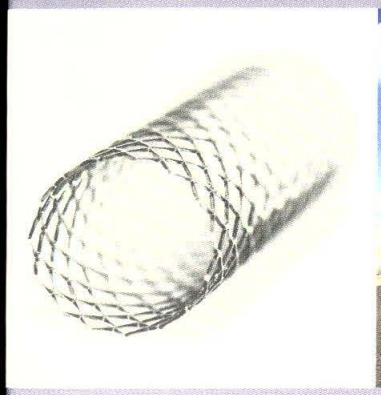
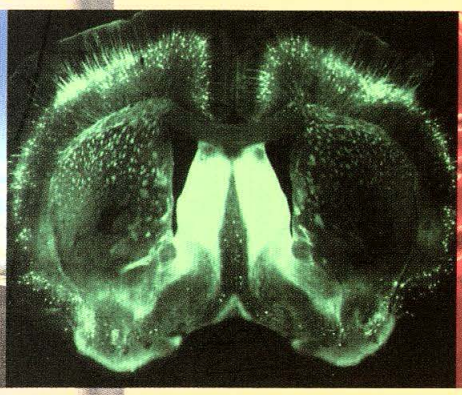
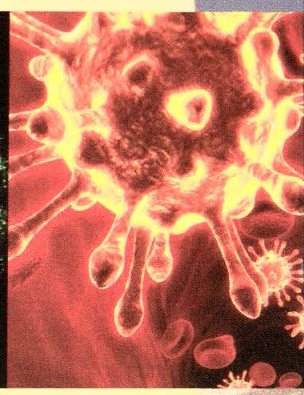
December 2011

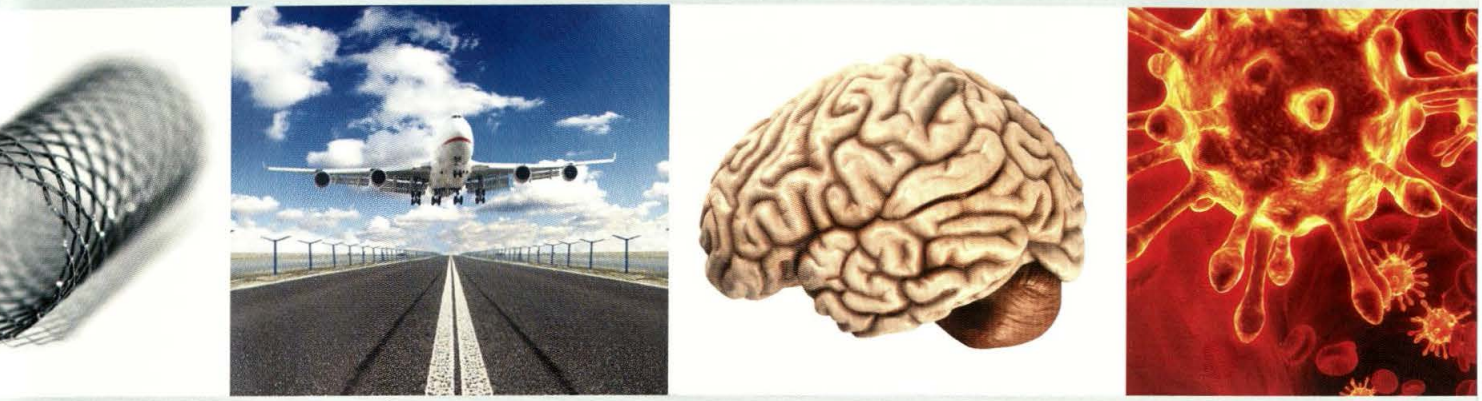






Research matters

A selection of research projects conducted at the University of Malta



Research matters

A selection of research projects conducted at the University of Malta

December 2011

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Some of Malta's best kept secrets...

Juanito Camilleri
Rector

Perhaps there has been one thing the University of Malta has not done well enough hitherto. We have not blown our trumpets loud enough vis-a-vis our research accomplishments.

Most academics worth their salt would rather get on with their research than spend time talking about it. Though understandable, such media shyness comes at a price. The perception one often reads from the general public – alas even amongst the political class – is that the University of Malta is predominantly engaged in teaching and that the research that takes place here is of little consequence nationally and is merely intended to support the teaching activity of the academics who conduct it.

Nothing can be further from the truth!

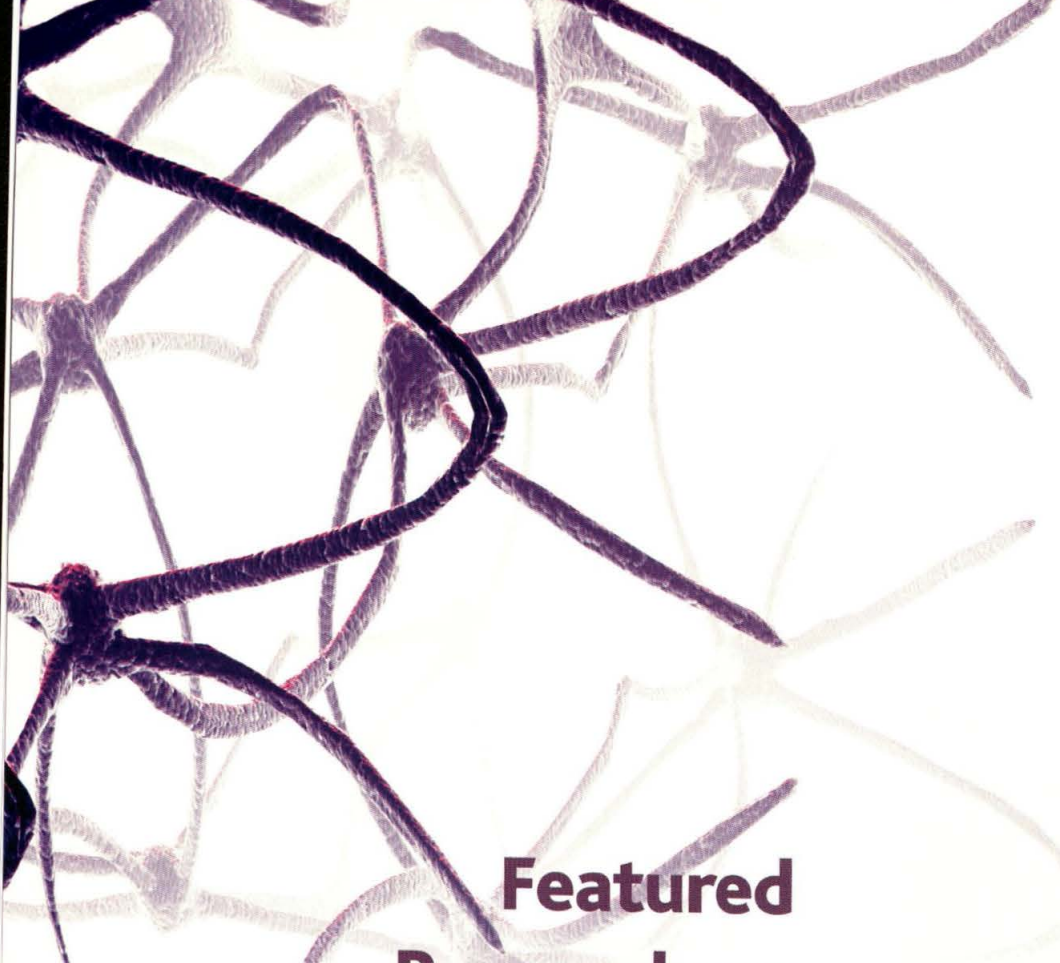
Although we are proud to offer an impressive array of degree programmes at undergraduate and postgraduate level, and although the funding available for research is but a fraction of what it ought to be, we have managed to achieve some very impressive results in a broad spectrum of disciplines. I believe that these results are noteworthy.

It is in this light that this publication has been conceived. This bi-annual magazine aims to open a window on some of the research activity that is underway at our Alma Mater. As we aspire to win popular support in our bid to augment our resources, an onus is cast upon us to explain in informal layman's terms what it is that we get up to on campus.

