flags in different directions. It's like an abstract work of art, which also uses form and material to express an emotion.'
Invisible to the user, the carousel contains a fair bit of technology developed in collaboration with electronic engineer, Luxen and programmers Aadjan van der Helm and Kerem Odabasi. Sensors measure the position of each of the flags and the rotation speed of the carousel 25 times per second. The results are transformed into high-order variables defined as numbers ranging from 0 to 1. The high-order variables are then used to derive the different atmospheres such as romantic, quiet, business-like, cosy, busy.


Active atmosphere
(also referred to as Nervous)


Romantic atmosphere
(also called Flirting atmosphere by the participants)


Business atmosphere


Happy atmosphere
(called Discotheque by the participants)


Cocooning atmosphere
(most popular for a night in together)


Yoga atmosphere
(called Zen by the participants)


Cosy atmosphere
See title picture for the Melancholy atmosphere.

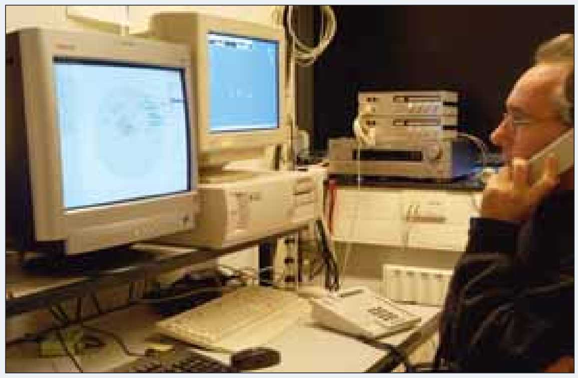
Besides the tablet PC interface, some sort of physical interaction could also be used to select the desired atmosphere. Graduate student Philip Ross has designed a device consisting of a rotating disc with four flags attached to hinges along the edge. The device (called Carousel) can be used to manually express an atmosphere by arranging the flags in a certain pattern. They can permanently increase or decrease the rotation speed of the disc by giving it a twist or by slowing it down.

The control principle is based on the fact that the pattern and the rotation speed can be connected with a certain atmosphere because it changes in real time. This mode of control relegates the technology to the background, leaving an object that naturally fits into the living room, according to Ross.

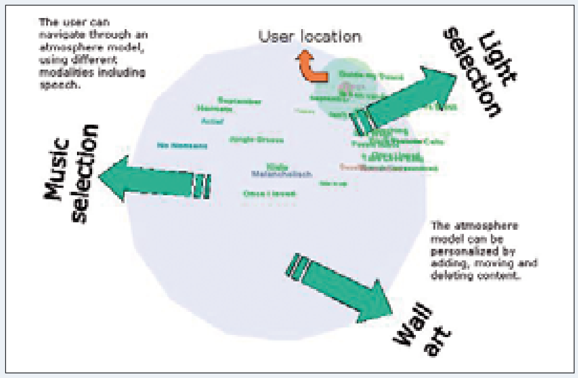
Hospital ¶ In early October 2003, Ross conducted the first test, using eight test subjects who were asked to create atmospheres using the carousel and its four flags. Ross wanted to find out whether people would shape the carousel the same way at different times, and to what extent similarities would exist between the different test subjects.
'The first conclusion is that there does appear to be a trend since people are inclined to create similar shapes to signify certain atmospheres. Moreover, they showed particular pleasure in handling the object.'
The carousel can be used to create subtle changes. It offers a continuous scale of change from one mood into another, and enables unique combinations to be expressed.
'This is a far cry from spoken commands, where everything has to be defined in advance. This object allows users to create their own significant environment.'
The basic principle might well work, so Ross has already concluded from his first results.
Keyson's group is working on the atmosphere control system as part of Residential Gateway Environment project (www.rge.brabantbreedband.nl). Within the project, researchers from TU Delft work closely with TNO Telecom, TU Eindhoven, and Philips Research. Whereas the other parties are interested mostly in technology, the group from Delft focuses on the user side of things.
The integrated atmosphere control, which automatically changes music, lighting and wall art, is a world wide first. There is no reason why the application should remain limited to living room use. Keyson already has a number of medical applications in mind.
'I think the atmosphere control system would work well in hospital waiting rooms, for example.'

For more information, please contact Dr. M.Sc. David Keyson, tel. +31 15 278 3374, e-mail d.keyson@io.tudelft.nl, www.io.tudelft.nl/research/intelligentproducts

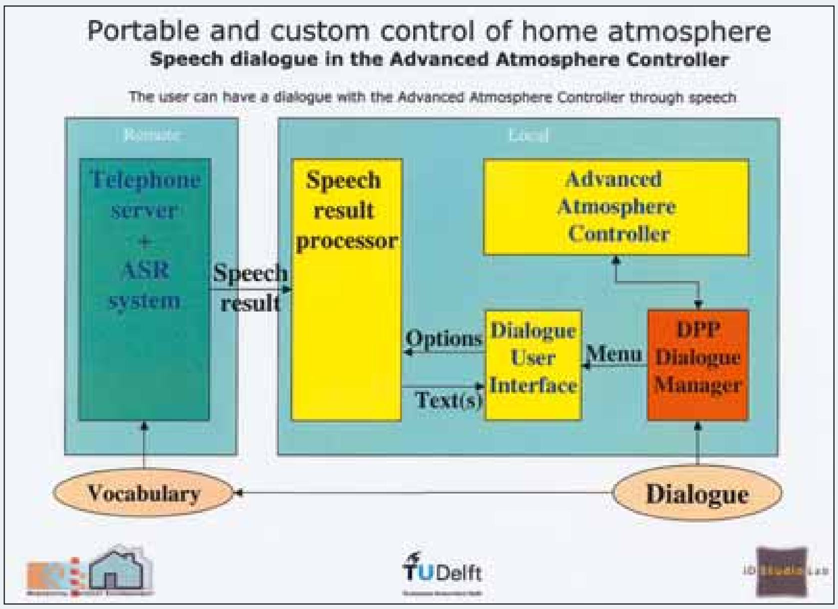
Software developer Marc de Hoogh has designed a voice-operated control system that can be used to set the right atmosphere in the house by telephone from a car or from the office. The current version offers a selection of Active, Snug, Romantic, Serious, Cosy, Crazy, and Quiet. The system could also be housed in a box installed in the living room, in which case additional variations on the atmospheres are possible by graduating each option, e.g. more or less snug. One problem with voice-operated systems is that users often don't know what they can say to them. At Studio Home Lab the problem is solved by projecting the options on the wall.



The room for observing the intelligent living room contains the telephone server (on the right) and the atmosphere controller (left).



The different atmospheres have been placed in a virtual space. Using a voice-recognition system, a tablet PC interface, or the Carousel, the user can navigate through the multidimensional space and so create different atmospheres.



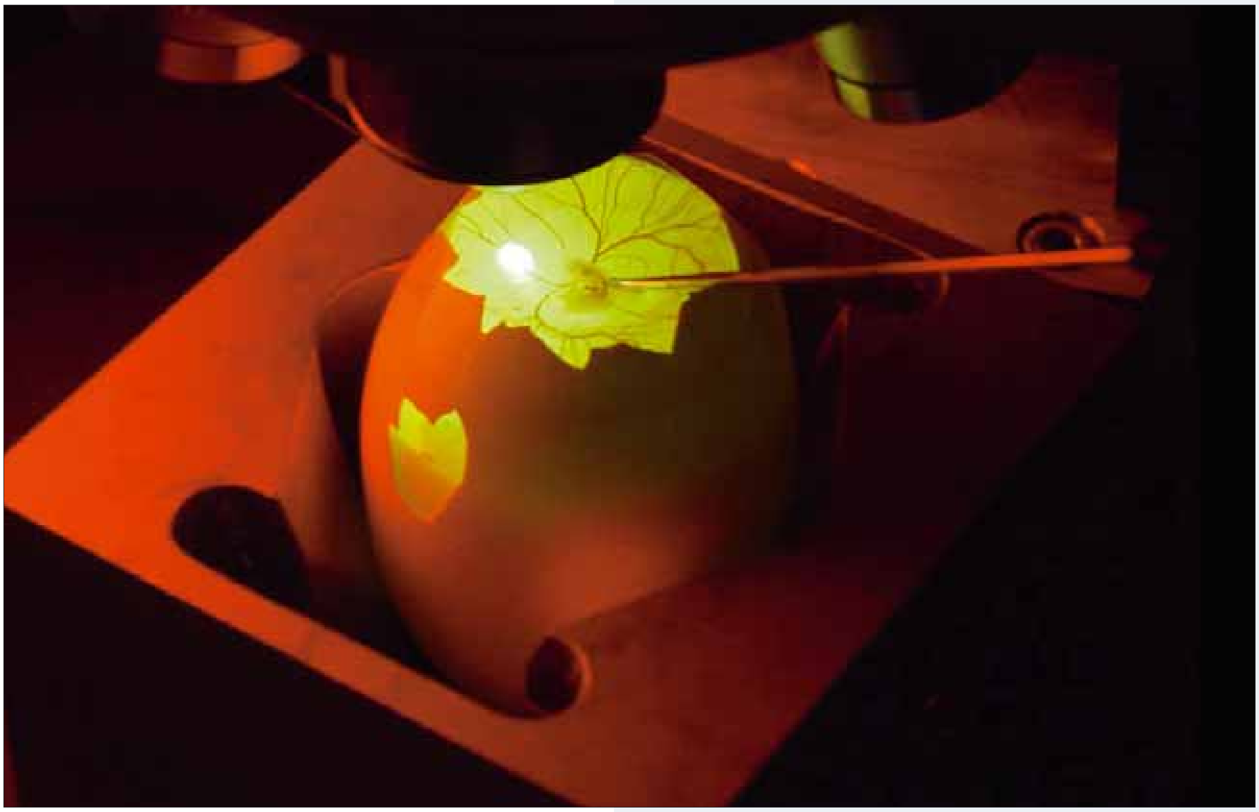
The voice control options shown to the user are reproduced by the Dialogue Prototyping Platform (DPP). The system can be used without any special training, and requires no programming knowledge. The speech recognition dialogue can be modified without having to tinker with the underlying software.

Challenging voicemail browser

Doctoral student Marco Rozendaal, of the Intelligence in Products group, is researching a new type of voicemail browser that is both creative and functional.
'I am looking for a design that combines functionality with a challenge to the user's sense of adventure,' Rozendaal explains. 'People hardly ever look at a product's functionality alone. A point of major importance is how much fun they will get out of it, and how exciting it will be. In addition there is the social aspect. A product could fit right in with a certain sub-culture, and so help to define the identity of a group.'
Rozendaal designed a circular drum like a cake tin, with sixteen circular hollow containers along its perimeter. Each container can hold a voicemail message, so to speak. In the centre of the drum is a holder containing a pen-like object that can be used to scan the voicemails stored in the device. Stick the pen into a container and you hear the corresponding message. The current design is intended purely to research the operating principle, and the end product could well look totally different.
Rozendaal experimented with three different ways of playing back messages. Over each container, an imaginary cone-shaped space has been defined. In the first operating type, the user hears an abstract sound, something like «plong», «poing», or «plop», every time he moves the pen into this space. Each voicemail message, i.e. each container, has its own sound. The sound varies in volume, pitch, and tone. The louder the volume, the more recent the message, and the higher the pitch, the more urgent it is. The tone is used to indicate the caller. This means that the user must first assign tones to different callers. The idea is that the design gains efficiency by using a single sound to convey three different meanings. If all the containers are full, and you move the pen around, you hear something that sounds a bit like xylophone.
In the second playback type, rather than hearing an abstract sound, the user hears the message itself. The idea is that each message floats above its container as it were, and is continuously played back. By moving the pen in a circle over the machine, the user can hear fragments of the telephone messages in succession. This time the result is like a conference line. It enables the user to quickly scan all his voicemails without having to listen to each full message in turn.
In a third design, Rozendaal defined three imaginary layers at different levels above the machine.
'The idea is to remove the complexity from the abstract sound. Hearing all three aspects of the sound at the same time is too complicated for many people.' So, in the top layer the user hears only the tone, which conveys information about who left the message. The middle layer adds volume to indicate which message is the most recent. The bottom layer adds the pitch, so all three aspects are once again combined in a single abstract sound.
The voicemail browser combines gestures, abstract sounds, speak, and touch into a creative means of handling voicemail messages. A number of test subjects spent an hour each practising with the system. The experiences of the test subjects vary considerably, according to Rozendaal.
'Some were keen to try and understand the meaning of the sounds, but some found it very difficult to work with sounds. The latter preferred to play back the full messages one by one. The product as a whole scored well in spite of the complexity. This is because the design's intricacy is compensated by the sense of adventure it offers.'
Objectively speaking using sounds may not be more efficient in some cases,' Keyson adds, 'but people don't always experience it that way.' The idea of engaging a number of different senses for control purposes could be adapted for use with the atmosphere control system.

Hidden particles reveal flow in chicken embryo hearts

Measuring with the heart's rhythm

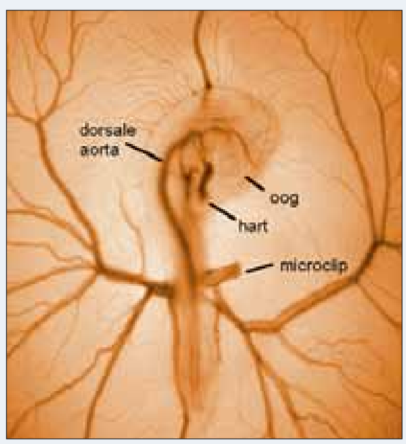


Experimental set-up for measuring shear stresses in blood vessels. Some schools of thought have it that the shear stresses caused by the blood flowing along the blood vessel wall can prod genes into activity. This might be how the development of the heart is controlled. In recent experiments, the blood flow in a chicken's egg has been observed in vivo through an optical microscope. For illumination, a laser shines through a hole in the side of the egg. An ultrasonic Doppler sensor has been fitted close to the embryo to measure the heartbeat.

by ASTRID VAN DE GRAAF

Blood is said to be thicker than water, and it may come as a surprise to learn that red blood cells 8 micrometres across routinely manage to work their way through minute blood vessels no more than 5 micrometre in diameter. How they do so remains a mystery, but thanks to a non-invasive optical measuring technique for fluids developed by researchers at the J.M. Burgers Centre for Flow Dynamics, physicians can now observe in vivo how the blood flows through blood vessels measuring as little as 60 micrometres in diameter. This offers a whole new perspective on fundamental questions about the development of the heart and cardiovascular disorders, and it offers clues for solving practical problems in the treatment of tumours. In addition, the Delft researchers have recently managed to successfully measure flows in non-biological microchannels as small as 40 micrometres across, with a resolution of 300 nanometres. The next step will be to perform measurements in biological microchannels.

'Our project is aimed at measuring the blood flow through the embryo's heart. Apart from the fact that a heart has a complex geometry, it is constantly moving. This makes it difficult to get it into focus under a microscope, but we recently managed to complete a series of in-vivo measurements on a chicken embryo', Prof. Dr. Ir. Jerry Westerweel of the Laboratory for Aerodynamics and Hydrodynamics at TU Delft explains. The laboratory forms part of the national research school for Flow Dynamics, the J.M. Burgers Centre.
In the last couple of months Westerweel's group has been concentrating on



View of a chicken embryo made using an optical microscope (magnification 2.5 x). The incubation time of the embryo is only 2.5 days, but even so the head with an eye, and the heart are clearly visible. The heart is still primitive, consisting as it does of nothing more than a curved length of blood vessel. The small clip in the picture is used to alter the blood flow.

(PHOTO: SANDRA STEKELENBURG-DE VOS, ERASMUS MEDICAL CENTRE)

finding ways of improving the technique for measuring pulsating flows in small, straight blood vessels of 200 micrometres diameter. During the early days of an embryo's development, the heart is nothing more than a straight, pulsating blood vessel. The main question is how the cells forming the wall of the blood vessel know that they are supposed to develop into heart cells.
Westerweel: 'We think that the shear stress exerted by the blood flow on the inside of the blood vessels' walls plays a role in the development of the heart. The constantly changing shear stresses along the blood vessel wall may activate certain genes in the wall's cells that determine what the heart will look like.'
Westerweel's group is conducting the research into the development of the heart in collaboration with the Leiden and Rotterdam Medical Centres. Westerweel is working closely with embryologist Prof. Dr. Rob Poelmann of the Anatomy and Embryology Department at the Leiden University Medical Centre. Poelmann has been researching the development of the chicken's heart for the past 15 years.