From ocean and seismic monitoring, to materials that behave counterintuitively when heated or compressed; from research which reveals a groundbreaking insight on the genetic mechanisms regulating and controlling haemoglobin switching to the engineering of intelligent molecules intended for medical diagnostics; from onboard control systems to improve runway safety during takeoff and landing to the design and development of systems for solar desalination; from mathematical theories which drive the design of revolutionary nano materials which can change our quality of life to the creation of a radically innovative ultra high-speed multi-vision "camera"; from understanding and monitoring the health of our territorial fish habitats to the creation of digital tools to valorise our Maltese language and empower its users with state-of-the-art linguistic tools.

Sounds interesting? Well, I invite you to read all about it and if the articles herein pick your interest contact us, or better still come and see us.

This issue is just an initial snapshot – there is more going on at our Alma Mater – much more than meets the eye. We promise to tell you all about it!



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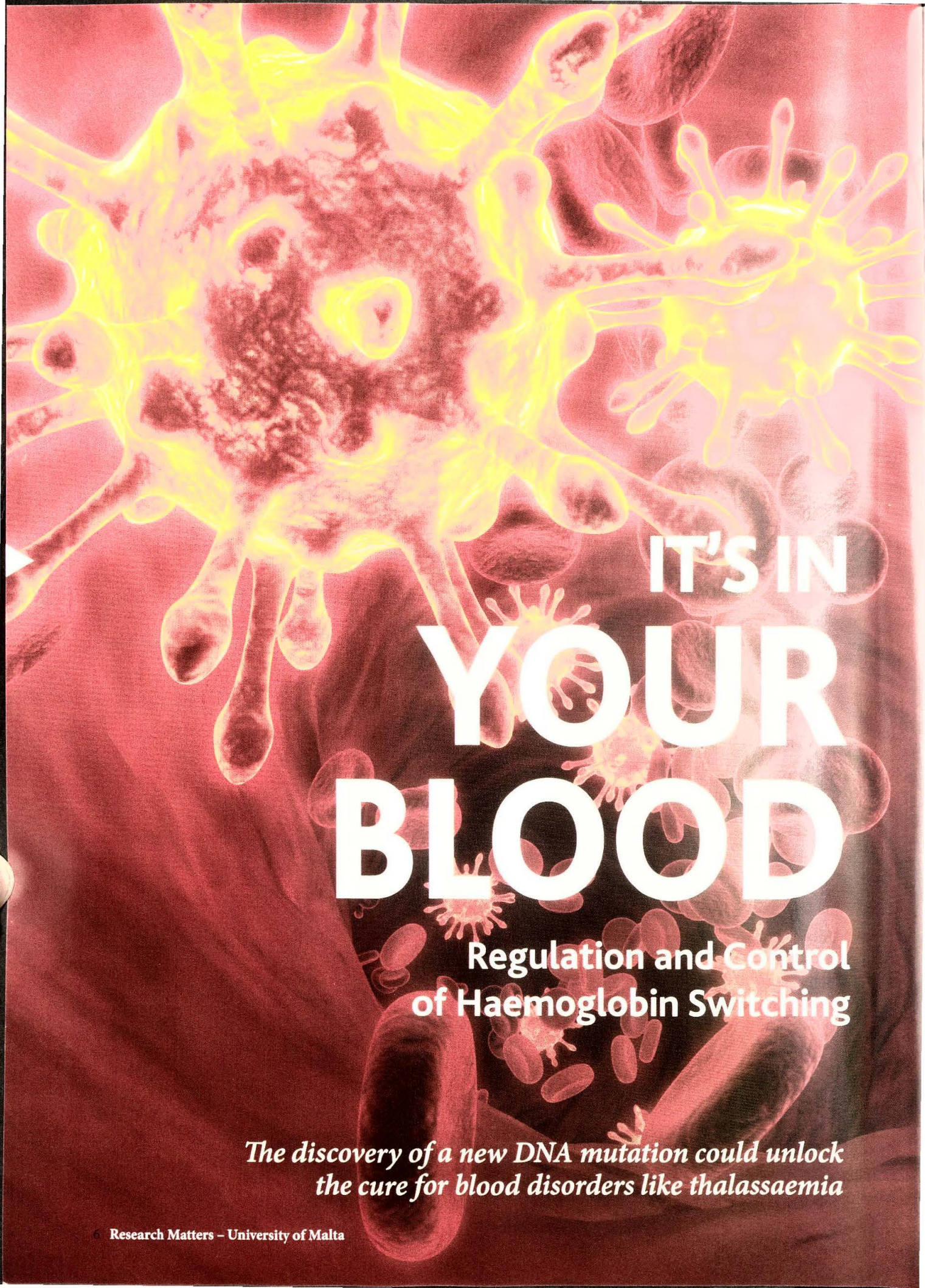


IT'S IN YOUR BLOOD

Regulation and Control of Haemoglobin Switching

The discovery of a new DNA mutation could unlock the cure for blood disorders like thalassaemia

Haemoglobin (Hb) carries oxygen throughout our bodies. It is the respiratory pigment of man and many other mammals. The molecule captures oxygen in the lungs and transports it within the red blood cells for release in the tissues.

Haemogloblin is a fascinating molecule. Although deceptively simple in structure, it is intriguingly complex in physiology and genetics. The fully functional molecule is one of the smaller proteins known. It is assembled from four subunits; all proteins and known as globins. Each globin resembles the structure of the simpler oxygen storage molecule, myoglobin, mostly found in muscle. There are 280 million molecules of haemoglobin in every red blood cell, and there are 30 trillion red blood cells in the body of a normal and healthy person. The genetic control of haemoglobin production i.e. globin biosynthesis, before and after birth is as complex and demanding as is the physiology of the molecule. Both matters have challenged some of the most leading luminaries in haematology, protein chemistry, physiology and genetics for the large part of the previous century. The molecular details of physiological function and the developmental control of globin gene expression remain fundamental inquiries even in contemporary human biology and medicine. The implications for health and disease are huge.

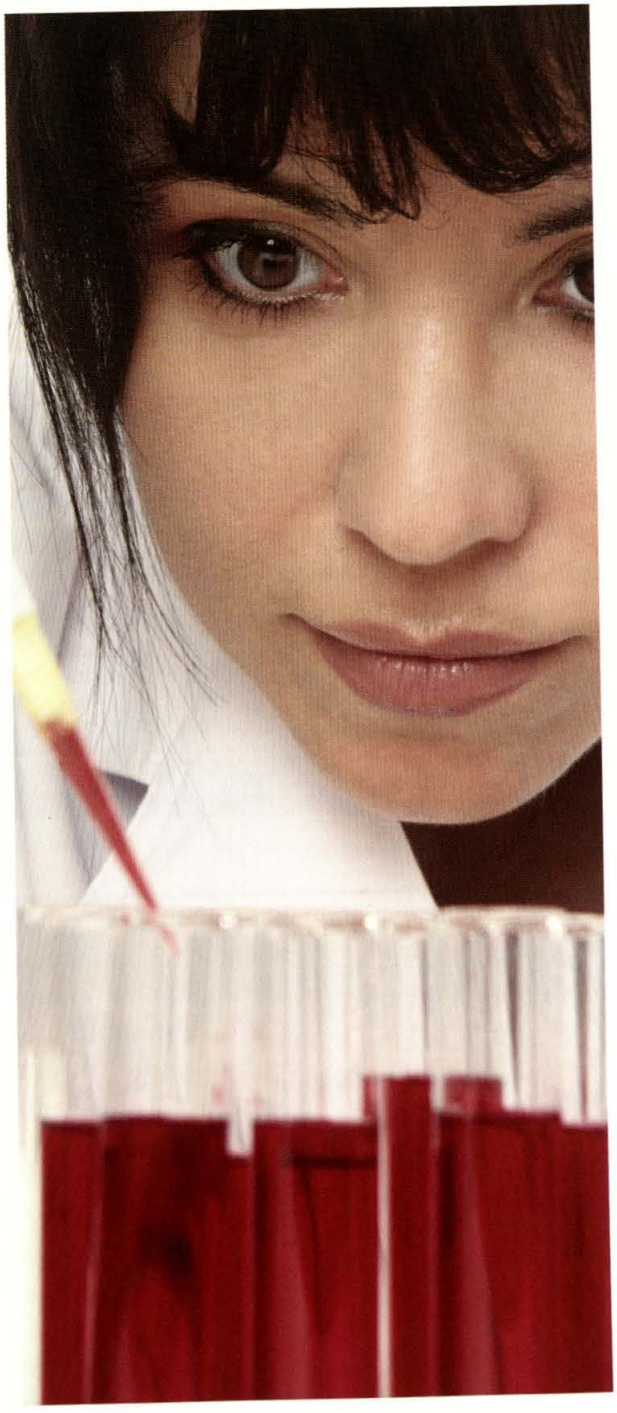
The haemoglobin content of a healthy individual is around 14g/dL. Many conditions decrease this concentration, such as iron deficiency anaemia, or heavy blood loss due to accidents. When haemoglobin decreases, the body goes into stress, and tries to bring levels back to normal. Anaemia occus when haemoglobin is very low, with sufferes complaining of fatigue amongst other symptoms. Nowadays such conditions or situations are easily cured or remedied by treatment within a few weeks.