River's edge ¶ The wall of the straight blood vessel – the first stage in the development of the heart – contains autonomous muscle cells that cooperate to create a blood flow. The frequency with which they contract slowly increases. The straight blood vessel changes shape and develops into a complex knot with a three-dimensional bend in which a right-hand and left-hand heart tube with valves can be detected. The final shape of the heart is in fact a double tube with the two blood flows crossing over.
'During the development of the heart, the frequency of the heartbeats increases, which in turn increases the flow rate of the blood. The endothelial cells, which form the inner lining of a blood vessel, react to this change by producing different proteins,' Professor Poelmann explains.
He compares the process with a river meandering through a landscape. The water flows fastest along the outside of each river bend, slowly eroding the river bed. Along the inside of the bend, the water flows slowly, causing silt and other particles to be deposited. Of course, the river's edge is a passive participant. The development of the heart involves an interaction between the shear stresses exerted by the blood as it flows along the wall, the activity of the heart muscle, and the reaction of the cells in the blood vessel. Where flow dynamics and gene expression meet, so do Leiden and Delft.
It is not yet known exactly how the shear stresses activate the genes. However, two signalling substances appear to play a major role in the process: nitrogen oxide (NO) and endothelin. One causes the blood vessel to dilate, and the other to contract.

Yolk sac ¶ Westerweel uses chicken eggs for testing purposes.
'They form a convenient modelling system, since the embryo is readily accessible for our measuring systems, and they can be used for experiments without complex research permits. And, of course, they are inexpensive,' Westerweel says.
It will take the Delft technologists a little while to get used to the idea of having to care for an incubator full of fertilised chicken eggs.
The experiments take place on day 5 after gestation. 'What makes the egg system ideal is that the embryo floats on top of the yolk sac. All we have to do is lift off the top of the egg, and we can start measuring. The blood vessels leading from the yolk sac to the embryo, providing the chicken-to-be with nourishment and oxygen, are clearly visible.'
At this stage, the size of the heart, which consists of a twisted loop with two constrictions and beats at a steady rate, is about 300 micrometres.

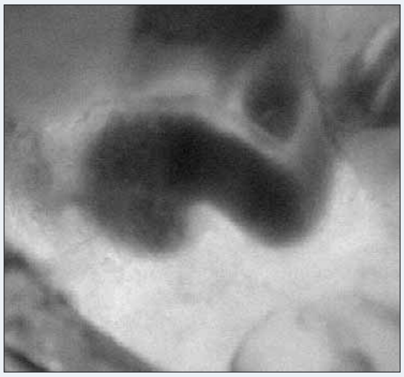
Synchronisation ¶ Measuring the blood flow requires a few precautions. The egg is placed in a heated aluminium receptacle under an infrared lamp, because the embryo is sensitive to changes in temperature and light. Suspended over the uncapped egg is a microscope to observe and record the proceedings, with a laser providing illumination from the side.
'Anything you do may affect the embryo and disrupt the rhythm of the heart', says Westerweel. 'The heart of a chicken embryo beats with frequency of about two beats per second. Unless we manage to synchronise the laser flashes to this rate, the system will be disrupted. We measure the rhythm of the heartbeat using ultrasonics. We use the result to control the laser so the flashes are fired in step with the action of the heart. The laser does not heat up the embryo. Initially, when the technology proved unable to keep up with the biological system, we came up with the idea of building a pacemaker for chicken


(PHOTO: SANDRA STEKELENBURG-DE VOS, ERASMUS MEDICAL CENTRE)

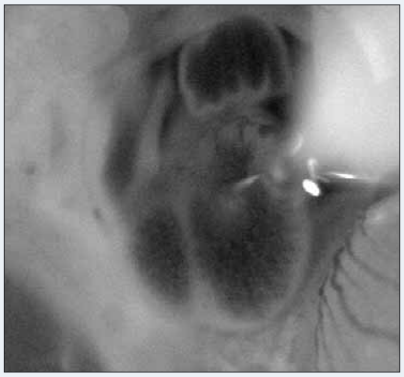
The incubation time of the embryo in this view is 3.5 days. The blood vessel that will form the heart has grown a little in diameter. In the previous view, the blood flow literally was a question of three steps forward and two steps back, but one day later muscles are beginning to form in the heart vessel that can contract to stem the flow of blood, acting as valves to increase the effectiveness of the motion.


(PHOTO: SANDRA STEKELENBURG-DE VOS, ERASMUS MEDICAL CENTRE)

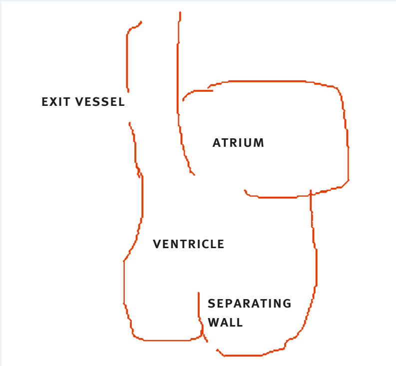
In this view, after an incubation time of 4.5 days, the heart of the embryo is beginning to take shape. To the left of the heart a piece of the wing can be seen. The bulbous object to the right containing the two small blood vessels is the brain.



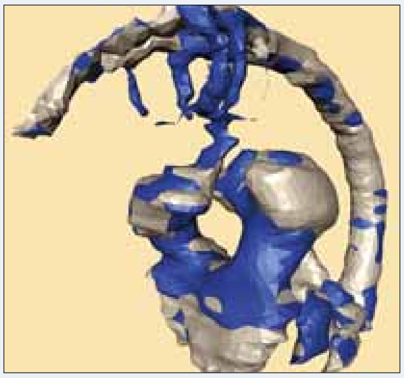
Close-up view of the primitive heart after 3.5 days incubation.



Close-up view of the embryo's heart at 4.5 days. This view shows the first developments of the atria and ventricles.



Schematic diagram of the embryonic heart at 4.5 days incubation.



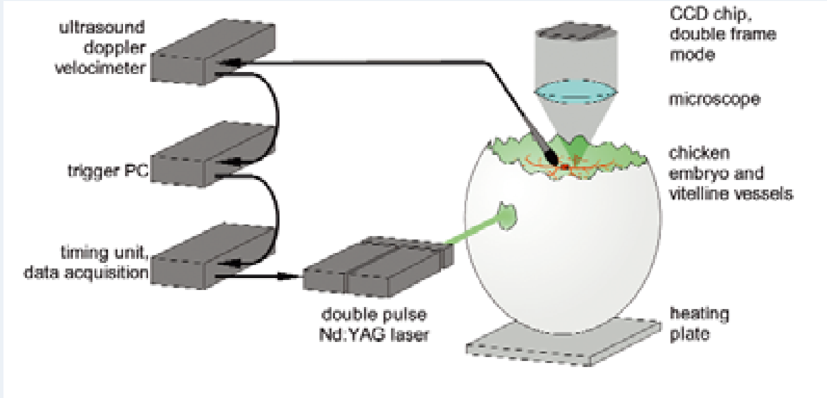
Reconstruction of the heart based on a number of sections through a prepared embryo heart. The blue regions indicate where certain genes responded to shear stresses in the blood vessel walls.

embryos, but we found out that such a thing already existed.'
The first results of the experiments look promising. A microscope with a magnification of 10 times is sufficient to observe the blood flow.
'We can now use optical means to measure the flow and synchronise the measurements with the heartbeat. Our next target will be to get as close as possible to the wall of the blood vessel. For this purpose we have developed a method that enables us to measure in non-biological micro channels with a resolution as small as 300 nanometres. The next step is to adapt this for use in a biological system. We hope to publish on the subject really soon.'

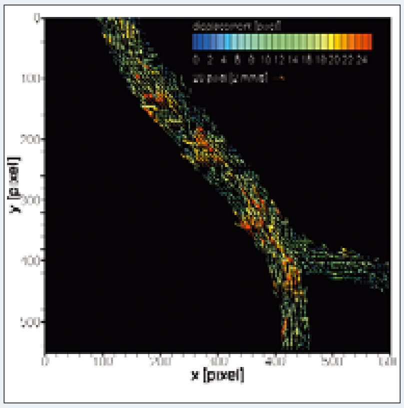
Invisible visible particles ¶ The first measurements involved observing the movement of red blood cells. It is a useful method, but there is a drawback: red blood cells do not pass close to the blood vessel's wall.
Westerweel: 'The changing flow rate near the wall creates lift, causing the cells to move away from the wall.'
Of course, the flow rate close to the wall of the blood vessel is what Westerweel and his colleagues set out to measure. In order to measure the blood flow in vivo, the scientists will use fluorescent particles developed by Dr. Timo ten Hagen of the Erasmus Medical Centre in Rotterdam. These particles are special liposomes that have been manufactured so as to be invisible to the immune system. Liposomes are little globules of fat containing liquid. On the outside of the liposomes, a layer of hygrophilic molecules (polyethylene glycol) has been applied. This causes a dense sheath of water to form around the globules, preventing antibodies from recognising them as foreign bodies.

Pattern recognition ¶ The camera enables Westerweel to see how the blood cells and liposomes form a pattern that moves with the flow. Changes in the pattern between two successive shots (made using high-resolution digital video equipment) are used to determine the direction and the magnitude of the flow at a large number of points simultaneously. The most probable translation of the particles is mathematically converted into a vector the length of which indicates the velocity of the particle.
'The system enables us to measure the direction and rate of a flow within a blood vessel only 200 micrometres across with a resolution of 10 micrometres. The gradient of the flow rate near the wall provides a measure of the shear stress it is subjected to.'
Westerweel laid the foundation of the technique for visualising flows in small vessels using particles during his doctorate research. The technique is known as Particle Image Velocimetry (PIV).
The ultimate goal is to prove a correlation between the measured wall shear stress and the activation of the genes in cells in the blood vessel wall. For this purpose, Dr. ir. Mathieu Pourquie of the Laboratory for Aerodynamics & Hydrodynamics has created a mathematical model of the complex geometry of the chicken heart to simulate the blood flow. The simulation uses fluid mechanics to indicate how shear stresses vary. Poelmann's research team at Leiden University are looking at the cellular level to see at which locations in the heart the genes become activated. This is where things become more complicated. The heart is frozen and cut into very thin slices. Fluorescence microscopy is then used to determine which genes have become activated and whether they match the high shear stress locations indicated by the calculations and the PIV measurements.
'The next step in the research is to do both flow measurements and gene expression measurements simultaneously in a living chicken embryo', says doctorate student Peter Vennemann, who has worked on the project for over twelve months now.

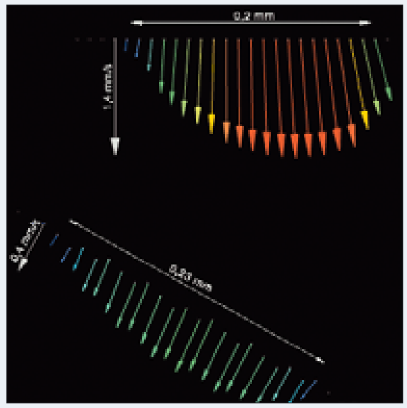
Tumour ¶ During the search for new applications of the PIV technique, Westerweel met Dr. Ten Hagen at the Erasmus Medical Centre, Rotterdam, who is doing research on the development of tumours in mice and rats. The blood flow in tumours is impeded and difficult to predict. This was confirmed by PIV measurements done on the blood flow in a rat's tumour. The blood vessels measured were 60 micrometres in diameter.
Westerweel: 'We started by conducting experiments on a voluntary basis with a limited number of measurements using a large group of enthusiastic people to see whether our technique was suitable for this kind of research.'
When treating a patient with a tumour, the restricted blood flow through the tumour is a major indicator for calculating chemotherapy doses. Medical



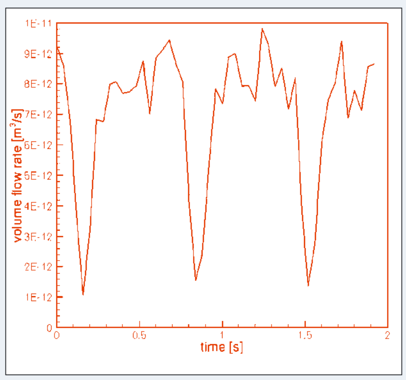
Graphical representation of the test set-up at the Erasmus Medical Centre.



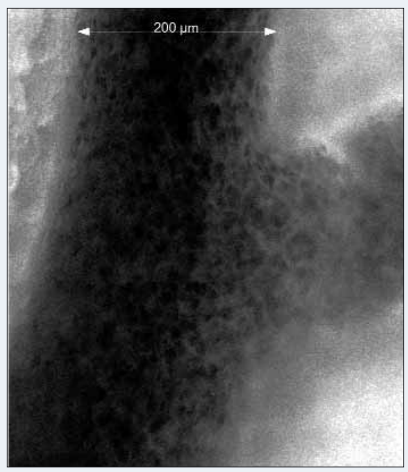
In this view of a blood vessel (made with normal halogen lighting) the translation of the red blood corpuscles has been used to calculate the blood flow rate. Using a video camera, two pictures were taken with a 1/25th second interval. The flow rate was deduced from the translation of the blood particles, and in this case averaged 2 mm per second.



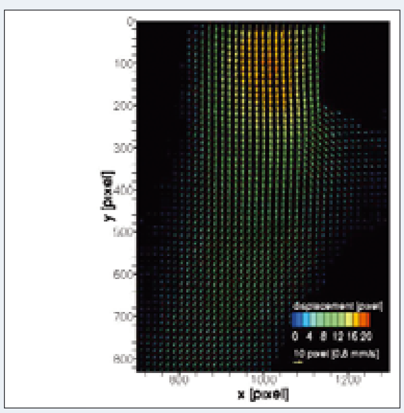
The result of two images (600 x 600 pixels) as described for the previous illustration. Using a correlation program, image information from the first image is compared with information from the second image, and the distance covered is calculated. The length of the arrows indicates the local velocity.



The pulsating blood flow over a short time interval, measured using PIV.



View of a blood vessel using a 10 nanosecond laser flash instead of white light. This technique can be used for measurements at high velocities and high magnification.

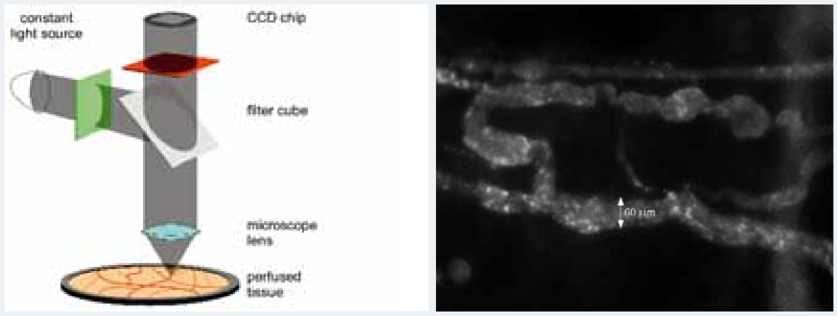


The average result of 50 heartbeat-synchronised measurements using a magnification factor of 10.

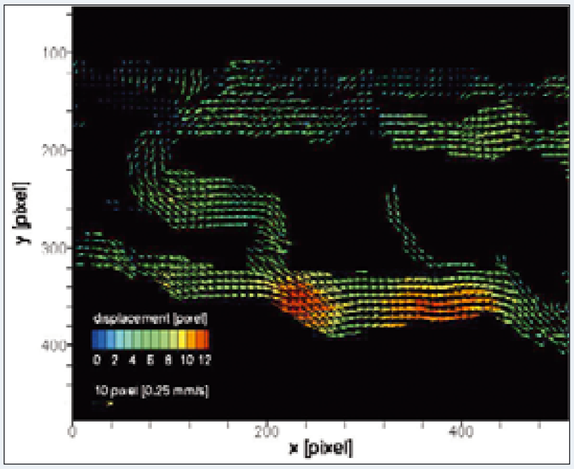
opinion has it that the treatment can be focused by first administering medication that improves the blood flow.
'We are very pleased with the first results, and we are now working on a joint research project to use PIV to measure the blood flow in tumours,' Westerweel says.

ICU ¶ Westerweel expects that five to ten years from now the measuring system will fit onto a microchip, in line with the current development of microelectromechanical systems (MEMS).
'During surgery, blood pressure and the oxygen levels of the major blood vessels are the only parameters that are monitored at present. However, these give no indication of the blood supply to the body's organs, which is where the exchange of oxygen and nutrients takes place, and which is where you should be measuring to check blood flows. The same goes for monitoring patients in intensive care units. We suspect that there may be a link between blood flow levels and death. Which is the cause and which the effect still remains to be seen. Once our technology can be fitted onto a microchip we could do without the microscope. We would be able to directly measure the blood flow of organs with a high resolution of only a few micrometres, using a catheter or similar means.' n

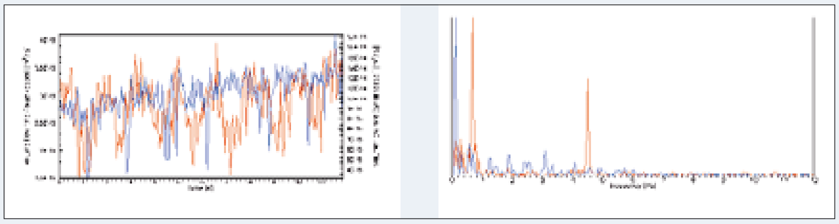
For more information, please contact Prof. Dr. Ir. J. Westerweel, phone +31 15 278 6887, e-mail j.westerweel@wbmt.tudelft.nl



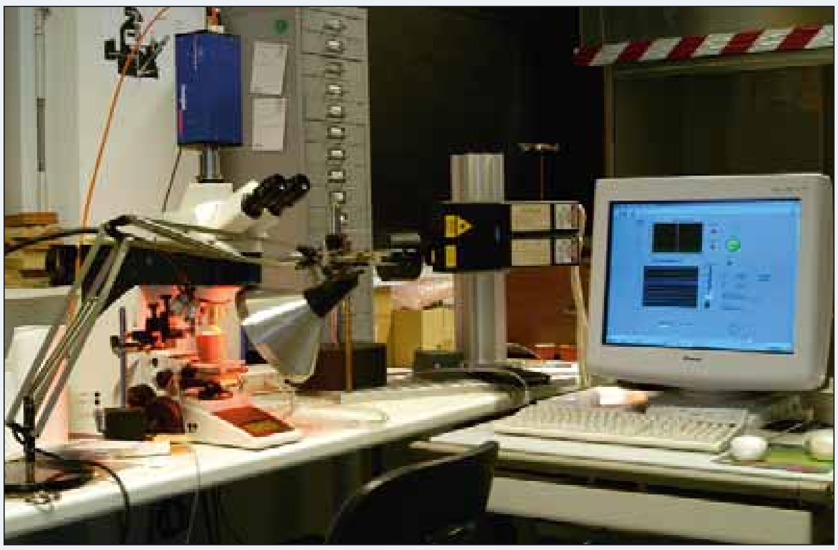
In some tumours the blood flow is very restricted. Whereas the purpose of certain techniques is to mortify the tumour by further restricting the blood flow, other medical opinions have it that the blood flow should be improved in order to make it easier for medication to reach the tumour. For the latter group, blood flow knowledge is a prerequisite. Tests at the Erasmus University use mice fitted with a small window in their skin through which the blood flow in the tumour can be measured.



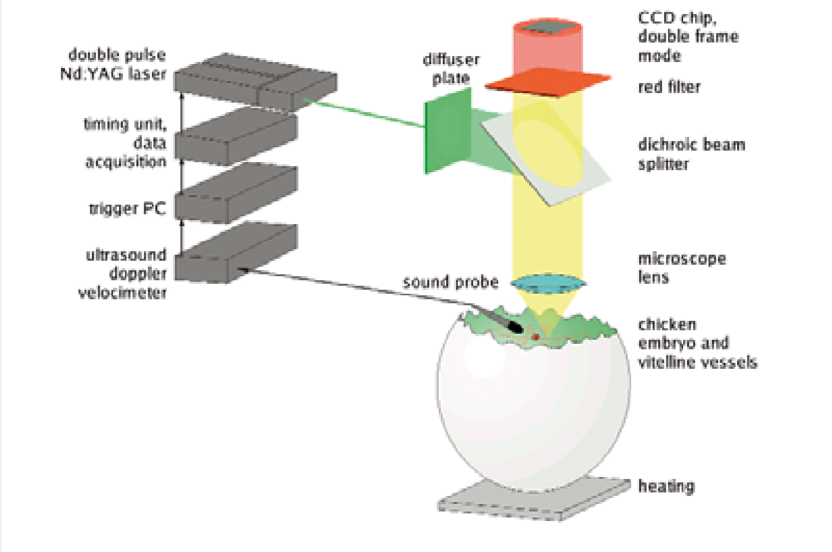
The flow rates inside the blood vessels of a mouse, measured with the aid of a fluorescence microscope.



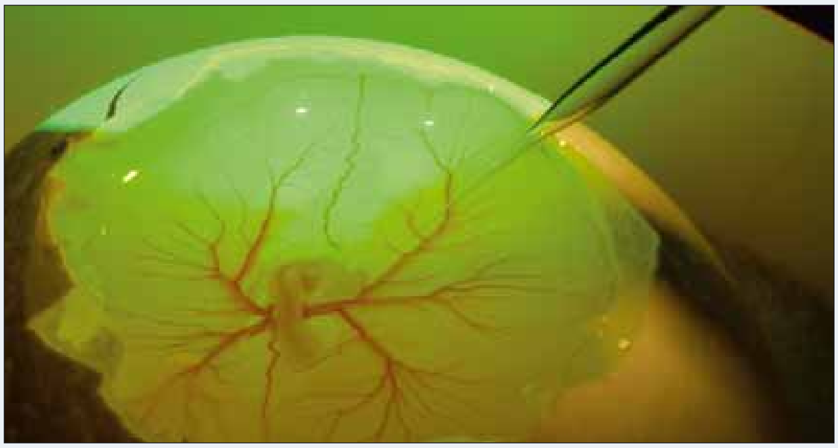
The blood flows as measured in blood vessels in healthy tissue (red) and in a tumour (blue). The healthy tissue shows a clearly pulsating flow with a frequency of 4.5 Hz. The blood flow in the tumour has no clear pattern; there is no pulsating flow with a dominant frequency.



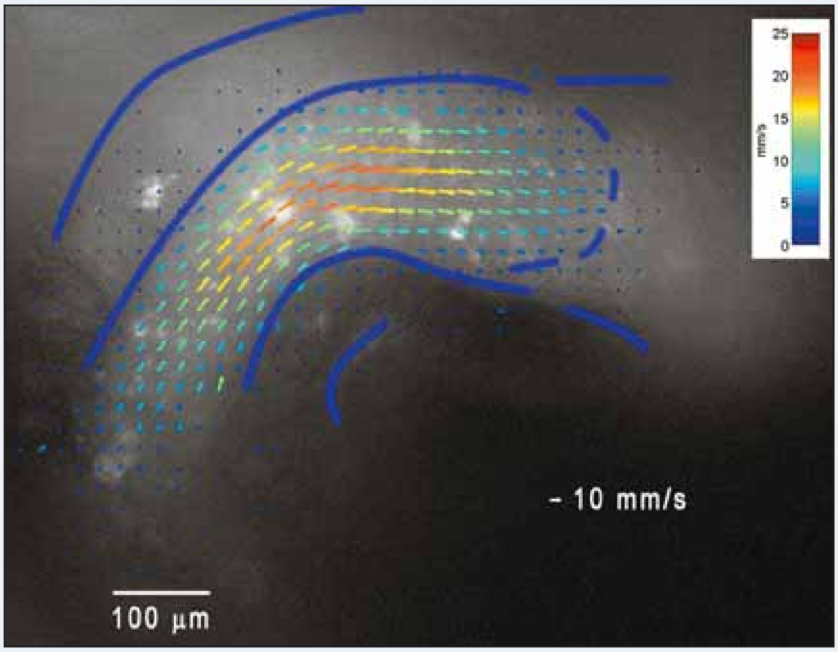
The new set-up at the Laboratory for Aero & Hydrodynamics. The microscope has been fitted with a digital PIV camera. In the centre is the laser, the beam of which enters the microscope through an optical system at the rear of the instrument. A mirror reflects the beam through the objective onto the blood vessel being measured, so the working distance is reduced to a minimum. The computer controls both the image processing and the synchronisation of the laser pulses with the heartbeats. The egg is kept warm by means of an infrared lamp.



Schematic diagram of the set-up at TU Delft. The relatively short wavelength (green) of the laser beam is reflected into the embryo by a mirror. As the beam hits the fluorescent particles in the blood flow, they produce light with a longer wavelength (orange). This light passes through the mirror in the direction of the camera. An extra orange filter has been included to remove any residual green light.



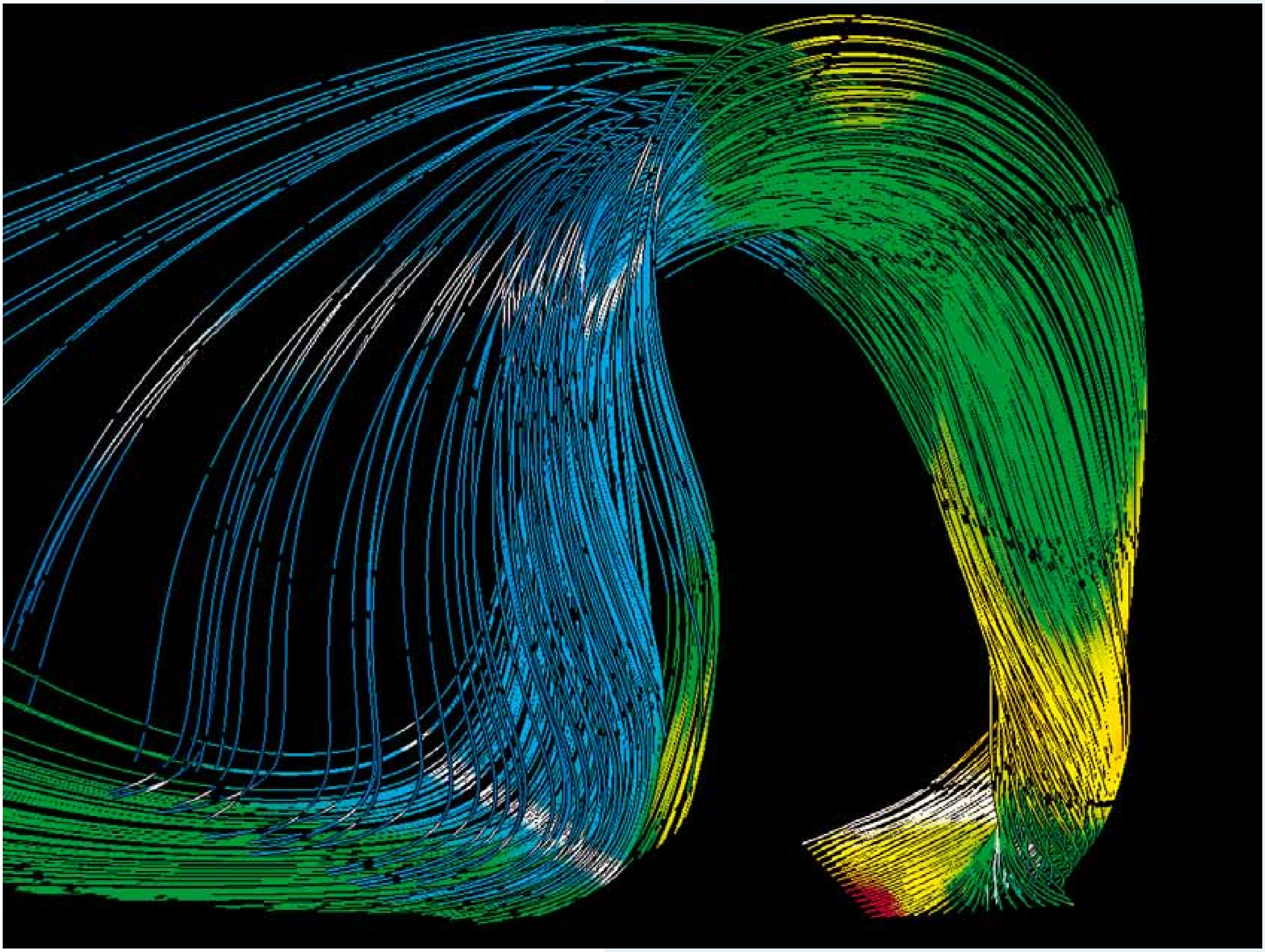
A glass syringe with a 10 micrometre tip is used to inject orange fluorescent particles with a diameter of 1 micrometre into one of the blood vessels radiating from the embryo.



The latest result: a measured velocity distribution in a plain of a fully expanded ventricle. In the background one can see the fluorescent liposomes that were used to trace the flow. To measure the high velocities of up to 25 mm per second, two images were taken with an interval of one millisecond. The flow was illuminated with short laser flashes.

Z

A lopsided swirl in a straight rectilinear grid



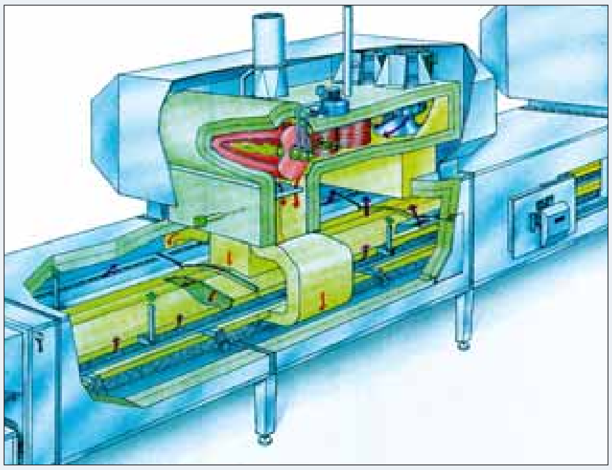
Broken symmetry inside ovens

by BRUNO VAN WAYENBURG

When you take a symmetrical oven and simulate the airflow inside it, you expect that it will be symmetrical as well, or at least that any lack of symmetry will eventually level off. However, Applied Physics researchers Luuk Thielen and Leon Geers found that this was far from the truth when they discovered a persistent vortex on one side of an oven. It was first discovered in Thielen's computer simulations, and later it also showed up in Geers' experimental set-up.

One thing should be made perfectly clear: it is far too early yet to talk about the «hot cake» effect, or the «Thielen-Geers vortex». Nonetheless, doctorate students Luuk Thielen and Leon Geers of the Thermal & Fluids Sciences Section at the Applied Physics department did bump into a very strange phenomenon indeed during their research into airflows inside baking ovens.
'Other scientists at conferences are reluctant to believe us,' Geers says. They discovered the highly unusual vortex in their highly-stylised version of a hot-air baking oven. Even though the oven is exactly symmetrical, the vortex occurs on one side of the oven only. This is not how it should be, according to Thielen,

A 3-D visualisation of a vortex as produced by a numerical simulation of a pizza oven. The oven uses the impinging jet principle, blowing hot air from above onto a conveyor belt. The image shows the air flow as it is deflected upwards and sideways after striking the conveyor belt. The AVS computer program is used to visualise flows by adding virtual particles that follow the flow. The coloured ribbons represent the trajectories of these virtual particles.



Cut-away view of a hot-air oven manufactured by the Rademaker Den Boer company. The oven was the subject of a study at TNO/TPD that later evolved into an STW research project. The purpose of the project was to map the transfer of heat to the products in the oven and to gain insight into the effect of flow on the heat transfer.

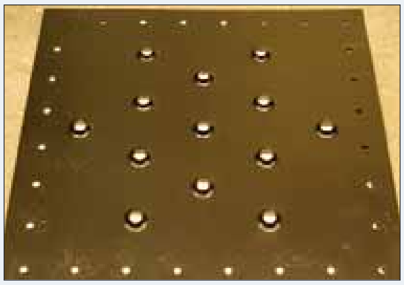
who first detected the phenomenon during a computer simulation. 'My immediate reaction was that it had to be a bug in the program code.'

Pizzas ¶ Their interest in baking ovens goes back about four years, when the Rademaker Den Boer company, manufacturers of baking ovens, approached the research establishment TNO/TPD in Delft for advice and were referred to Delft University. They wanted to know whether there wasn't a more scientific way of fine-tuning their most popular models.
'These are ovens for any number of baked products, including bread, pizzas, cakes and what have you,' Geers explains. A conveyor belt carries the products through the oven's two chambers where hot air is blown onto the food through hundreds of nozzles. 'This is called the impinging jet principle,' Geers explains. 'It is a highly efficient method of transferring heat.'
However , it can take as much as a couple of weeks to find the correct settings– pressure, temperature, distance between the jet nozzles – for a new oven. According to the researchers most of the work is still done by trial and error, which works well enough, but the manufacturer wondered whether there might be a quicker or more efficient way to find the settings.