The same cannot be said for other genetic conditions that are inherited. Conditions such as sickle cell disease and thalassaemia, involve either an abnormal haemoglobin protein or a complete absence of the normal protein. In turn, this will lead to unsuccessful or inefficient oxygen-carrying capacity in our human body, leading to chronic (lifelong) anaemia. The only possible treatment is by blood transfusion every 4 to 6 weeks coupled with iron chelating therapy that removes excess iron from the body. This has two drawbacks. One

280

million molecules

of haemoglobin in every red blood cell, and 30 trillion red blood cells in a person



is purely personal and patient-related. Having blood transfusions every month is not very ideal for a normal lifestyle, not to mention all the complications that can accompany it. The second drawback would be on the society itself, since such blood transfusions will deplete the stores that may be otherwise used for other emergency situations and haematological malignancies.

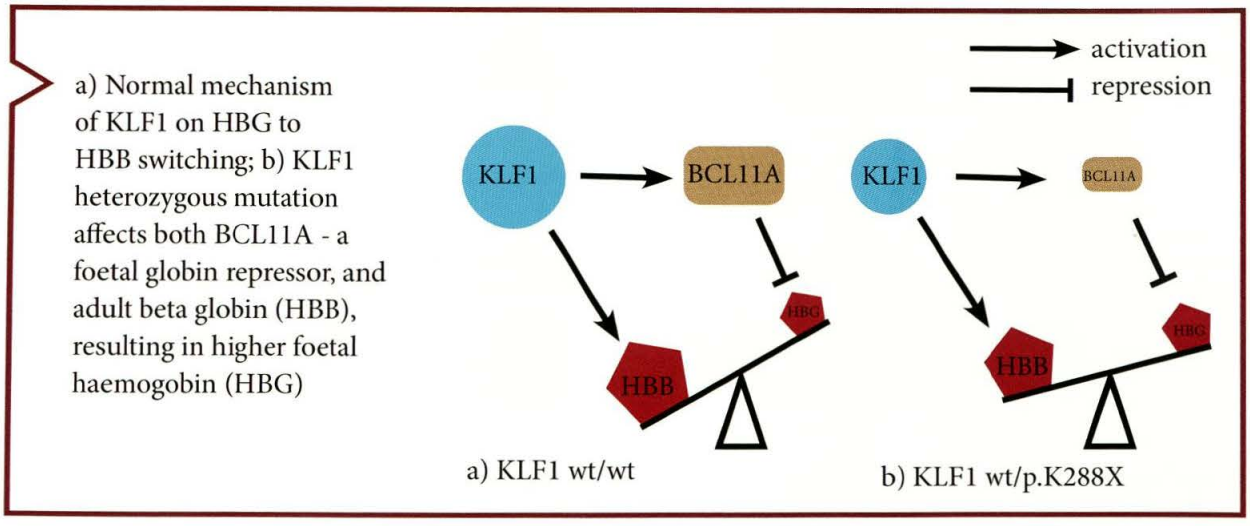
The composition of the haemoglobin protein changes during the early stages of life. There is a switch from embryonic to foetal and eventually from foetal to adult. In most cases of thalassaemia the adult haemoglobin is defective, which has a direct effect since it is usually the predominant form. Foetal haemoglobin (HbF) is expressed in very high levels in the foetus, and starts to decline steadily round the time of birth. The switch is complete around 6 to 9 months after birth. At this stage the adult form of haemoglobin would have become the predominant one. Since the adult haemoglobin is defective in beta thalassaemia patients, having higher levels of foetal haemoglobin *in vivo*, will generally lead to a better quality of life, reduced symptoms and possibly render them free from transfusions.

Scientific studies have tried for years, to induce high levels of foetal haemoglobin in adults suffering from haemoglobin disorders. Many studies focused on drugs and compounds that act on DNA sequences and other protein molecules. To be able to switch on foetal haemoglobin efficiently, the switching mechanism must be well understood.

One large study that has made an international impact originated from the University of Malta (Borg *et al.*, 2010). A Maltese family was studied that exhibited abnormally high levels of foetal haemoglobin in their blood (lowest ranging from 3.3% and highest up to 19.5%). "Why did these people carry high levels of foetal haemoglobin?" Knowing the answer may help develop drugs or compounds to treat patients with beta thalassaemia.

The research study identified a new DNA mutation in a gene called Erythroid Krupple-Like Factor 1 (KLF1) on chromosome 19. The participating Maltese patients donated 30mL of blood that were used to culture red blood cells. The patients had abnormal expression levels resulting in high foetal haemoglobin that was very different from individuals with normal levels of foetal haemoglobin. KLF1 is a transcription factor and its main role is to bind and initiate transcription (switch on) of the adult beta globin gene. The KLF1 protein in the Maltese family members was compromised due to the presence of the mutation, meaning that only one copy of KLF1 was functioning correctly. Since KLF1 is important to express the adult beta globin gene, this gene was compromised, reducing beta globin gene production. To compensate for low adult globin levels, foetal haemoglobin was switched on. Moreover, KLF1 appears to bind and regulate a foetal haemoglobin repressor - BCL11A. Hence, less BCL11A, resulted in even more foetal haemoglobin production.

Currently, the Malta group is analyzing additional DNA sequences that may regulate and control foetal haemoglobin *in vivo*. The results can