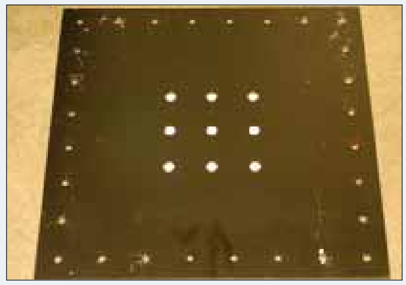
Volume elements ¶ One thing led to another, and the researchers have now been working on the project for four years. It is being co-financed by STW, the Netherlands Technology Foundation, as part of research into airflows inside baking ovens. There's enough science in it to keep the Delft researchers occupied for a while yet. One of the problems that inevitably crops up is turbulence, the wild, unpredictable flow phenomenon that was once called the trickiest problem in all of physics.
'The air flow is described by the Navier-Stokes equation,' Thielen starts to explain. 'Now this is a relatively simple-looking formula that describes how the velocity, direction, and density of the flow changes in each volume element at any given moment in time.'
Solving the equation is a different matter, and requires the use of a computer. To give the computer something to work on, one has to cut up the virtual baking oven into a number of volume elements, and divide time into small intervals. As the time and space intervals become smaller, the accuracy of the simulation increases, but so does the calculation time. Thielen uses hundreds of thousands of such elements, but he used a simplified model for his virtual baking oven featuring a virtual plate with nine instead of hundreds of holes in a square pattern. The air is blown downwards through the holes.
'The pattern being symmetrical, you would expect the four jets on the sides and the four jets on the corners to be identical,' Thielen says.

Vortex ¶ The original Rademaker oven featured a different, triangular pattern, but the square pattern proved to be easier to generate using the simulation software.
'If I had not changed the pattern, we would never have found the effect,' Thielen says. As it was, the behaviour of the virtual flow wasn't even close to what was expected. In the graphs produced by Thielen's computer program (in which, to simplify matters, only one quarter of the nine-nozzle plate is shown) one of the two side jets is blown off course by a small vortex. However, the corresponding column of air diagonally across the plate shows no movement at all. In a view closer to the impingement surface, the asymmetrical vortex can even be seen to one side of the diagonal as a small, convoluted hurricane in the jumble of lines.
'This was very strange, and when after several weeks I still hadn't managed to find a bug in the code, I began to believe something else was going on,' Thielen recalls. One option would have been to change the computer model.
'The problem with turbulence is that the vortices also appear in space and time scales smaller than the ones you are looking at,' Thielen explains. 'This means that you have to make assumptions about the average effect of the smaller scales, in the form of a turbulence model. There are simple and more complex models, but none of them is perfect.' Even when Thielen opted for a different turbulence model, the asymmetry persisted.

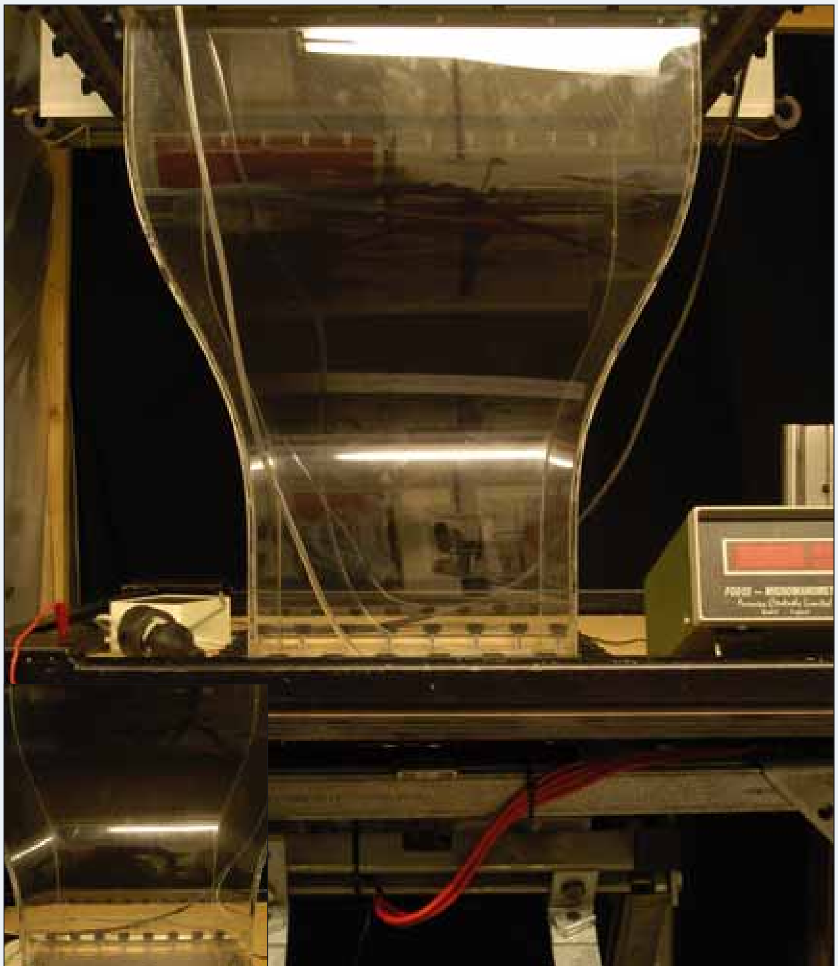
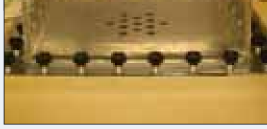
Experiment ¶ It was about time to look for experimental evidence. This was done by Leon Geers in a test rig that looks a bit like a kitchen extractor hood located in the centre of a basement of the Applied Physics building.
A fan extracts air from the room through a hose as thick as a man's arm, and blows it through a grille. Geers indicates how the air flows thus produced hit a



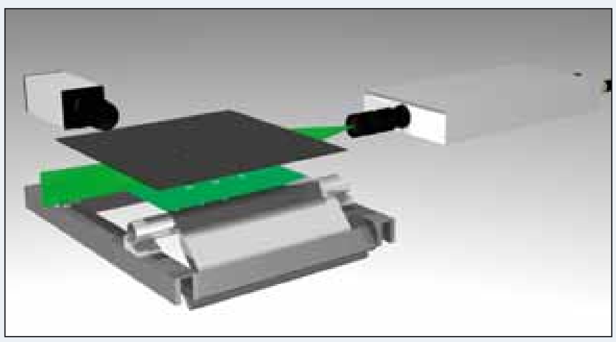
In his experimental set-up, researcher Leon Geers used plates with jet nozzles in a matrix similar to that used in the ovens made by Rademaker Den Boer.



The matrix on the left turned out to be a bit too complex for the simulation program, and so the square matrix shown on the right was used. A modified nozzle plate was made to validate the simulations.

The experimental set-up used by Geers. An open end wind tunnel gives onto a Perspex duct terminated by the jet nozzle plate.

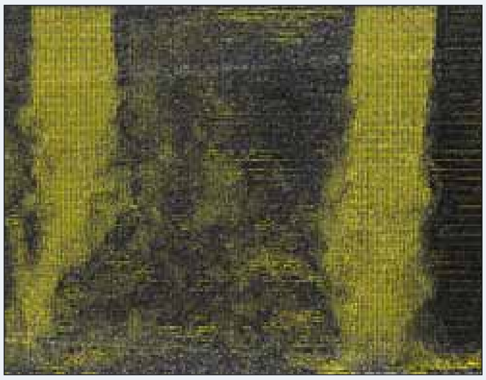


Drawing showing the measuring section of the experimental set-up used to measure flow velocities. Upstream, a mixture of glycerol and water is atomised in the wind tunnel. The laser on the right creates a plane of light perpendicular to a row of nozzles. The velocity of the droplets can be calculated later by flashing the laser at intervals of a few microseconds and recording the results using a CCD camera. The method is known as PIV (Particle Image Velocimetry).

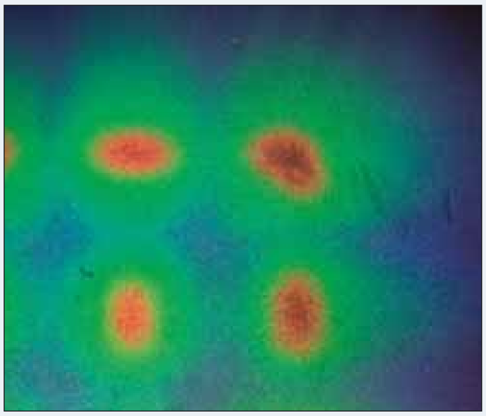
piece of metal film stretched below the hood.
An electric current flowing through the metal film heats it to a temperature of about 40 °C . At the same time the film is cooled by the jets of air striking it, which are at room temperature. This is exactly the opposite of what happens inside an oven where hot jets of air hit cold pizzas.
'Physically speaking, the processes are identical,' the researcher explains, 'or rather, mutatis mutandis, the equations that apply to the former situation also apply to the latter.'
The bottom side of the metal film is coated with temperature-sensitive liquid crystals like the ones used in baby baths that change colour as they heat up or cool down. Geers uses these to measure the transfer of heat from the film to the jets. In order to map the flow itself, he creates a fog of minute droplets of a glycerol/water mixture that is injected into the airflow. A laser stroboscope is then used to capture the result on video. For each exposure, two laser pulses with an interval of a few microseconds illuminate the droplets in a plane. During the short interval, each droplet will have moved slightly, and the movement of the airflow can be readily deduced from the video recordings. According to Geers the measuring technique is far from easy, since the results include quite a bit of noise.
'A single velocity field image takes three thousand exposures that have to be averaged to remove the noise.'

Car windscreen ¶ The efforts paid off in the end, since the experimental set-up also showed the vortex on one side. 'Once you get the same results from calculations and from experiments, you have a strong case,' Geers says. 'Later, at a conference, we found out that others had observed similar phenomena, but under different conditions and only at limited velocities. This phenomenon had never been discovered in impinging jet flows.'
Whatever the case the effect is not going to set the cash registers ringing for the oven manufacturers. For one thing, Geers suspects that the transfer of heat will not be greatly affected by the vortex. On the other hand, researchers need to constantly update their knowledge of flows if they are to improve the models they use, and this certainly is an unexpected new element that requires study. What's more the models are of use to others besides oven manufacturers. Jets of air are also used to cool the hot glass of newly-produced car windscreens and the hot metal surfaces of large ball bearings. Even turbine blades in aircraft engines are cooled by them from inside. These are all high-tech applications in which the smallest improvement in efficiency could result in massive cost savings. However, Geers and Thielen are making no promises.
'For the time being the only ones who can enjoy this will be scientists,' Thielen says. 'Asymmetrical phenomena like these are known in the field of physics as «symmetry breaking». The vortex «breaks» the initial symmetry by moving to one side of the grid.'
Whatever the case giving the phenomenon a name does not provide an explanation for it.
'Lots of possible explanations exist but each of them can be refuted in one way or another. We have enough questions to keep us going for the next decade,' says Geers, who, like Thielen, recently gained his doctorate, and who likes to think that his successors will continue the work. Which is why they think it is still too early to stick a label on the effect. Putting forward your own name is out of the question in scientific circles, but even so Thielen thinks that perhaps they might spend part of an afternoon on the subject. n

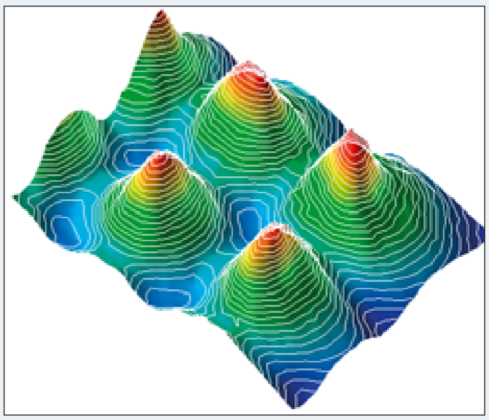
For further information, please contact
Dr. Ir. Leon Geers, phone +31 15 284 3405, e-mail geers@pml.tno.nl, or
Dr. Ir. Luuk Thielen, phone +31 15 269 2118, e-mail thielen@tpd.tno.nl, or
Prof. Dr. Kemal Hanjalic, phone +31 15 278 1735, e-mail k.hanjalic@tnw.tudelft.nl



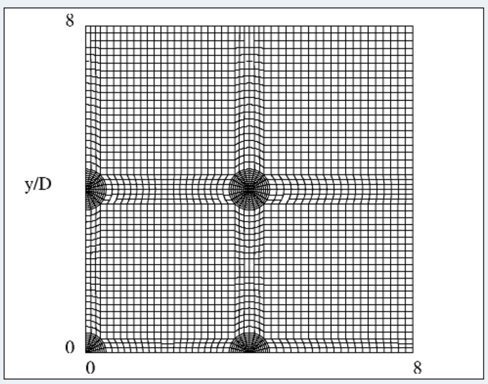
View taken by the CCD camera of the underside of the metal film which has been coated with paint onto which a layer of liquid crystals has been air-brushed. When illuminated by white light the crystals reflect light with a colour determined by their temperature. Red is cold, blue is hot.



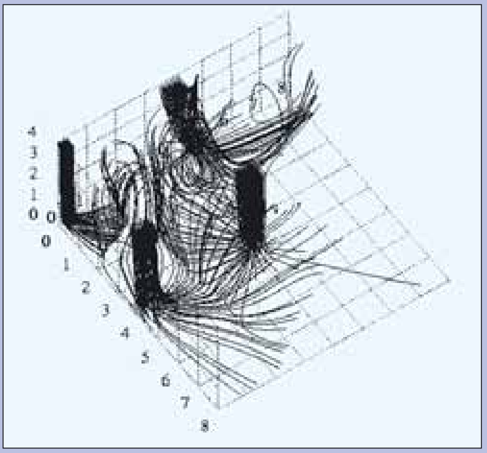
The droplet velocity vectors calculated using the video material were then used to create this image. It shows two jets of air impinging on a sheet of stretched metal film. The jets diverge in all directions at the points where they strike the film. Where the diverging flows meet each other, an upwash is created.



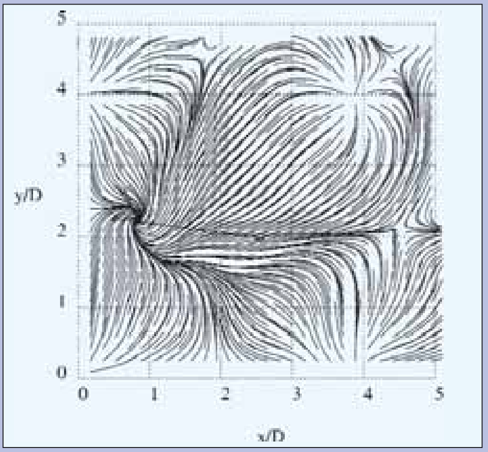
The data obtained from the CCD camera are used to create a visualisation of the heat transfer. This image clearly shows that the heat transfer at the impingements points is very high. At other locations much less heat is being transferred because the velocity of the flow along the film decreases as the distance from the impingement point increases. In addition, the air gradually heats up as it moves along the film. As the difference in temperature between the film and the airflow decreases, so does the efficiency of the heat transfer.



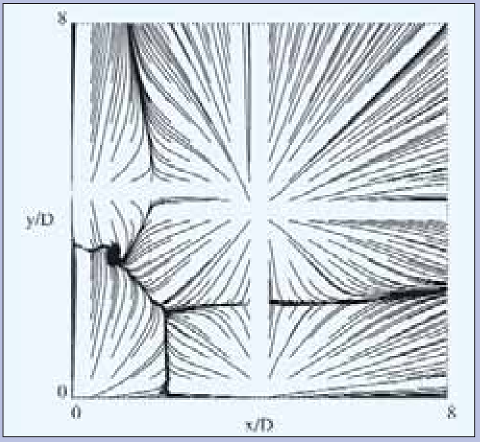
For numerical simulations a grid generator is used to first prepare a calculation grid consisting of small cells. The grid is then used to solve the flow equations by means of a finite volume program called X-stream, which has been developed by TNO/TPD. In view of the symmetrical layout of the set-up only one quarter (i.e. 2x2) needs to be considered.



Calculations made with X-stream showed that one of the four airflows in the square matrix (the one at 12 o'clock) was being pulled out of line. Further research showed that the effect was being caused by an unusual vortex. Intuition suggests that the system should be symmetrical along the diagonal.

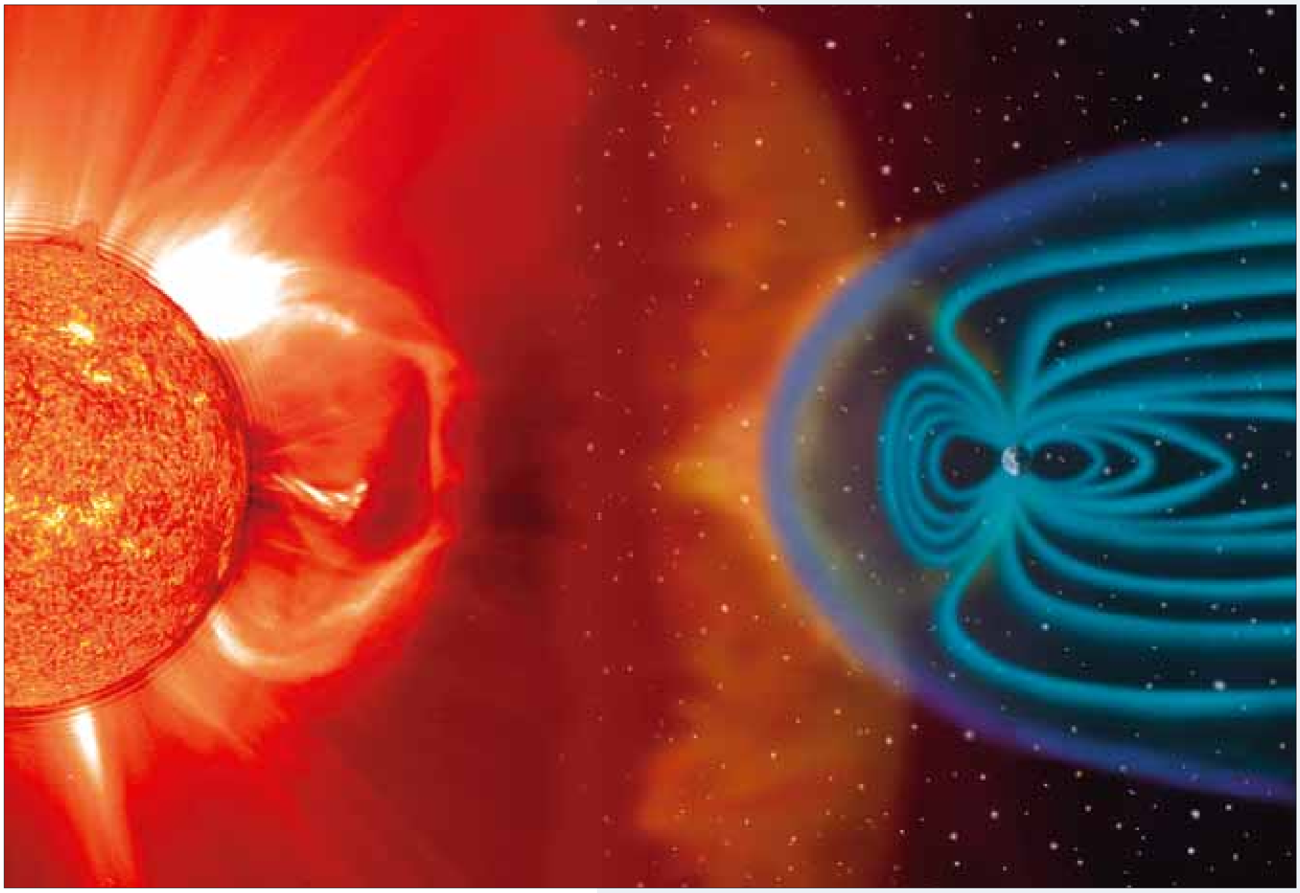


Data obtained by measuring the airflows from a 2x2 matrix confirm the existence of the special vortex, as shown by this visualisation.



A different representation of the same simulations was made using the AVS program to show the unusual vortex better. The view of this plain shows a situation parallel to the metal film and one-tenth of a millimetre above it. When Thielen brought the vortex to the attention of the audience during his presentation at an international conference, the response was sceptical. During informal meetings later on, several people admitted having seen something similar, albeit under different conditions and at lower velocities.

Micro satellite swarm reduces vulnerability



Adaptive electronics modify receiver/transmitters to match conditions

by JOOST VAN KASTEREN

Bacteria, polyps, ants, and bees are the living proof that, given inhospitable conditions, colonies stand a better chance of survival than individuals. At TU Delft, this biological principle is now being used on spacecraft. A colony of micro satellites will be less vulnerable than a «normal» satellite, not only to gamma radiation and solar storms, but also to cutbacks. After all, micro satellites are small and light, and will – someday – be mass-produced.

Nature is a source of inspiration not only to artists, but also to engineers. At least, it is to Dr. Ir. Chris Verhoeven of the department of Microelectronics at the Information Technology and Systems (ITS) faculty.
'Name the one most successful type of organism on Earth,' he says. Count out elephants, whales, or any other of the large mammals. All of these are facing extinction because their habitats are rapidly being wiped out or polluted. The most successful animals on our planet are those that live in colonies, ants for example. Their combined biomass far exceeds that of elephants and whales, and what's more, they can be found all over the world. The success of ants living in colonies forms the source of inspiration for what Verhoeven calls his boyhood ambition, which is to have colonies of micro satellites that can be used both for earth-based tasks (such as telecommunication and earth observation) and for exploring the solar system and beyond. Instead of having a single Starship Enterprise, which is far too vulnerable, we

z Artist's impression of the sun and the so-called Van Allen Belts around the earth. Sun spots and eruptions on the surface of the sun (protuberances) are the cause of, among other phenomena, a hail of particles such as protons and electrons, some of which travel in the direction of the earth. The particles are captured by the magnetic field surrounding the earth, and form the Van Allen belts. The conditions in these areas play havoc with the electronics inside satellites. Solar panels lose capacity, memory chips get their contents changed, and electronic components can become disrupted or even fail altogether. (Image not to scale)

(PHOTO: NASA)

The Northern Lights are the visible evidence of the violence that shakes the Van Allen belts.

would have dozens of small spacecraft the size of a shoe box.

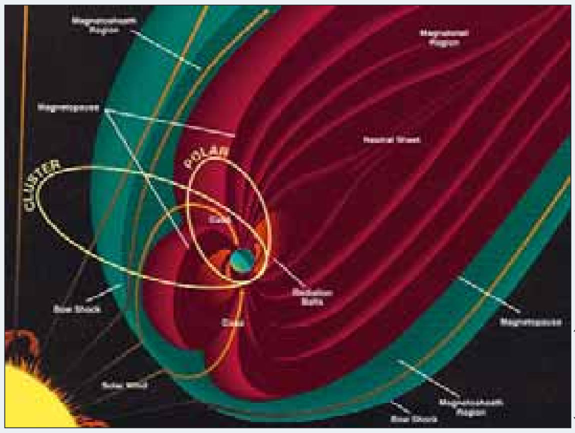
University satellites ¶ Even space travel cannot escape the truism that the longest voyage starts with a single step. That first step is to actually develop a micro satellite that is small, light, and cheap enough to be manufactured and launched in relatively large numbers. The current generation of micro satellites, a number of which have been developed and built by universities, is still too heavy and too expensive.
'What we need is a quantum leap,' says Dr. Ir. Wim Jongkind of the department of System Integration at the faculty of Aerospace Engineering, 'a fundamental reshaping of systems and in particular, the connections between the systems on board satellites.'
Jongkind, who has been closely involved with Dutch space engineering activities since 1964, is the coordinator of the micro satellite project, or MISAT. In fact, it is a cluster of projects that form part of MicroNed, a micro systems technology research and development programme (see text box). To find funding for the MicroNed programme, the Dutch BSIK knowledge infrastructure investment programme (a 900 million euro nest egg based on natural gas profits) was tapped into.
Although the current generation of university-developed micro satellites is characterised by its relatively low cost, according to Jongkind they also suffer from less than optimal design, low precision (positional and orbital), and high risk of failure because the systems are not fully redundant, in other words there are insufficient backup systems. As a result, the failure of a single component jeopardizes the entire satellite. What the proposed Dutch micro satellites have in common with the current generation is that they are small and light, but they differ in that they feature high orbital accuracy, accurate position control, low energy consumption, and a high level of redundancy. In addition, satellites should be adaptive thus capable of adapting to changing conditions.

Blue Tooth ¶ To meet these apparently conflicting requirements, the project requires the support of micro technology and advanced ICT techniques. Jongkind: 'One of the reasons why satellites are relatively heavy is that the wiring between the various parts does not lend itself to miniaturisation. Therefore a different solution must be found. One option is to combine several components as microstructures on a single microchip. DIMES, the institute for microelectronics and submicron technology of Delft University, has a lot of know-how in this field. As an option for wireless connections, Blue Tooth or infrared communication was suggested, the type of communication technology that by now is part of the standard package offered by any cell phone. But at the moment Delft scientists have opted for ultra-wide band communication. What's more, interconnection of satellite parts could be simplified by adopting a single plug-and- play standard, say USB-like protocol. This fits in well with the aim of the European Space Agency which is to stimulate recycling and series production of parts to minimise mission costs.'

Wine glass gyroscope ¶ Proposals are put forward for the development of different micro systems as part of the micro satellite research programme. One example of this is the development of a micro navigation system in which the instruments for controlling attitude and orbit are combined in a single microchip that includes the ancillary electronics. This type of chip would have to contain a gyroscope, an accelerometer, and a magnetic sensor to control the satellite's attitude relative to the magnetic field of the earth or another planet or star. Miniature versions of each of these different components are already available. For example, a U.S. company currently produces a «wine glass gyroscope» measuring 10 x 10 millimetres, and a miniature version of the magnetic sensor based on single electron tunnelling (SET) technology also exists. Lastly, the accelerometer is a well-known component found in car air bags. The trick is to combine all these different components in a single microchip and eventually find a way of producing them reliably in series.
Other research proposals relate to the development of miniature versions of other components of AOCS, the Attitude and Orbital Control System. These include optical systems that use the sun (a miniature sextant) and an accelerometer based on a spring-loaded mass system.
Another major issue is that of cooling. In our solar system at least, exterior temperatures can vary considerably, so an active control system is required to keep the temperature of the satellite within acceptable limits. Moreover, micro

(FOTO ESA)

This Integral satellite weighs 4 tons, stands 5 metres high, and is 3.7 metres in diameter. Integral's mission is to measure gamma flashes. A satellite like this is not only very expensive to build but also requires very laborious testing. In the case of Envisat part of the certified approvals had been obtained even before the remainder of the satellite had been tested. The limits to satellite size appear to have been reached. As far as effective size is concerned, a colony of small satellites the size of a shoe box would be unhindered by such limits.



(TEKENING ESA)

Drawing of the earth and the Van Allen belts surrounded by satellite orbits. This clearly shows the difference between good and bad orbits as far as operating conditions are concerned. The so-called polar orbit is very unfavourable because it takes satellites straight through the Van Allen belts. Universities can often hitch a ride on commercial launches to get their research satellites up, but this does not let them choose the orbit. This is why these satellites are designed to cope with the worst possible conditions.

MicroNed lays foundation for microsystems

MicroNed is a consortium of eight universities and research institutes and 22 industrial partners. The consortium has submitted a plan to the government to reinforce the micro systems technology infrastructure. The government has decided to grant 28 million euro for distribution to MicroNed, including Microsat. The question put to the project leader, Dr. Ir. Fred van Keulen, professor at the Faculty of Design, Construction and Production, is why micro systems should require government funding. Why should normal market mechanisms not be up to the job?
Van Keulen: 'The problem is that the activities in the field of micro systems technology in the Netherlands tend to be rather fragmented. One could consider leaving it to the market to find a way of undoing this fragmentation, but then you would miss the boat. It is the very nature of micro systems technology that forces us to structure and stimulate collaboration between the various disciplines and between research institutes and the industry. For example, there are scale effects to take into account; a liquid acts very differently inside a channel a few micrometres in diameter on a chip than it would inside a pipeline half a metre wide. The production process also affects the properties of the product. Therefore, the development of micro systems forces us to transcend the boundaries between the disciplines.'

systems generate heat which has to be extracted. Since space is a vacuum, air cooling (or convective cooling) is not an option, so the heat from systems and – insofar as still present – wiring and ports must be removed by means of conduction and radiation. The Infrared Astronomical Satellite (IRAS, launched in 1983) enabled the Netherlands to gain quite a bit of expertise in the field of cryogenic liquid cooling systems. In IRAS, the infrared detectors had to be cooled with liquid helium to 2 degrees above absolute zero. One of the research proposals is aimed at utilising this know-how for the development of miniature cooling systems.

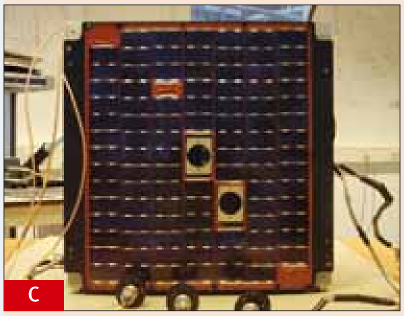
Wireless transceivers ¶ The avenue being explored for the communication between satellites and ground stations and for inter-satellite communications is a wireless receiver/transmitter that adapts to different conditions and tasks. In other words, a system that is continuously being reconfigured. Depending on the conditions, the electronics could autonomously configure a receiver/transmitter for short-wave use, for instance for a communication link to Earth, or into a giga hertz-range transceiver. All it would take would be to feed different commands to the same components, or change the connections between them. Verhoeven is the project leader for this part.
'Wireless transmitters are still being constructed according to principles laid down in the nineteen thirties when vacuum tubes ruled the roost. The design of a transceiver takes into account the receiving conditions. The designer will assume the worst possible conditions, so he will be designing a transceiver suitable for conditions that rarely, if ever, occur. This results in excessive power consumption, and still conditions may present themselves with which the transceiver will not be able to cope,' Verhoeven says.
These days, vacuum tubes have been replaced by transistors, with microchips packing hundreds of thousands of them in the space of a few square millimetres.
Verhoeven: 'We have much more processing power at our disposal which we can use to design a transceiver that will adapt to current conditions. We can thus greatly reduce power consumption while the added advantage is that the colony can autonomously adapt the means of communication to new tasks as the expedition progresses.'

Memory metal ¶ Most earth-based systems do not readily lend themselves to use in the harsh conditions in outer space where they are constantly being bombarded by space debris, X-rays, neutron and gamma radiation, as well as the occasional solar storm caused by eruptions of hot plasma. To minimise damage from meteorite impact, a research proposal has been drafted to develop a smart memory metal or SMA (smart metal alloy), in particular using aluminium capable of restoring its former shape. Prof. Dr. Ir. Sybrand van der Zwaag of the faculty of Aerospace Engineering has conceived a self-repairing system consisting of an aluminium grid containing granules of memory material. A thermal treatment is applied to push the granules just beyond their state of equilibrium, so they remain on the brink of their energetically optimum state.
Van der Zwaag: 'Suppose a satellite is hit by a piece of space grit, creating a small crack. This crack will tend to grow, but it is stopped in its tracks by a granule of memory metal which absorbs the energy from the crack and uses it to regain its energetically optimum state, thus limiting the impact damage. Even better, the damage could be repaired by exposing the metal to a slight rise in temperature that would push the granules back beyond their state of equilibrium. In other words, you could repair the damage in flight, which would enormously extend the life cycle of the micro satellite.'

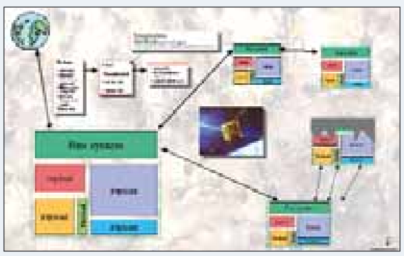
Super telescope ¶ Since micro satellites are small and cheap, they can be produced in large numbers. We can thus shape the colonies so as to reduce their vulnerability and improve their reliability. A first step in this direction is the European Space Agency's Darwin project. This consists of an array of six infrared telescopes positioned so as to form a system that can be configured for use as a single giant telescope, like the Synthesis Radio Telescope at Westerbork, where fourteen 25-metre diameter telescopes together form a super telescope with an aperture of one mile.
For Verhoeven, the Darwin project is still too static with satellites that are too big and vulnerable. His concept involves a swarm of dozens of identical micro satellites, each of which on its own would be of little use, but which acting together as a colony would have the necessary intelligence for example to

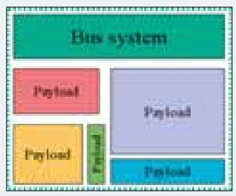

A


B


C

A) This German mini satellite (which has had some of its solar panel cladding removed) is a study object at the faculty of Aerospace Engineering. Its twin is currently circling the earth. The satellite is still rather big due to the «classic» way the electronics of the device have been constructed. Making full use of the possibilities offered by microelectronics and micro-systems technology will enable us to reduce its size further. The wiring and galvanic insulation between the various components still take up a great deal of the volume and weight of the satellite and are the result of stringent requirements regarding the satellite's reliability. In the MISAT project, the focus is on the reliability of the *colony* as a whole, which is why the requirements for the reliability of *individual* satellites can be more relaxed. Moreover wireless communication between the various components of the satellite is being considered in the same way Blue Tooth is being used to link computers, printers, and networking systems in the wireless office.
B) Wiring detail. Since the satellite will be operating in what is practically a vacuum, the use of standard wiring or connectors is out of the question. Gases trapped inside the insulation of a wire could suddenly escape, destroying the insulation. Certain metals used in standard connectors on earth would quickly evaporate in space. The quality of a connection in an earth-bound connector would rapid deteriorate in space. This makes wiring a satellite an expensive exercise as well.
C) The exterior of the satellite is covered in solar panels. A central power supply system distributes the power from the solar panels among the various components of the satellite, including the batteries, which provide the satellite with power while it is in the earth's shadow. In the MISAT project, certain components may get their power from their own solar panels, with local battery support if necessary. This would limit power supply problems to certain components without affecting the operation of other parts of the satellite. An autonomous sensor system can also establish contact with another satellite from the colony if part of its system fails, thus ensuring that the information provided by the still functional sensor in the partially disabled satellite would not be lost to the colony.