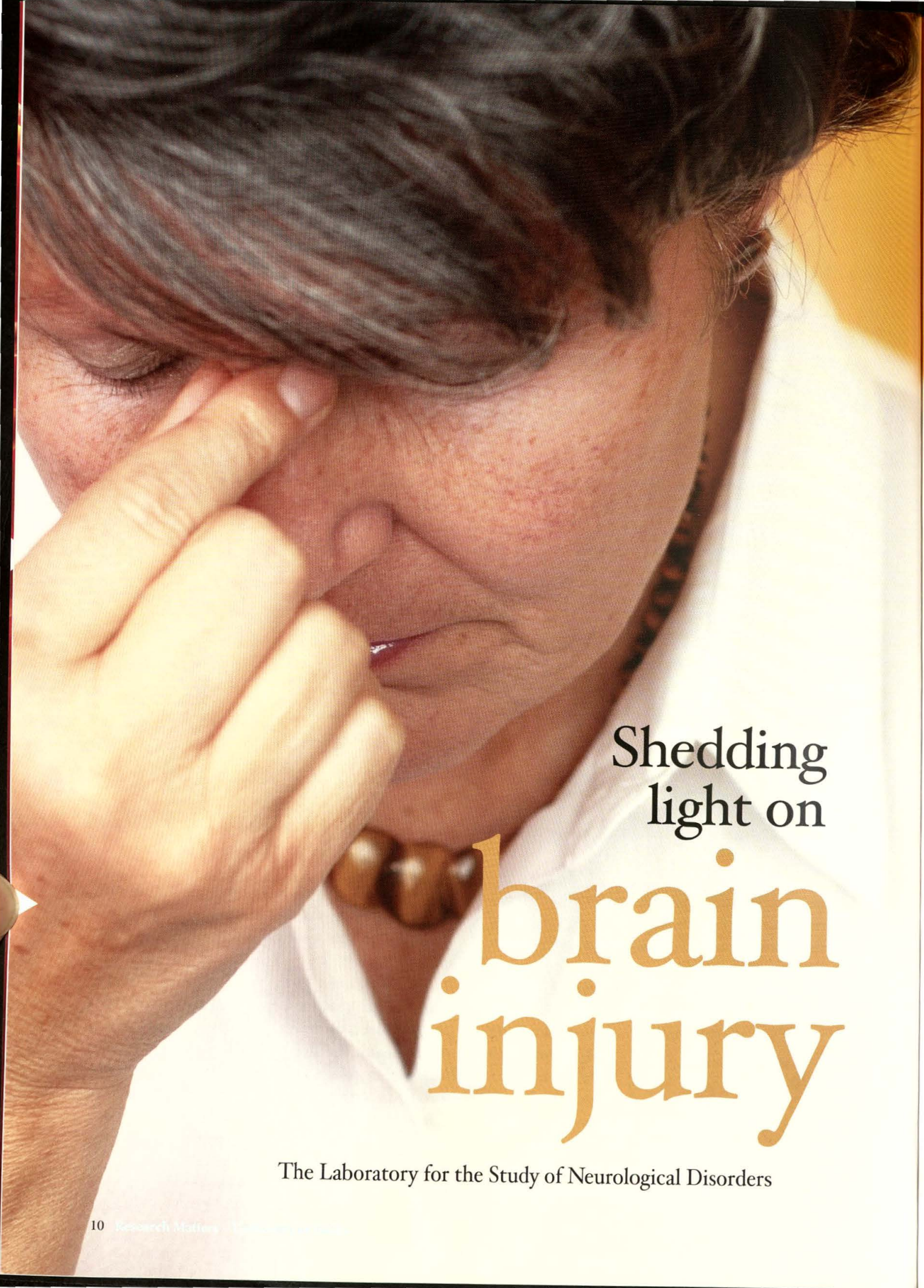
a) Normal mechanism of KLF1 on HBG to HBB switching; b) KLF1 heterozygous mutation affects both BCL11A - a foetal globin repressor, and adult beta globin (HBB), resulting in higher foetal haemogobin (HBG)

The KLF1 protein in the Maltese family members with high foetal haemoglobin was compromised due to the presence of the mutation, meaning that only one copy of KLF1 was functional

yield potential targets for therapeutic intervention allowing the switch to high-level expression of foetal haemoglobin and possibly curing syndromes such as beta thalassaemia.

The Malta group is led by Professor Alexander E. Felice with active participation and leading roles by of Dr. Joseph Borg and Dr. Godfrey Grech on cell manipulation and culture studies. Ms Ruth Galdies and Ms Wilma Cassar on haematological testing using analytical lab techniques, and Professor Christian A. Scerri as a genetic counselor at the Thalassaemia and Molecular Genetics Clinic, located at the Mater Dei Hospital. The Malta Group is also supported by undergraduate students as well as graduate (M.Sc studies) and post-graduate (PhD studies) who take active parts on haemoglobin and related research.

This research team has repeatedly made international headlines, hinting at the importance of these blood disorders that affect millions world wide. Finally, the decades long search for a beta thalassemia cure seems elusively near, since this team has uncovered an important underlying mechanism to genetically switch on foetal haemoglobin. The futue for curing thalassemia has become much brighter. ●



Shedding light on brain injury

The Laboratory for the Study of Neurological Disorders

Each year millions of people worldwide suffer from brain injury. Strokes, heart attacks, physical force and low oxygen levels can all lead to permanent damage. These injuries can lead to emotional, mood and behavioural problems. Speech can become slurred, whilst in the worst cases memory lapses occur, muscle weakness can kick in and it can even lead to death.

The worst thing is that there is little that can be done. Dead neurons cannot be replaced, but this old dogma is falling apart. Neurons can be regenerated, due to a type of cell that can develop into a neuron and replenish our brains. In part, these discoveries are due to multiphoton microscopy that can peer into neurons and discover what makes them tick and what makes that tick stop: the death of neurons.

It is now possible to capture cellular and molecular events deep down in the brain to study how cells communicate, develop, and how injury and reconstruction occurs. Knowledge of the intricate dynamics and cross-talk between neurons, glia and the vasculature is unraveling what causes these cells to die and how they could be made to recover. These and other discoveries will progress into clinical practice, and lead to a revolution in neurology and neurosurgery.

Along with the measurement of the typical ionic and electrical signature of the cells in nervous system, scientists combine state of the art imaging directly into the live rodent brain to observe and quantify changes that occur during injury and recovery and propose the use of new drugs to help in the restoration of brain function and recovery.

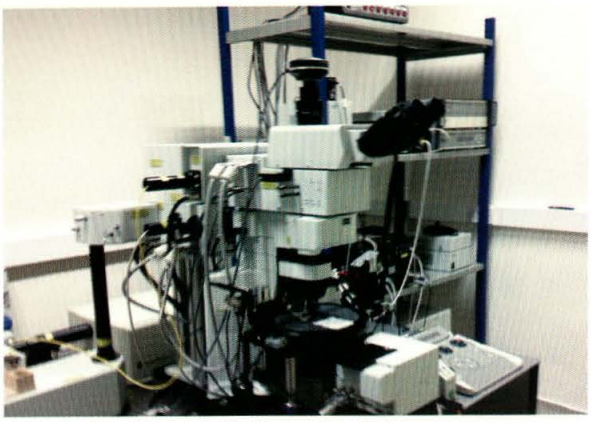
The Laboratory for the Study of Neurological Disorders of the University of Malta was established by Prof. Richard Muscat and Dr Mario Valentino in 2005. Research in this laboratory is directed to understanding cellular mechanisms of damage and the pharmacological recovery in brain injury. Since its establishment, the laboratory has expanded its research and moved its focus to include the broad study of stroke development, using a combination of multiparametric and non-invasive approaches to follow brain injury over time. Experimental methods used in the lab include brain slice, and in vivo stroke models in transgenic mice.

During the past decade, the rapid improvements in the tools available for labelling proteins within cells, has increased the lab's ability to unravel the finer details of cellular events. One significant reason is the development of fluorescent proteins that can be incorporated into proteins by genetic fusion to produce a fluorescent label.

Microscopic techniques include confocal microscopy of thin fixed brain slices, deep tissue imaging of live slices and whole animal preparations under multiphoton microscopy. Other research avenues include spreading depression during stroke and in vivo microdialysis.

Research activity

Normal brain activity critically depends on a continuous supply of oxygen and glucose through cerebral blood flow (CBF). Although cerebral energetic demands are very high, the brain can



The FV1000-MPE Olympus multiphoton system

only store a little energy. Because of this unique characteristic, local brain activity has to be matched by a concomitant increase in local CBF (a phenomenon referred to as functional hyperemia or neurovascular coupling). Functional hyperemia is involved in the pathophysiology of many acute neurological and neurodegenerative diseases, such as stroke, hypertensive encephalopathy, Alzheimer's disease, and vascular dementia. Moreover, functional hyperemia forms the basis of many modern non-invasive functional neuroimaging techniques that use this phenomenon to map brain activity in animals and humans.

Despite the importance of functional hyperemia for clinical neurology and neuroscience, the underlying mechanisms have remained largely undefined. Over the last years, many different transmitters and pathways have been implicated in functional hyperemia, but the relevance of these mechanism *in vivo*, as well as the exact sequence of events and the different cell types involved, remain to be determined.

In such cases, the goal of the research team is to study these mechanisms in the living, intact brain of anesthetized rodents, using molecular *in vivo* imaging techniques. They aim to define the role of different cellular pathways in functional hyperemia, and explore the perturbation of this phenomenon in animal models of neurological disease. The core instrument used in these projects is centred around the use of the two-photon microscope, funded by the European Regional Development Fund. In this way, fluorescently labeled cells are routinely imaged *in vivo* through a cranial window, which has allowed Dr Valentino and his team to precisely record changes in neuronal and glial activity, as well as CBF changes in single blood vessels, in living anesthetized animals with unprecedented resolution.