In a colony of satellites the various tasks can be efficiently distributed. Although each satellite by itself can contact the ground station, the task can be left to a single satellite allowing the others to save energy by limiting communications to exchanges within the colony. If the satellite maintaining the link with earth should fail, or pause to recharge its batteries, a different satellite can take over. Their collaboration within a colony enables the satellites to form a giant virtual antenna that could maintain contact with the earth in spite of adverse conditions. They could also act as a single giant radio telescope. The Darwin satellite system is an example of this technique.



A micro satellite within the colony will consist of a number of separate units. The bus system, the intelligent carrier to which the other units are connected, coordinates the behaviour of the satellite, handles communications with the outside world, and maintains wireless links with the payloads (sensors and experiments). If the bus system fails, the payloads can contact the bus system of one of the other satellites. In future, building a micro satellite will involve little more than bringing together a number of units. Few, if any, physical connections will be required. This makes it possible to vary the composition of the satellites at minimal cost. Reliability can be improved by using units that have proved their worth during earlier flights. The plug-and-play concept will substantially reduce the cost of space exploration.

investigate a comet and possibly even land on its surface. Like an ant, each single satellite would have the capacity to execute all of the tasks required, but by creating a division of labour, the colony will be able to function as a super organism.

'Suppose you have forty micro satellites,' Verhoeven says. 'En route to the target comet, one quarter of these will fail, but the remaining satellites together still form a fully functional system. If ten of those were to land on the comet's surface, in the process of which half would be destroyed, you would still have a fully functional system in place. If during the attempt to land on the comet's surface all, or almost all, of the satellites were to be destroyed, the system would have to be intelligent enough to decide to abort the attempt.'

Portuguese man-of-war ¶ It sounds like science fiction, a swarm of micro satellites that – on behalf of humanity – explores the solar system and beyond. But according to Verhoeven, nature itself shows that relatively unintelligent creatures together demonstrate a certain measure of intelligence using simple rules for intercommunication. If you look at a single ant, its behaviour appears to be rather disorganised and relatively simple, but when you observe the behaviour of the colony as a whole, it is remarkably consistent.

'This phenomenon is not limited to ants and bees, Verhoeven explains, 'it also occurs in lower organisms, such as certain types of jellyfish. The Portuguese man-of-war for example, one of the deadliest species of jellyfish around, appears to be a single animal, but is in fact a colony of collaborating polyps.'

Even our own brain could be considered a colony of collaborating neurons, according to Verhoeven. 'We have manufactured components with single-electron tunnelling transistors whose behaviour is comparable to that of neurons. The small networks we are currently capable of constructing are still limited in use, but I think that it won't be long before we can imitate the neural network of say, a worm. Once that can be done, building an ant is a small step. The real challenge will be to find out what the mechanisms, rules, and algorithms are that make a colony more intelligent than its constituent parts, the individual animals, and to use that knowledge to create an artificial colony capable of surviving the extreme conditions of outer space.'

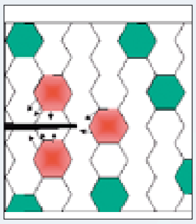
Climate research ¶ The Dutch micro satellites offer opportunities for research into the rules of behaviour that impart intelligent behaviour to a colony, for example by launching two micro satellites that will collaborate with ten or twenty virtual satellites on a computer. In the meantime, the two micro satellites can also be used to perform other tasks such as high-accuracy measurements of the earth's field of gravity, or measuring the density in the upper layers of the atmosphere. The latter is important for long-term weather forecasts, but is still little done because satellites at that altitude suffer greatly from the effects of solar storms. Another possible application will be to measure the composition of the atmosphere at an altitude of several hundreds of kilometres, data that are crucial to climate research.

These applications alone would justify the development of a new generation of micro satellites. The research into colonies of micro satellites would simply be a bonus. Added to this comes the fact that the development of micro components may produce an even bigger spin-off in the form of new and improved earth-bound products than «traditional» space exploration has done.

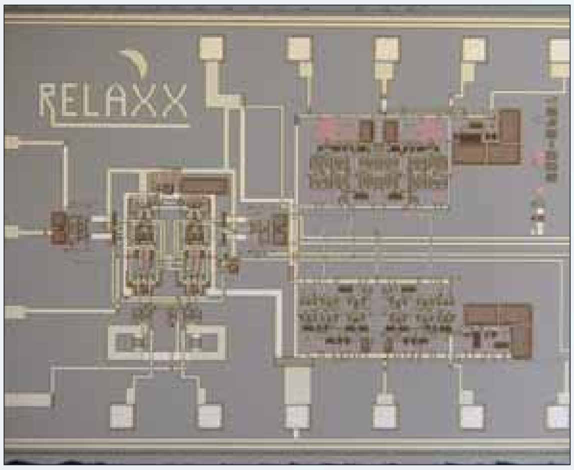
'Moreover,' Jongkind says, 'Dutch research and industry will be greatly stimulated if the Netherlands manages to be the first to develop a new generation of micro satellites. To me it appears to be the next logical step, after the «traditional» ANS and IRAS satellites.' n

For more information please contact
Dr. Ir. Wim Jongkind, phone +31 15 278 7458, e-mail w.jongkind@lr.tudelft.nl,
Dr. Ir. Chris Verhoeven, phone +31 15 278 6482, e-mail c.j.m.verhoeven@et.tudelft.nl, or
Dr. Ir. Fred van Keulen, phone +31 15 278 6515, e-mail a.vankeulen@wbmt.tudelft.nl

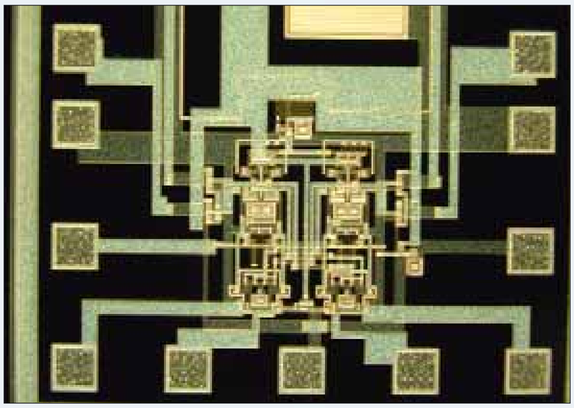
Memory metal. Schematic diagram of the microstructure of a composite metal consisting of aluminium granules (white) and memory metal granules (green = untransformed, red = transformed). The memory metal granules near the crack transform from unstable to stable and so close the crack.



The electronics inside the micro satellite will have to be highly flexible. This micro chip designed at DIMES is part of an early experimental radio system that will be fully reconfigurable during flight. The wireless chip will have to be able to handle all communications, both internally and with the rest of the colony and earth. Finding the optimum configuration will ensure that power consumption can be minimized.



Oscillators are important components of any communication system. This detail shows a quadrature oscillator consisting of two coupled relaxation oscillators. This patented circuit was developed at TU Delft and will form an essential component of the reconfigurable transceivers.

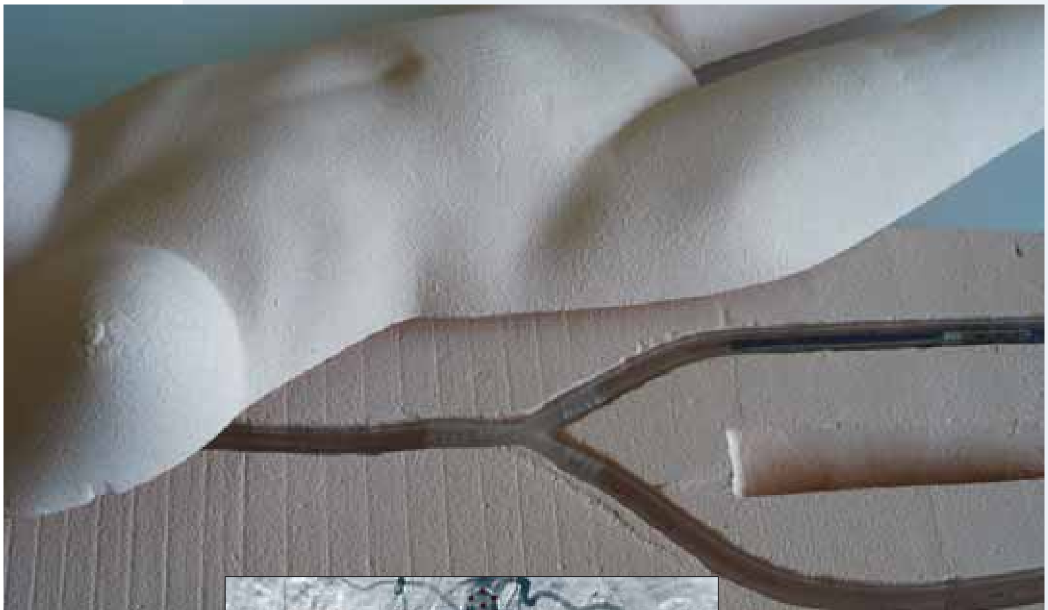


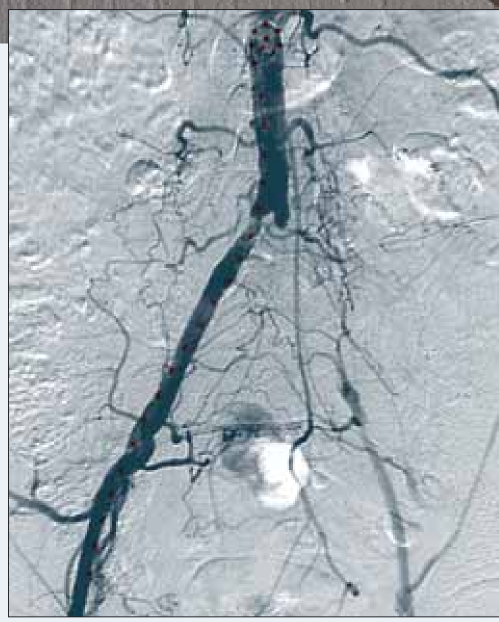
Communication with satellites requires a perfectly operating ground station. To get off to a good start, work on a new ground station has already begun on the 22nd floor of the faculty of Electrical Engineering, Applied Mathematics, and Information Technology. The ground station's array of aerials will consist of two Yagis and a dish aerial. The number of satellites currently in orbit is sufficient for practice purposes. On 8 August 2003 an improvised set-up was used to establish the first contact using the OSCAR 40 satellite with a radio ham in Pennsylvania. The ground station that day consisted of an Icom transceiver and a Yagi aerial (which for lack of a rotor device had been strapped to an office swivel chair). The satellite was tracked by carefully swivelling the chair. The aerial platform can be viewed through a webcam at http://delficam.ewi.tudelft.nl

Magnetic-field navigation for catheters

Integrated chip for triple blood sampling

by BENNIE MOLS





Roughly half of the number of deaths in the western hemisphere are currently attributable to cardiovascular diseases. Treatment used to involve open surgery but nowadays catheters are the instrument of choice for the heart and vascular system. A catheter is usually a very thin tube that can penetrate deep into the body through a blood vessel. Before a catheter can be inserted, a guide wire is introduced into the blood vessel. This very thin wire acts as a guide along which the catheters can be pushed to its destination. This x-ray image shows the aorta (top) where it divides into the lower body. The blood vessel on the right is blocked, which is why it does not show up very well. The guide wire has been inserted into the left leg artery, with the curved tip at the upper end. To track the guide wire's progress up to 20 x-ray images per second are normally made during such operations. The total radiation load may be small for the patient but the cumulative effect for physicians doing this kind of work daily, can be considerable in spite of the lead apron.

Catheters are semi-rigid, hollow plastic tubes that are indispensable when it comes to local surgery inside the heart, brain, arms, legs, or lungs. But how can a surgeon tell whether the catheter is going the right way? Most hospitals still use x-ray methods to check the catheter's progress. To navigate the catheter's passage in real time, some ten to twenty x-ray images are made every second. Even though the radiation dose involved is very low, no radiation at all would be much healthier both for the patient and the medical staff who run the risk of being exposed to the radiation on a daily basis. Researchers of the TU Delft faculty of Electrical Engineering, Mathematics & Computer Science are currently developing a magnetic navigation system for medical instruments such as catheters and guide wires. A magnetic sensor on the tip of the medical instrument measures an external magnetic field and reports exactly where the tip of the instrument is located. In addition, the team is developing sensors that can measure a number of blood parameters simultaneously. Current systems allow the doctors to measure only a single parameter at a time so that a new catheter has to be inserted for each subsequent reading. A reduction in size of the sensors will bring this to an end.

In the western world cardiovascular disease is the number one cause of death or disability. As the average age of our society increases the number of people suffering from cardiovascular diseases will increase with it. Possible problems include vascular constriction, blood clots, deposits on the vascular walls of blood cells, thrombocytes, fat or cholesterol; thrombosis, (clotting of the blood without injury), or local vascular dilation (aneurysm). Both diagnosis and treatment of these medical problems involves the use of catheters and guide wires.

The catheter is inserted into a blood vessel, usually in the groin or an arm. From the point of entry, the surgeon has to push the catheter to its destination, which may be the heart, the brain, an arm, a leg, or a lung. The diameter of the blood vessels varies from about three centimetres where they run along the spine to 1.5 centimetres in the legs and main arteries, one millimetre for the heart, and down to eight thousandth of a millimetre for the capillaries. The human body contains a total of about one hundred thousand kilometres of blood vessels, 96 percent of which take the form of these minute capillaries. Since catheters vary in diameter from one to about ten millimetres, they can only enter the larger blood vessels.

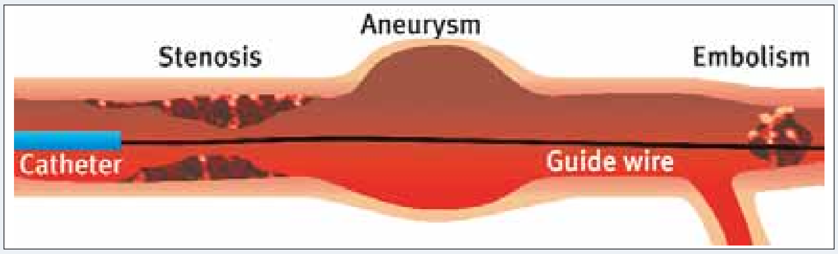
Catheters, being semi-rigid, are difficult to steer so a guide wire is first inserted. This guide wire has a curved tip and is flexible enough to enable it to negotiate bends. Once the guide wire has been pushed to its destination in the body the surgeon can use it to introduce a catheter. The wire acts as a guide for each instrument the surgeon subsequently inserts, be it a scraper, a balloon-catheter, or a catheter carrying a sensor. With the guide wire in the right place, each catheter – whatever its task once it reaches the destination – is certain to reach the right spot.

Snaps shots ¶ The surgeon has to be able to see where the catheter tip is going to be able to find the right route through the maze of blood vessels. . He does this by taking a series of «snap shots» showing each subsequent catheter position. The most popular technique is fluoroscopy. Since a normal x-ray image does not show the blood vessels, injecting a contrast fluid is used to obtain a road map of the vascular system. Fluorescence makes the contrast fluid light up, and the physician is presented with a double view: an x-ray image of the skeletal structure and the catheter on one side, and an x-ray image of the blood vessels and the catheter on the other side.

Although the amount of radiation used for making the x-ray images is very small, it may become a problem for the radiologists who have to make x-ray pictures on a daily basis. The problem with radiation is that its effects accumulate in the body over time. When navigating a catheter along its voyage through the blood stream physicians may need to take up to twenty x-ray pictures every second. The result is that medical staff involved in such operations will be exposed to relatively large doses of radiation. Researchers at the TU Delft Faculty of Electrical Engineering, Mathematics & Computer Science have been working on a new type of navigation system to minimise exposure to radiation and to make catheter location more accurate. As part of her doctoral research, Dafina Tanase, MSc, together with her supervisors, Dr. Ir. Hans Goosen and Prof. Dr. Paddy French, looked into the feasibility of using a magnetic navigation system for medical instruments. They also designed a set of multi-sensors for catheters, i.e. sensors that can simultaneously take readings of a number of different blood parameters. TU Delft is working in close collaboration with medical staff from the Academic Medical Centre of Amsterdam on this project.

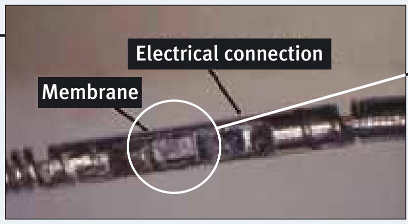
Location ¶ At the request of the research team from Delft the physicians drew up a list of requirements for a new navigation system. The total radiation dose would have to be reduced by at least 10 to 20 %, the positional uncertainty would have to less than two to three millimetres, and the orientation uncertainty of the catheter tip would have to be no more than ten degrees. Moreover, the new method would have to affect current medical procedures as little as possible to allow doctors to stick to their proven routine as far as they can.

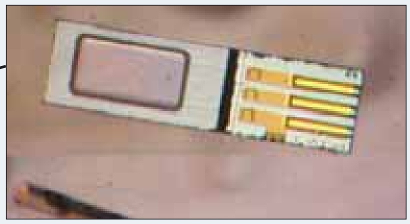
Tanase started out with the idea of using a magnetic navigation system. A number of commercial systems based on magnetic navigation exist but most of these are intended to be used in the heart or the brain only which is why they use a very localised magnetic field. The Delft team intended to develop a system suitable for use in the blood vessels of the arms and legs, i.e. the body's major veins and arteries, in procedures that are collectively known as interventional radiology. What's more, current magnetic field methods do not provide an absolute position reading, merely a relative position measured from the start position.



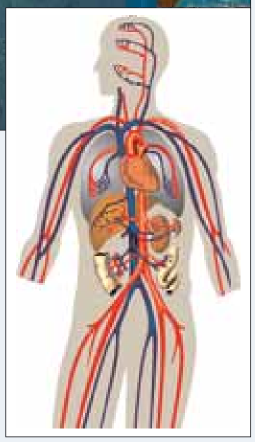
Catheters are used to treat stenosis (partial occlusion of the blood vessel), aneurysm (dilation of the blood vessel resulting in stretching of the vessel wall) and embolism (complete occlusion of a blood vessel by a blood clot or some other particle). The catheters may contain a balloon that can be used to stretch the blood vessel, or a rinsing mechanism or laser device to remove an embolus. They are also used to measure blood pressure in situ. Sometimes a catheter is used to deliberately create an embolism, for example to stop the flow of blood to a tumour in order to mortify it. An aneurysm can also be treated by means of embolisation (see also «Silicone arteries» in Delft Outlook 2002•1).

Close-up of a catheter and guide wire. The wire is 0.3 mm thick, and the catheter has a diameter of 1.6 mm. In a recess at its tip, the guide wire carries a piezoresistive sensor to measure blood pressure (see the two images below). (Radi Medical Systems, Pressure Wire)





A catheterisation treatment room. The patient is positioned between the x-ray source (bottom) and the image amplifier (the large drum above). The physician can follow his movements on the displays in front of him.



The usual catheter entry points are in the neck (to get to the brain), the upper arm (to access the brain and the heart), and the groin (for the heart, the abdomen, and other blood vessels).

A general-purpose magnetic navigation system would be a great leap forward. 'The basic idea,' Tanase explains, 'is to create a known external magnetic field. A sensor at the tip of the catheter could then measure the strength of the field along all three axes. These readings can then be used to calculate exactly where the tip is located since the magnetic field strength is known for each position in space.'

Generating a magnetic field outside the patient's body proved to be simpler than generating a magnetic field on the thin catheter which could be measured outside the body.

Tanase constructed a prototype in which three coils generate an external magnetic field. A constantly pulsating electrical current of six amps flows through each of the coils resulting in three pulsed magnetic fields. The sensor measures the components of the magnetic field along all three axes. Next, the readings are subjected to a special algorithm to rapidly calculate the position of the catheter tip relative to the external source of the magnetic field after which a display shows the surgeon where the catheter tip is.

'This method obviates the need to take ten to twenty exposures every second for the current procedure,' Tanase explains, 'although we might still require a single large exposure to obtain a reference image on which the position of the catheter tip can be displayed as it moves along. By attaching the magnetic field generator to the x-ray machine, the position of the catheter will always be directly related to the reference image. This enables the surgeon to keep track of the catheter tip almost continuously.'

Whenever the position of the patient on the operating table changes, a new x-ray exposure must be made. Even so Tanase's calculations show that the magnetic navigation system reduces the radiation exposure by approximately 55% compared with conventional interventional radiology methods.

Magneto resistors ¶ At the heart of the magnetic navigation system is the sensor that measures the magnetic field strength.

'We have used two different types of magnetic field detectors, Hall plates and magneto resistors,' Tanase says. 'A Hall plate is a chip through which a current flows that is deflected by a magnetic field, resulting in a voltage that increases with the strength of the magnetic field. Although far from accurate, it has the benefit of being relatively cheap, easy to obtain integrated circuit technology. Magneto resistors, in which the resistance depends on the strength of the magnetic field, are much more accurate but also cost a lot more. Using these the system becomes accurate down to one or two millimetres; so I used magneto resistors for my final test measurements.'

The positional accuracy depends on the distance between the magnetic field source and the sensor. As the distance between the two increases the field strength decreases and so does the positional accuracy. The weakest magnetic field measurements showed a field that was about twice the strength of the Earth's magnetic field. The Earth's magnetic field and the magnetic fields produced by the surrounding equipment are first measured to obtain a reference measurement, i.e. without switching on the field generators. The value thus obtained is subtracted from the magnetic field measured with the field generators switched on. Increasing the external magnetic field would improve the positional accuracy but this would require higher electric currents which would cause problems with the heat dissipation in the coils. In addition, the higher inductive inertia of the coils would reduce the measuring rate.

Tanase tested the magnetic navigation system on a solid dummy patient in which she constructed a blood vessel model through which she could insert and move the catheter she built herself. She then tested the positional accuracy with a magnetoresistor sensor.

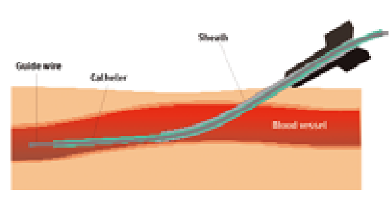
Tanase: 'Besides the magnetoresistor sensor we had a number of different Hall plate designs made on a silicon wafer so we could test which of the sensors worked best.'

At present the Hall sensor and its measuring electronics measure seven by two centimetres, which is much larger than will fit onto the catheter tip. Miniaturisation is therefore required, which is where the need for funding comes in. 'Whatever the case,' Tanase says, 'the technology for integrating and miniaturising the sensor and the electronics is available. If we can continue this project we will be able to reduce the dimensions.'

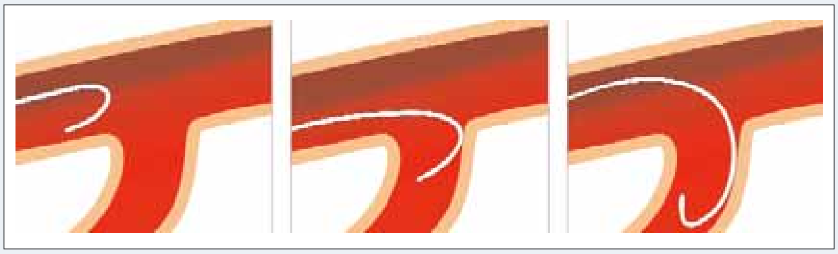
The sensor also has to be somewhat flexible if it is to negotiate the curves and bends of the vascular system.

The coils that generate the magnetic field measure 8.8 centimetres in length and 10 centimetres in diameter.

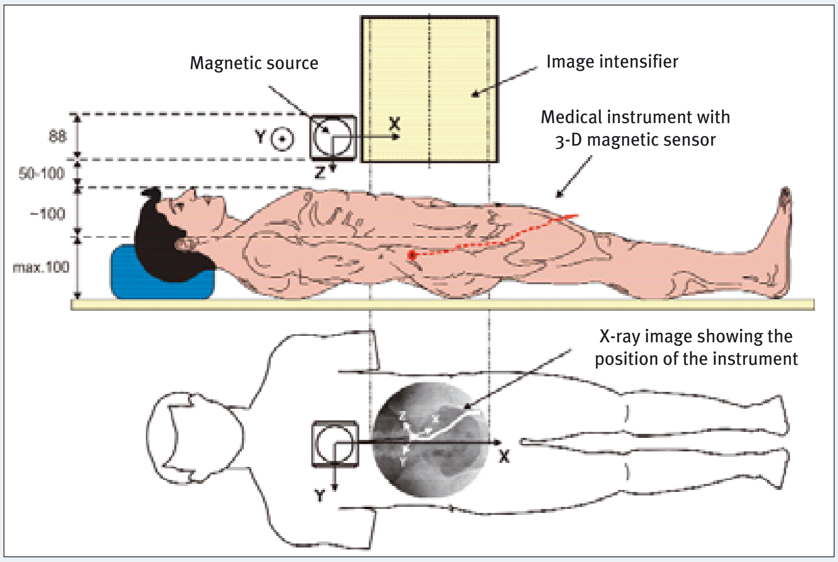
Radiation limits for personnel working with ionising radiation [mSv]		
	Quarterly limit	Yearly limit
Total body	30	50
Other organs or tissue	300	500
Lens	80	150
Radiation limits for personnel not working with ionising radiation [mS]		
Total body	5	
Other organs or tissue	50	



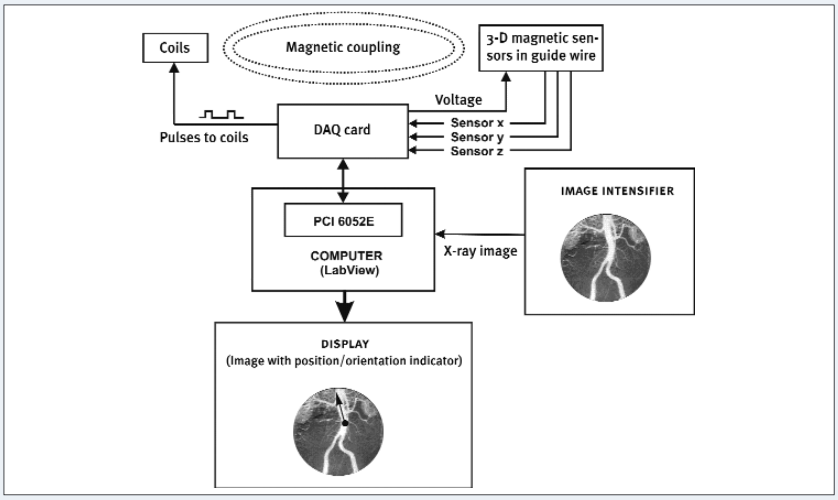
Section through an inserted catheter.



The tip of the guide wire is curved to enable it to negotiate bends. To get the wire to its destination, the surgeon has to slide and rotate it between his thumb and index finger until the tip can move in the right direction. The physician can follow his movements from the x-ray images.



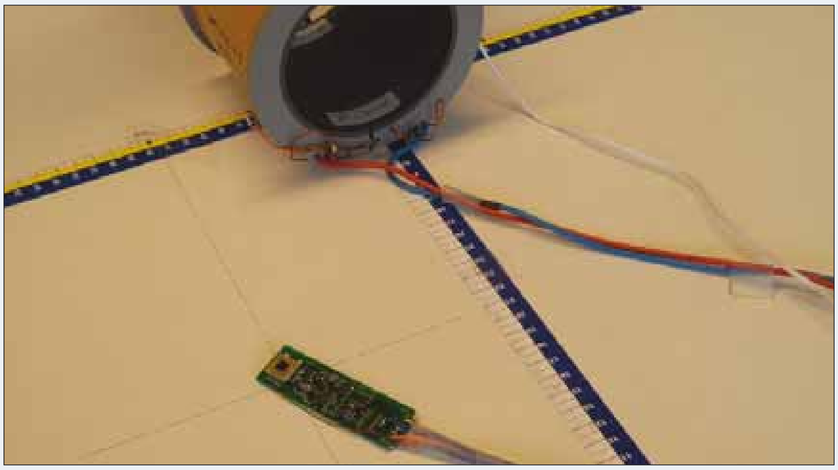
Dr Dafina Tanase has developed a system that enables the progress of a guide wire to be tracked using a magnetic field instead of x-ray images. The magnetic field is generated by means of three coils mounted in a single unit on the image amplifier.



Block diagram of Tanase's system.

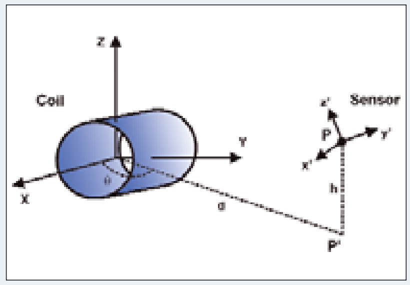
'In a commercial system the three coils would have to share the same centre point,' Tanase says, 'as this would render the position calculation much simpler and more accurate. The coils I used don't have this property.'

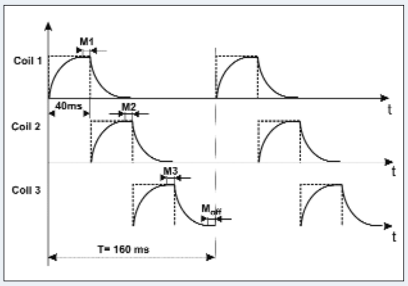
Multi-measuring ¶ The current catheterisation method has another drawback in addition to the exposure to x-rays. For each parameter he wishes to measure, the physician has to insert a new catheter. Suppose the surgeon wants to monitor four blood parameters, i.e. pressure, flow rate, temperature, and oxygen saturation level. This increases the intervention time as well as the stress on the patient, and the readings have to be taken at different times, at least thirty seconds apart – if the surgeon is very quick. With more than half a minute separating the readings they can hardly be considered to represent the same situation. In other words the best thing is to measure as many parameters together as possible. Multi-measuring is the solution.
Professor of Electronic Instrumentation, Paddy French intends to find out which combinations of measurements are best for which applications.
'We look at the medical interpretation, in other words which combination of readings provides the best picture of the state of affairs? In some cases all a doctor needs is a rough indication, not an exact diagnosis, for instance in the aftermath of an accident before the patient is transported to hospital.'
As a postdoctoral student his colleague Hans Goosen developed a chip capable of measuring three blood stream parameters simultaneously: flow rate, pressure and oxygen saturation level. In the current situation surgeons still have to carry out each of these measurements separately.
Goosen: 'It is the combination of these three readings that will provide the surgeon with proper insight into local conditions so he can decide whether he is dealing with a constriction rather than a dilation for example. A change in a single parameter can have different causes. By combining three measurements, the number of possible causes can usually be reduced to just one. The combination of the three readings will also show whether the catheter tip is close to the vascular wall or further away from it.'
The three readings are produced by a single chip though based on different operating principles. The blood pressure shows how much blood is flowing through a blood vessel. The pressure sensor consists of a membrane covering an enclosed space with a reference pressure. Any difference in pressure between the blood and the reference pressure will cause the membrane to flex. This flexure is a measure of the difference in pressure from which the blood pressure can be calculated. The flow rate sensor is based on a thermal principle. A resistor acts as a heating element that raises the temperature of the blood flowing past it. The difference between the temperatures downstream and upstream of the heating element is measured by a pair of thermocouples. As the flow rate increases the blood will cool faster and the temperature difference will increase. The oxygen saturation level is the percentage of haemoglobin to which oxygen has been bound. The level gives an indication of how well the oxygen supply to the body works. The sensor measuring the oxygen saturation level works by measuring the difference in light absorption between haemoglobin and oxyhaemoglobin in the blood by means of photodiodes.
The problem with measuring three different parameters is that you need to feed ten electrical wires back to the outside world. These wires must run through the hollow outer wall of the catheter, since the guide wire takes up the open centre. Feeding all those wires through the catheter wall would be too expensive, so Goosen intends to manufacture an electronic component that can send the signal though one or two channels instead of ten.
Most intravascular blood pressure readings are taken using a hollow tube, Goosen explains.
'The assumption is that the pressure at the tip of the catheter is the same as the pressure at the end outside the body but it isn't. Even though the readings obtained in this way are inaccurate they produce more than just qualitative figures. The materials used are definitely high-tech but the technical design of the sensors could do with some improvement.'
Another benefit of multi-measuring is that it enables physicians to derive other properties that are all but impossible to measure, such as the coagulatory properties of blood. Goosen thinks that simultaneously measuring the flow rate and pressure may even provide information about the rigidity of the blood vessel.
'The extent to which a blood vessel yields to pressure is an indication of its state of health. We are currently looking at the possibility of extending the multi-measuring capabilities to include the concentration of carbon dioxide or other

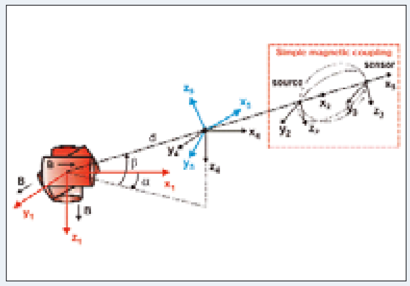


The magnetic coil and the sensor used by Tanase for her tests. Both the coil and the sensor were developed and manufactured at the faculty.