Role of astrocytes in functional hyperemia

Astrocytes, the star-shaped glial cells found in the brain and in the spinal cord, are in close contact with neuronal synapses as well as with blood vessels, making them ideal candidates to convey changes in neuronal activity to the vasculature. Using *in vivo* two-photon microscopy to probe neuro-glial network activity and CBF, with the help of fluorescent dyes and transgenic animals expressing optical markers of cellular activity, the research team focuses on how the intracellular pathways trigger functional hyperemia.

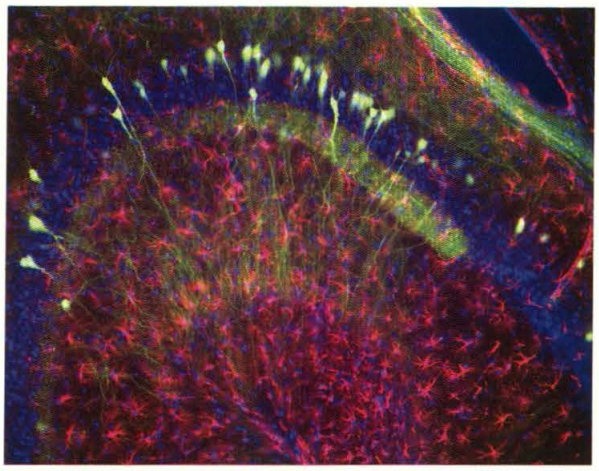
Astrocytic function and functional hyperemia are severely impaired after a person suffers a stroke. This likely contributes to accumulation of water in the brain, known as celebral edema, and enlargement of the ischemic area, but the underlying mechanisms have remained unclear.

The research group is actively involved in collaborative research projects with Max Planck Institute for Neurological Research in Cologne, with whom they are currently working on a non-invasive method to look at blood flow changes that will allow researchers to image aberrant changes in blood flow that evolve over time in cases of traumatic brain injury, stroke and subarachnoid haemorrhage. Other collaborative research partners include the Department of Cell Physiology and Pharmacology of the University of Leicester, the Laboratory of Eukaryotic Signal Transduction and Gene Expression, University of Ghent in Belgium and the Department of Internal Medicine, University of Perugia in Italy.

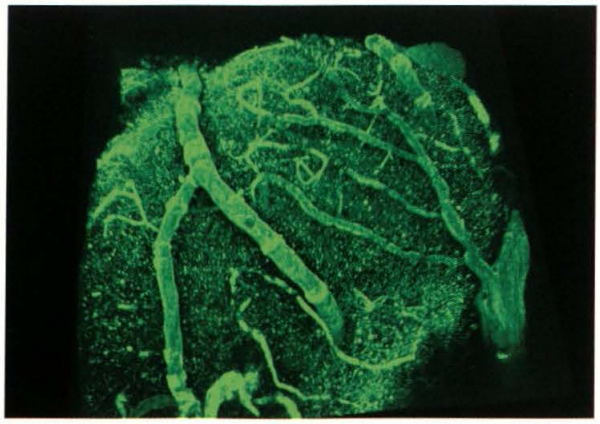
In this project, the research team monitors cellular activity of astrocytes and neurons together with CBF changes in real-time during and after focal cerebral ischemia in mice, using two-photon microscopy. By doing this the team aims to unravel the pathways and molecules involved in these pathological mechanisms, and investigate if pharmacological intervention of these pathways can ameliorate ischemic damage.

Imaging the muse brain in 3D is giving new insight into the development of brain injury that will allow Dr Mario Valentino and his team to visualise the damage step by step. Knowing which brain cells die off first, allows for the development of drugs and techniques to reduce brain injury and guide the surgeons' knife. This research will help millions of sufferers world wide.

A coronal section from a mouse brain that expresses the fluorescent GFP dye in its nerve cells



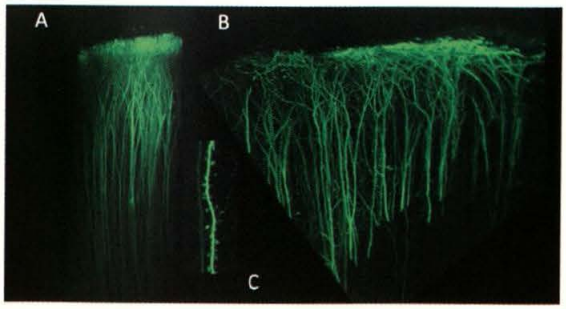
Looking closer into the hippocampus (Blue DNA, Red Astrocytes, Green Neurons)

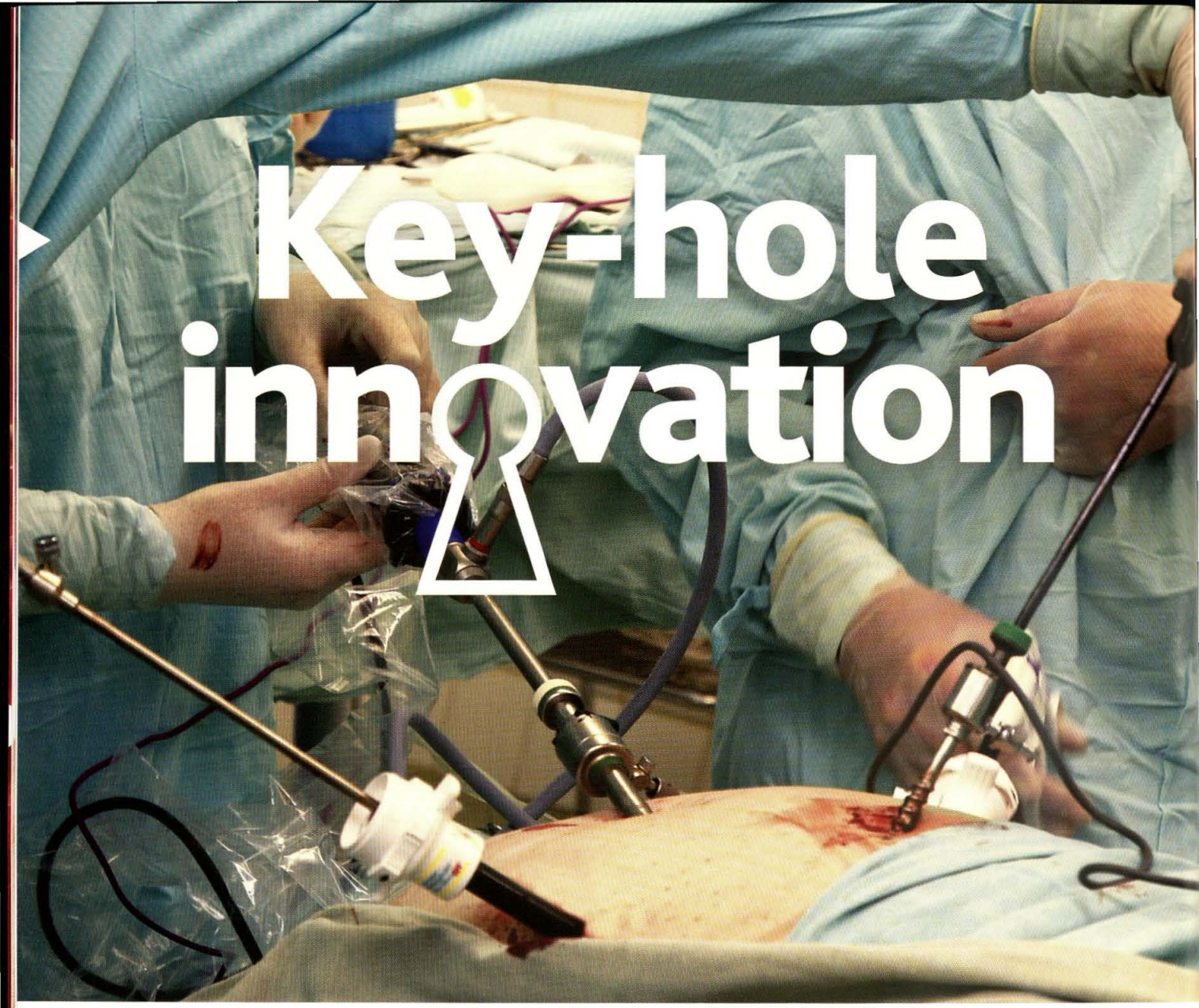


The mouse brain in 3D with blood vessels. The brain from the surface showing an area of around 1mm squared. Highly visible is the vasculature (in green) surrounded by tree-like branched extensions from the nerve cells below the surface (also in green)

Three-dimensionally constructed images of neurons expressing YFP-H in the cerebral neocortex of a mouse under anesthesia. Images captured using the Olympus Fluoview FV1000-MPE multiphoton system with a 25x objective.