Schematic diagram of the location and orientation of the sensor relative to the coil. The magnetic field around the coil is symmetrical. The sensor measures the strength and direction of the magnetic field relative to itself. This provides sufficient information to calculate a unique position in space. This requires at least three coils with known orientations.

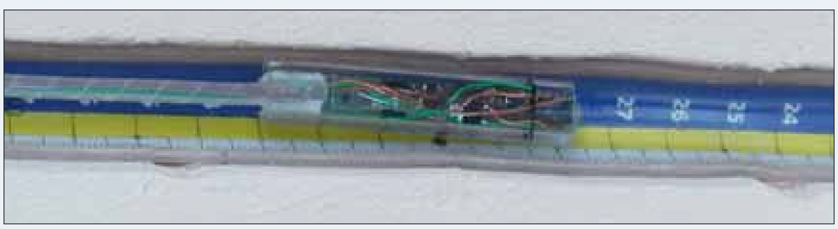






The coils are energised in succession at known times to distinguish between the three different magnetic fields. Hence the system will always know which magnetic field the sensor is measuring. In addition, a fourth reading (M) is taken with none of the coils energised. This is used to calculate the sensor error and to compensate for other magnetic fields in the area.

For her tests Tanase used a life-size patient dummy with a model of the aorta and the main arteries in the legs (see opening picture). The dummy was constructed at the Electrical Engineering faculty workshop.

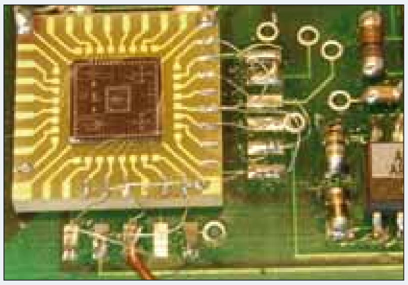


During the tests the dummy is closed. Afterwards the position readings are compared with the actual location of the sensor. The sensor shown here is magnetoresistive and was used to demonstrate the feasibility of the system.

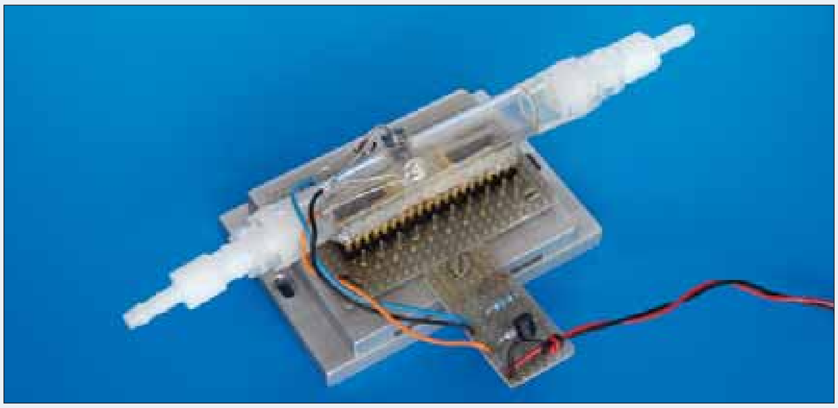
gases that play a role in certain body processes.'
Whereas Tanase's magnetic navigation system is to be attached to the guide wire, Goosen's multi-sensor is to be placed on the catheter tip.

Sensor in catheter ¶ The next step in the research will have to be to attach the multi-measuring sensor to the catheter.
'And that is far from easy,' Goosen says. 'It takes more than spending a Saturday afternoon with a Stanley knife and a bit of Sellotape to stick it to the catheter tip. This is a high-tech operation. In fact it would have to be integrated into the catheter manufacturing process, which could prove very expensive. An added problem is that our university research is aimed at making a single leap forward, whereas biomedical production companies tend to think in small steps at a time. They are careful and consider our targets a bit too far off to make them suitable for funding.'
'Before we can test our system in medical practice, it would have to be developed further,' Goosen explains. 'In fact it will have to be fully built before we can use it for testing on a patient. We cannot just walk into the operating theatre carrying a box of bits and pieces.'
'The first version of the magnetic navigation system could be improved on a number of points,' Tanase admits. 'The system now uses three different sensors to measure the three components of the magnetic field so the readings don't come from exactly the same spot, resulting in an additional error of one or two millimetres. We can considerably reduce the error if we manage to integrate the sensors in a single small component. We could also considerably reduce the size of the magnetic source. Given sufficient means we could investigate the options for much more accurate sensors. However, the principal aim of my thesis was to demonstrate the principle of magnetic field navigation for operations inside the major veins and arteries of the human body, and in this we have succeeded.
Tanase has now completed her four-year research and has gained her doctorate.
n

For more information, please contact
Dr. Dafina Tanase MSc., phone +31 15 278 6432, e-mail d.tanase@its.tudelft.nl,
Dr. Ir. Hans Goosen, phone +31 15 278 6500, e-mail j.f.l.goosen@wbmt.tudelft.nl, or
Prof. Dr. Paddy French, phone +31 15 278 4729, e-mail p.j.french@its.tudelft.nl

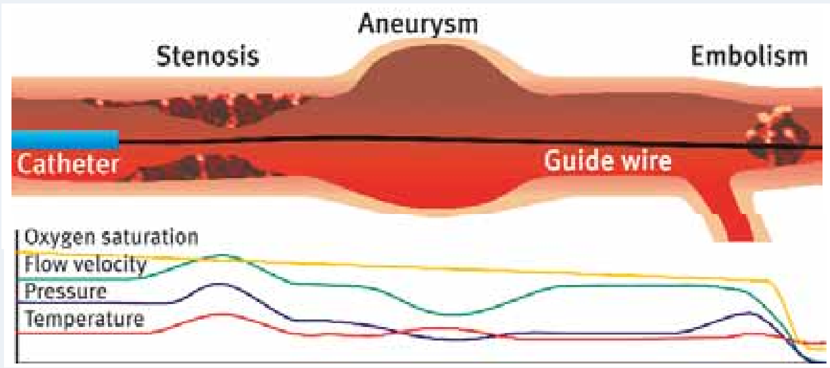


As the overall system was being developed, parallel research focused on developing a 3D sensor based on Hall plates (see also «The needle makes way for the plate» in Delft Outlook 99.3). This will enable three-dimensional readings to be taken at a single point, something a test sensor with its magneto resistors cannot do. A number of different Hall plate designs have been etched onto this chip but the circuit in the lower right-hand corner is the only active one. The electronics still require miniaturisation to make them suitable for mounting on the tip of the guide wire. The faculty is currently looking for funding to continue the project.

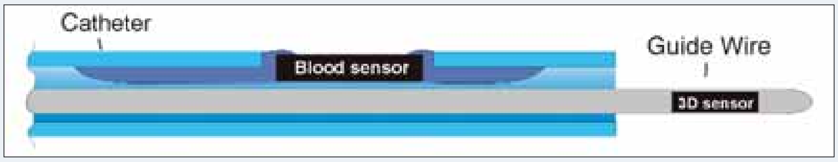


In some cases it is necessary to take blood pressure and flow rate readings inside the patient's body. The current method requires the insertion of two different catheters in succession for this purpose. Dr. Ir. Hans Goosen has developed a measuring chip that can measure both these parameters as well as the oxygen saturation level of the blood. The prototype was successfully tested during test surgery at the Amsterdam AMC where it was located between a goat and the heart/lung machine.

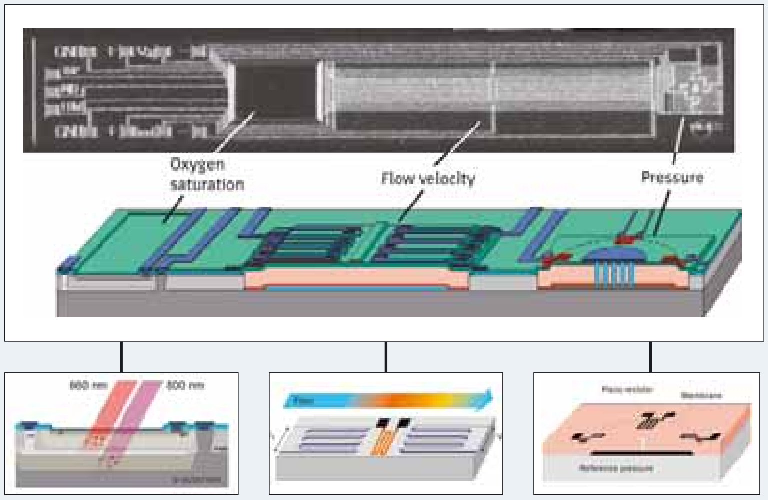
The active component in the current, rather oversized, casing consists of a silicon chip measuring 0.9 by 7 mm. Miniaturisation is not a problem in this case but it still needs the addition of some signal processing circuitry so the current set of ten wires can be replaced by three wires of approximately 0.15 mm diameter.



Goosen's measuring chip can provide more than just the individual readings. Local pressures and flow rates can change in seconds. If the physician uses several probes to take different readings in succession his chances of taking them in exactly the same spot are remote making it impossible to combine readings for the same time and location. Goosen's chip, on the other hand, is able to provide these combinations and so improve the quality of the diagnosis.



The future as seen by Tanase and Goosen: her navigation sensor on the guide wire and his measuring chip in the catheter wall.



Close-up of the measuring chip. The oxygen saturation level is measured optically using an external fibreglass-guided light source. The redness of the blood is a measure of the level of oxygen saturation. To measure the rate at which the blood flows past the sensor, the temperature of the blood is raised locally by 2 °C and then measured again a few millimetres downstream. The decrease in temperature is a measure of the flow rate. The blood pressure is measured by means of piezo resistors attached to a membrane. As the membrane flexes under the pressure of the blood, a voltage is produced.

WHO AND WHERE

TU DELFT
P.O. BOX 5
2600 AA DELFT
THE NETHERLANDS
TELEPHONE +31-15 278 9111
TELEFAX +31-15 278 6522

Delft University of Technology has seven faculties, each of which is engaged in education and research in one or more disciplines. The University was founded in 1842 by King William II.
With 13.000 students, 2.800 scientific staff members and 2.500 technical and administrative employees, it is the largest university of technology in The Netherlands.

DISCIPLINES

Aerospace Engineering
Kluyverweg 1
NL-2629 HS Delft
Telephone +31 15 278 1455

Applied Earth Sciences
Mijnbouwstraat 120
NL-2628 RX Delft
Telephone +31 15 278 1423

Applied Physics
Lorentzweg 1
NL-2628 CJ Delft
Telephone +31 15 278 5355

Architecture
Berlageweg 1
NL-2628 CR Delft
Telephone +31 15 278 4237

Chemical Technology & Bioprocess Technology
Julianalaan 136
NL-2628 BL Delft
Telephone +31 15 278 3659

Civil Engineering
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 5553

Electrical Engineering
Mekelweg 4
NL- 2628 CD Delft
Telephone +31 15 278 6260

Geodetic Engineering
Thijsseweg 11
NL-2629 JA Delft
Telephone +31 15 278 2586

Industrial Design Engineering
Landbergstraat 15
NL-2628 CE Delft
Telephone +31 15 278 3984

Life Science & Technology
Julianalaan 67
2628 BC Delft
Telephone +31 15 278 2413

Marine Technology
Mekelweg 2
NL-2628 CD Delft
Telephone +31 15 278 6595

Materials Science
Rotterdamseweg 137
NL-2628 AL Delft
Telephone +31 15 278 3659

Mechanical Engineering
Mekelweg 2
NL-2628 CD Delft
Telephone +31 15 278 6595

Computer Science
Mekelweg 4
NL- 2628 CD Delft
Telephone +31 15 278 4568

Applied Mathematics
Mekelweg 4
NL- 2628 CD Delft
Telephone +31 15 278 4568

Technology, Policy & Management
Jaffalaan 5
NL-2628 BX Delft
Telephone +31 15 278 3620

MULTIDISCIPLINARY CENTRES

Adhesion Institute
Kluyverweg 3
NL-2629 HS Delft
Telephone +31 15 278 5353

Netherlands Institute for Metals Research (NIMR)
Rotterdamseweg 137
NL-2628 BL Delft
Telephone +31 15 278 2535
Fax +31 15 278 2591

Biotechnological Sciences Delft Leiden (BSDL)
Julianalaan 67
NL-2628 BC Delft
Telephone +31 15 278 6316

Centre for International Co-operation and Appropriate Technology (CICAT)
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 3612

Centre for Transportation Engineering
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 6634

Koiter Institute Delft (Institute for Engineering Mechanics)
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 5464

Instute for Wind Energy
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 5170

Interfaculty Reactor Institute
Mekelweg 15
NL-2629 JB Delft
Telephone +31 15 278 6712

OTB Research Institute for Housing, Urban and Mobility Studies
Thijsseweg 11
NL-2629 JA Delft
Telephone +31 15 278 3005

Open Building Working group (OBOM)
De Vries van Heystplantsoen 1
NL-2628 RZ Delft
Telephone +31 15 278 5400

Delft Institute for Microelectronics and Submicrontechnology (DIMES)
Feldmannweg 17
NL-2628 CT Delft
Telephone +31 15 278 3868

Interduct Delft University Clean Technology Institute
Rotterdamseweg 145
NL-2628 AL Delft
Telephone +31 15 278 3341

J.M. Burgerscentrum
Centre for Fluid Mechanics
Rotterdamseweg 145
NL-2628 AL Delft
Telephone +31 15 278 3216

Netherlands Schools for Advanced Studies in Construction
Stevinweg 1
NL-2628 CN Delft
Telephone +31 15 278 3332

Advanced School for Computing & Imaging
Mekelweg 4
NL-2628 CD Delft
Telephone +31 15 278 8032

TRAIL Research School
Kluyverweg 4
P.O. BOX 5017
NL- 2600 GA Delft
Telephone +31 15 278 6046

CENTRAL LIBRARY

Delft University of Technology Library (DUTL) supplies information and provides services, particularly in the area of the technical sciences.
It comprises a central library and twelve sub-faculty libraries housed at the respective sub-faculties and institutes.
The DUTL is intended for students and staff at the Delft University of Technology. However, as the task of the library is to provide scientific and technical information at a national level, its facilities are also available to the general public. As well as all areas of technology and natural sciences, the library also contains a general collection in the social sciences, economics etc.
This relates not only to books or periodicals, but also to standards, reports, reference works and congress proceedings.
Literature not in the collection or not on hand can be obtained through Delft University's Central Library from other libraries in the Netherlands or abroad.

For further information:
Delft University Central Library
Prometheusplein 1
P.O. BOX 98
NL-2600 MG Delft
Telephone +31 15 278 8022

DELFT UNIVERSITY PRESS

Delft University Press publishes scientific books and electronic magazines, such as the quarterly journal 'International Shipbuilding Progress' (LSP) (http://isp.tudelft.nl), European Journal of Transport and Infrastructure Research (http://ejtir.tudelft.nl) and the Journal of Design Research (http://jdr.tudelft.nl).
A catalogue is available free upon request.

Delft University Press
Prometheusplein 1
P.O. BOX 98
NL-2600 MG Delft
Telephone + 31 15 278 3254
Fax + 31 15 278 1661
dup@library.tudelft.nl

INFORMATION

General information:
Information office
P.O. BOX 5
NL- 2600 AA Delft
Telephone +31 15 278 5404
http://www.tudelft.nl

Information on facilities for foreign students:
Student Advisory Office
Julianalaan 134
NL- 2628 BL Delft
Telephone +31 15 278 6098

Liaison between business and research:
Liaison Office
Julianalaan 134
NL- 2628 BL Delft
Telephone +31 15 278 1500

Information on research fellowships:
Mrs. M.Y.M. Spiekerman
Julianalaan 134
NL- 2628 BL Delft
Telephone +31 15 278 3773

General information on university education in the Netherlands:
Min. of Education, Science & Culture
Central Information Dpt.
P.O. BOX 25000
NL-2700 LZ Zoetermeer
Telephone +31 79 353 1911

(POST GRADUATE) COURSES

Delft TopTech
(vocational courses)
Mekelweg 2
P.O. BOX 612
NL-2600 AP Delft
Telephone +31 15 278 8019
Fax +31 15 278 1009
www.delft©toptech.nl

Institute for Biotechnology Studies Delft Leiden (BSDL)
Julianalaan 67
NL-2628 BC Delft
Telephone +31 15 278 6316

For information on courses in the Dutch language:
Language Laboratory
De Vries van Heystplantsoen 1
NL-2628 RZ Delft
Telephone +31 15 278 4124