(A) Live imaging of anaesthesized mouse through a cranial window up to 614µm deep below the pial surface showing distinct pyramidal neurons with axons extending down to layer IV and (B) at a of 450µm. In the cortex, most studies of dendritic plasticity have taken advantage of apical tuft dendrites of layer 5 neurons and layer 2 and layer 3 neurons that reach near the surface of the cortex. Near the cortical surface, the tuft dendrites curve and almost run parallel with the pial surface. These parallel running dendrites have spines (C) projecting laterally taking full advantage of two-photon microscopy's good resolution with depth.





Key-hole innovation

The challenge to design a new multifunctional tool that would enhance surgical interventions

In the early 20th century a new surgical technique known as laparoscopic surgery or 'minimally invasive surgery' was introduced by Swede surgeon Hans Christian Jacobaeus. The procedure allowed the surgeon to perform surgical interventions, such as the removal of the gall bladder or the removal of the appendix by introducing laparoscopic probes from a small incision in the abdomen.

These probes are used to cut, trim, grab, biopsy, inside the abdomen, without having to perform a traditional incision, but which are introduced into the abdomen through what has been popularly called 'key-hole' incision.

The advantages of the technique used by means of laparoscopic probes as against the traditional procedures are various. The tiny incision allows less risk of infection and haemorrhaging is reduced significantly. There is also less pain in the process and recovery time is shorter.

There are however some disadvantages, particularly related to the surgeon's manoeuvrability, or the lack of it, when using the laparoscopic probes.

Surgeons are demanding more specifications for the tools they use such as multifunctionality, dexterity, reliability, biocompatibility and ergonomics.

From an engineering perspective, such tools present increased challenges to develop and need inter-disciplinary design knowledge to solve their complexity.

The challenge was taken up by the department of Industrial and Manufacturing Engineering of the University of Malta. Having secured funds from the National Research and Innovation Programme, a team of researchers, led by Prof. Jonathan Borg set out to develop an innovative laparoscopic prototype that would address a number of the demands and challenges facing surgeons.

The Challenge

Having observed laparoscopic procedures in detail, the research team identified tool swapping as one of the major problems faced by surgeons. In the course of a laparoscopic Cholesystectomy procedure, during which the gall bladder is removed, surgeons use 3 different tools for a number of functions – the grasper, the clipper and the scissors. Observation revealed that during such a procedure, the surgeon performs no less than 10 swaps of the tools in order to conduct different functions in the course of the surgical intervention.

The challenge was to design a new multi-functional tool that would incorporate all the three tools together, thus reducing the number of tool swaps and which would eventually result in shorter surgical interventions. The benefits that such results will have on patients and medical teams are numerous.

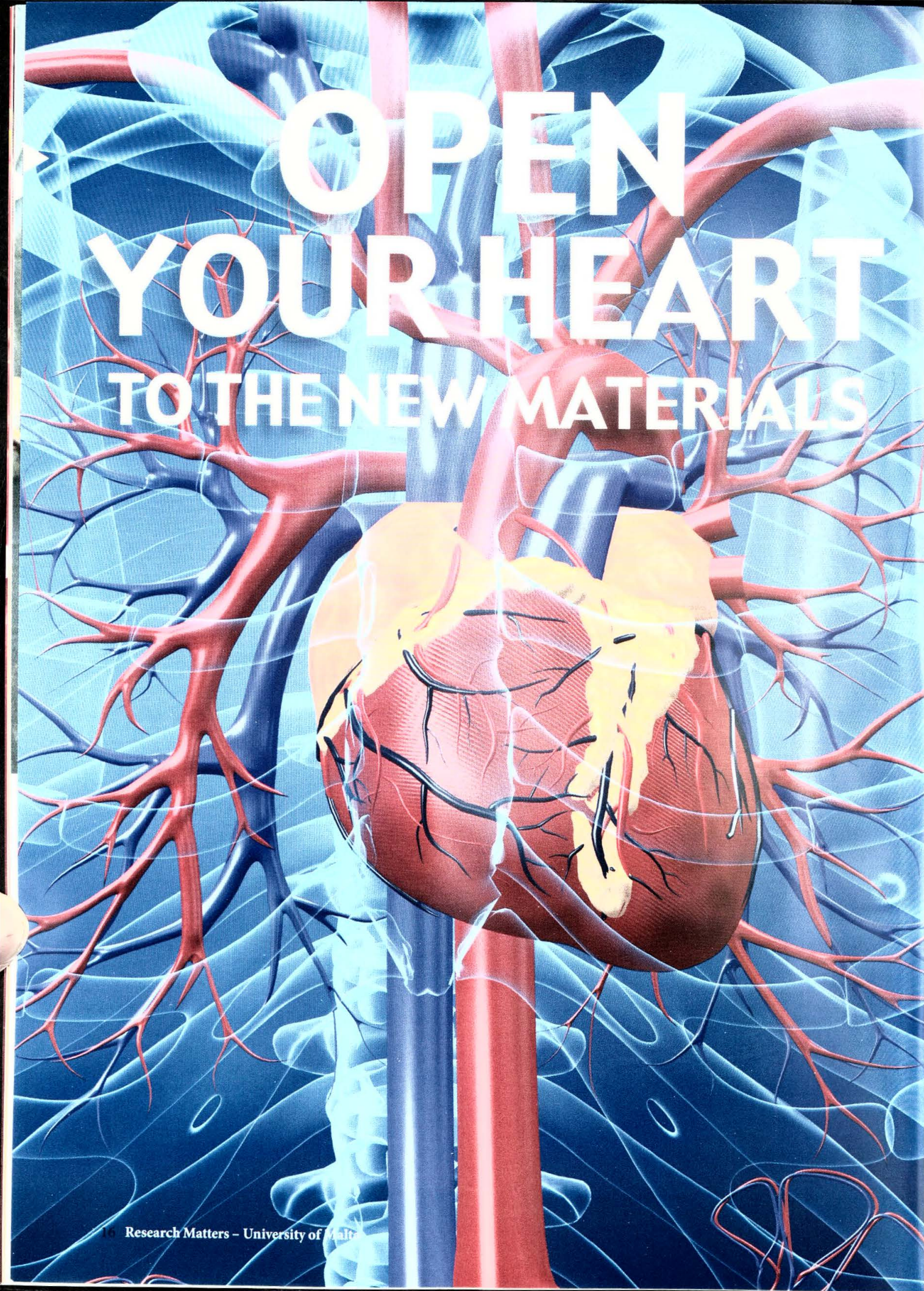
The prototype developed by the University research team incorporating scissors, the grasper and the hook in one tool

Design and prototyping

The team decided to move on two product design specifications – one having a universal approach and another one with more specific functionality. In order to understand the internal structure, functional parts, sub-assemblies, assembly features and form features of a laparoscopic tool, an existing disposable one was disassembled. Following this benchmarking process, a number of conceptual design sketches were developed for both concepts. A Failure Mode and Effects Analysis (FMEA) chart was drawn up to establish which of the two concepts has the highest risk probability of failing. After one of the concepts was selected for further development, the conceptual drawings were transformed into more detailed ones and modeled in Autodesk Inventor. The handle, end-effector and jaws of the first prototype were manufactured using Stereolithography. The threads of the outer shaft and inner rod were turned on a centre lathe.

The tools used in minimally invasive gynaecological operations (such as hysterectomies) are very similar to those used in laparoscopy. For this reason the first prototype was shown to two local surgeons – a laparoscopic surgeon and a gynaecological surgeon to obtain feedback on the design. Both surgeons commented that the concept of multifunctionality is much needed and that the concept of combining scissors, hook and grasper is very useful. They both forwarded a number of suggestions related to improvements that may be done to the end-effector. Following the feedback, one of the major improvements that was done to the second prototype was the removal of one of the hooks as one of the surgeons commented that hooks create problems when it comes to electrocautery since usually only one side needs to be heated up. The end-effector and handle of the second prototype were machined on a milling machine while the shaft and inner rod were turned on a lathe and made out of stainless steel.

Having filed a patent with the World Intellectual Property Organisation, the next step for the University of Malta would be to commercialise the invention, something that would bring about significant changes in the way key-hole surgery is performed today. ●


OPEN
YOUR HEART
TO THE NEW MATERIALS

About a third of the human population are likely to suffer from ischaemic heart disease, with the rate of coronary heart disease increasing to around 58% in 65 year olds. Stenting is one approach for treating narrowed blood vessels

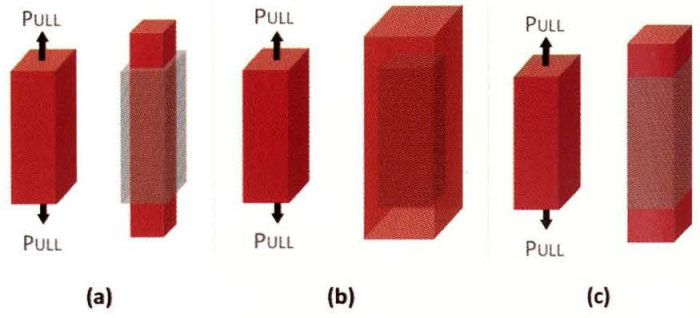
Stents are metal tubes that save millions of lives every year. They are flexible devices with a honeycomb structure that can be deployed inside a blood vessel to act as a scaffold to support the vessel wall. Since their introduction in the 1970s, stents have become a common place treatment for ischaemic heart disease.

One of the major problems with stents is when they become detached from the vessel wall leading to early and late thrombosis and restenosis, that are a major threat to the patient. Another common problem is their shrinking in length on deployment or foreshortening which is a direct consequence of the geometrical pattern on which the stent is based. In extreme cases this can lead to the detachment from the vessel wall, an effect which is known as longitudinal compressibility. Stents can also suffer from induced longitudinal straightening or vessel straightening due to spend implantation, which is a predictor for major adverse cardiac events (MACE) and angiographic restenosis due to high vessel walls stress at the stent extremities.

Local researchers have just applied for a patent in Malta and the UK for a new stent design that solves these problems. University of Malta academics Dr Daphne Attard, Dr Ruben Gatt and Prof. Joseph N. Grima from the Metamaterials Unit together with cardiac surgeon Dr Aaron R Casha are currently working in collaboration with Hallman-Vella Research and Development and Tek Moulds Precision Engineering Ltd. to develop innovative stent designs, having obtained funds from through the National Research and Innovation (R&I) Programme.

The new stent designs are based on honeycomb geometries with zero and negative Poisson's ratio so that they remain the same thickness or expand when stretched (Fig. 1). The main feature of such zero Poisson's ratio honeycombs is that they can be stretched in one direction without altering the dimensions in the other direction, that is they become neither thinner nor wider. This behaviour has some very important implications in stent design. In particular, foreshortening is absent in these stents. In addition, these honeycomb structures also have the ability to form perfectly tubular shapes. This limits the tendency of conventional stents to 'dog-bone' or form terminal

Figure 1
Behaviour of a material with a (a) positive (b) negative and (c) zero Poisson's ratio when they are uniaxially loaded



flanges leading to high localised wall stress and early atheroma formation, damaging blood vessels.

Since modern stents are placed at the site of bifurcation lesions, where two arteries come together, their design to allows side-branch stenting or stent-in-stent placement. In order to achieve good sidewall apposition and prevent stent fracture and polymer peeling with consequent loss of its drug delivery capability, stents are designed so that their unit cell size has a perimeter that equals the circumference of the side-branch. Zero Poisson's ratio geometry stents with missing ribs and large cell size have been designed with this aim.

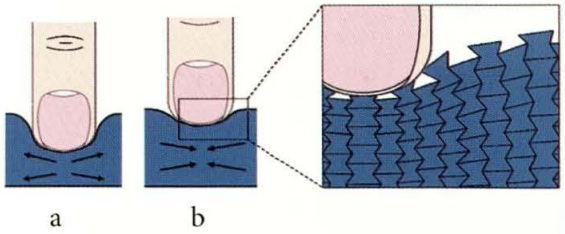
Cases where stents have to be deployed in tortuous winding vessels are also very common. In such circumstances, the ability of a tube to conform to the curvatures of the vessel without kinking and excessive build up of stress is essential. Stress can damage blood vessels. To achieve such flexibility, the Maltese team is proposing hybrid designs which employ different geometries within a single stent.

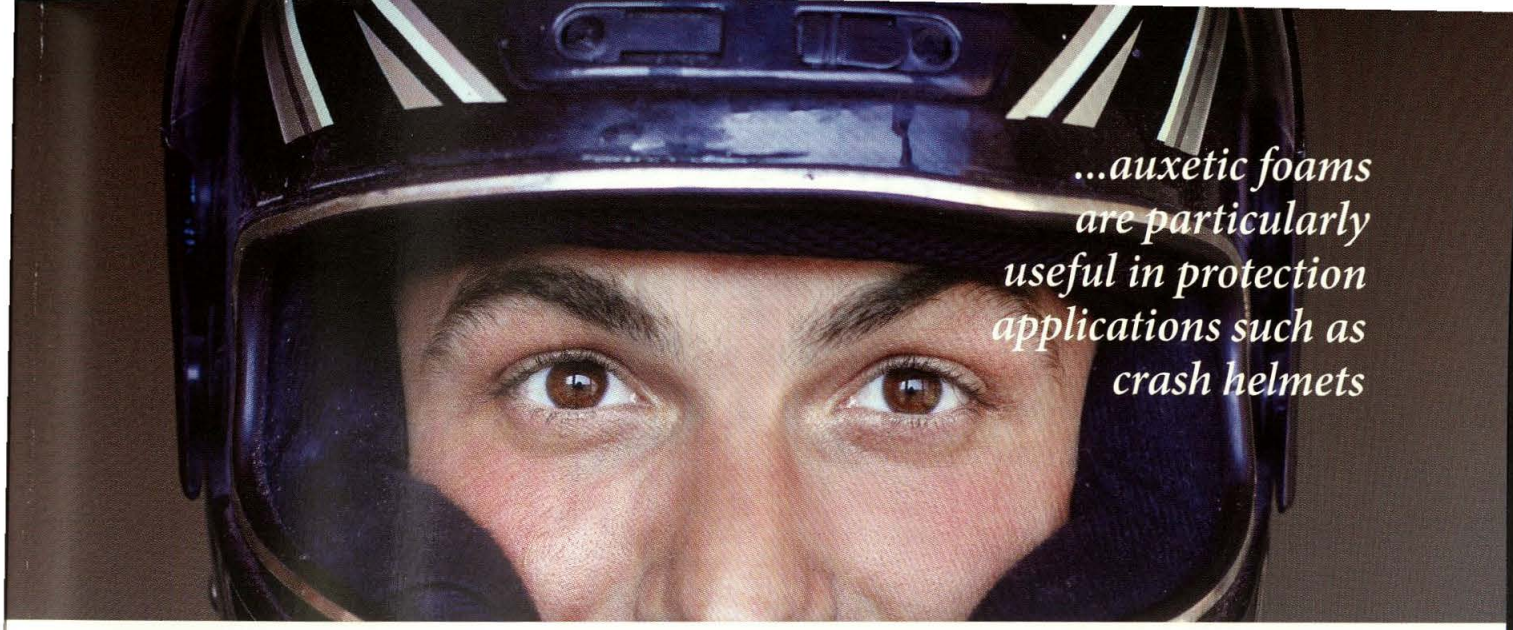
The Metamaterials Unit is not only interested in stenting devices and works on various other projects on new materials and structures that exhibit a negative Poisson's ratio (auxetic) which get fatter rather than thinner when stretched and negative thermal expansion materials which shrink rather than expand when heated. In particular, they modell and manufacture foams that have a negative Poisson's ratios. The use of polymeric foams has currently infiltrated a vast majority of items which we use on a daily basis. Foams have found a vast number of applications, due to their very particular properties. Foams are commonly used in protective applications. Owing to their specific microstructure, foams have the ability to diminish impacts and significantly reduce damage from blows which may otherwise prove fatal. Foams save lives.

University of Malta academics, in collaboration with Method Electronics Malta Ltd. are currently designing of a new way to produce auxetic foams. This work is also funded by the National R & I Programme. Auxetic foams (negative Poisson's ratio foams) were first made in the late 1980s using a process which utilises simultaneous heating and compression of conventional open-cell foam. Until recently, this has been the only technique. The Metamaterials Group has now found a new route which could be cheaper and faster. It involves the use of solvents instead of heat. The team are currently seeking further development of this process to optimise it and apply it on an industrial scale.

Auxetic foams are expected to have significant impacts on industry and lifestyle. These foams benefit from a number of superior properties when compared to conventional foam. Auxetic foams push back. They have an increased indentation resistance resulting from densification of the material under the point of impact (Fig. 2). The observed resistance is due to the foam's geometrical features, which allows the cells to fold up on themselves to densify

Figure 2
Indentation resistance in:
a) conventional and b) auxetic foams





the material beneath the indenter, returning back to the original shape as the load is removed, resulting in better resilience. The extent of densification is strain dependent, allowing for the impact of a sudden blow to be reduced gradually. Undoubtedly, these properties make them particularly useful in protection applications, including safety equipment such as knee and elbow pads, bullet proof vests, crash helmets, in seat cushioning and packagings.

Auxetic foams also behave synclastically in response to a bending force (Fig. 3), they form a doubly curved surface (dome shape) as opposed to conventional materials which adopt a saddle shape conformation (anticlastic behaviour). This gives them the ability to wrap around and adopting to body curvatures in a much more versatile way than conventional foams can. This makes them ideal in ergonomic cushions, seats and mattresses.

Auxetic foams can also be used in smart, adjustable filters, whose pore size can be controlled by applying a strain (Fig. 4). Such filters allow for the separation of different sized particles in mixtures without the need to dismantle the filter and change its pores size. They are also more convenient to clean by stretching them to open up the pores, allowing any residues to pass through more easily. Therefore filtration systems which use these types of foams are expected to considerably reduce the downtime of machinery and hence increase the efficiency of filtration processes.

Auxetic materials are finding use in a vast range of applications. The next few years will see many of these items coming to market, which will advance medical devices, research equipment and everyday household goods. Auxetics are becoming the next big leap in material science. ●

Figure 3
Response of: a) positive
b) negative and c) zero Poisson's ratio materials to bending forces

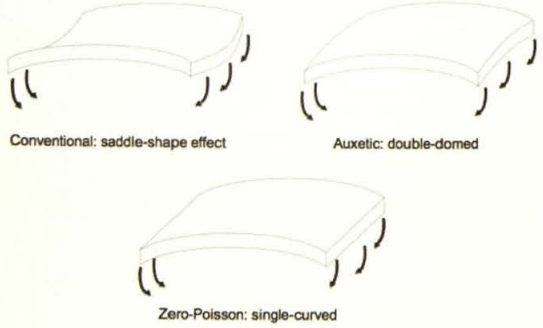
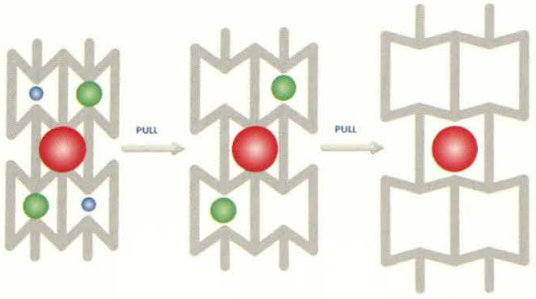
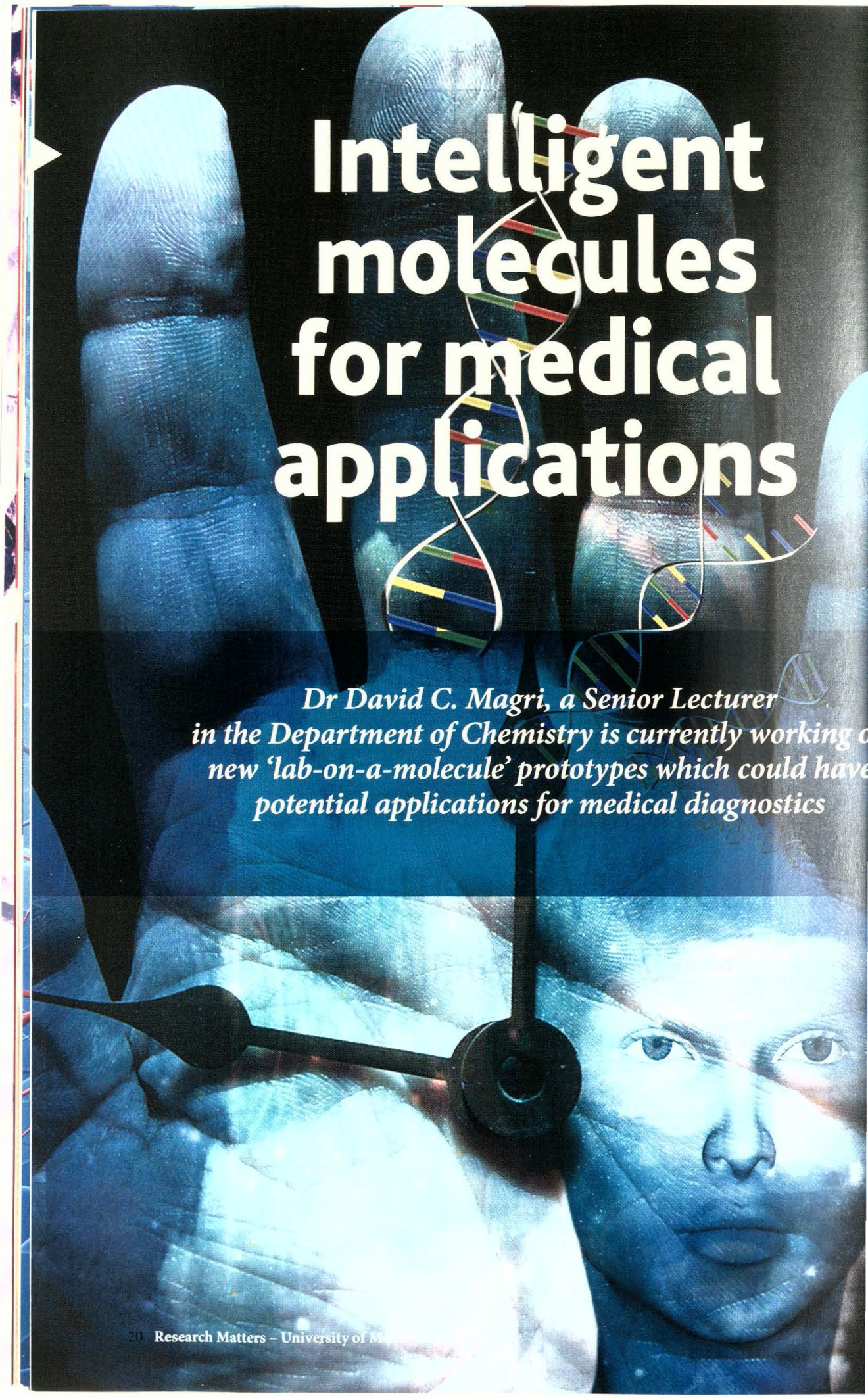


Figure 4
Smart filter made from an auxetic honeycomb which is very similar to the microstructure in auxetic foams. The pores of the honeycomb get larger as it is stretched allowing larger particles to pass through



Intelligent molecules for medical applications



Dr David C. Magri, a Senior Lecturer in the Department of Chemistry is currently working o new 'lab-on-a-molecule' prototypes which could have potential applications for medical diagnostics

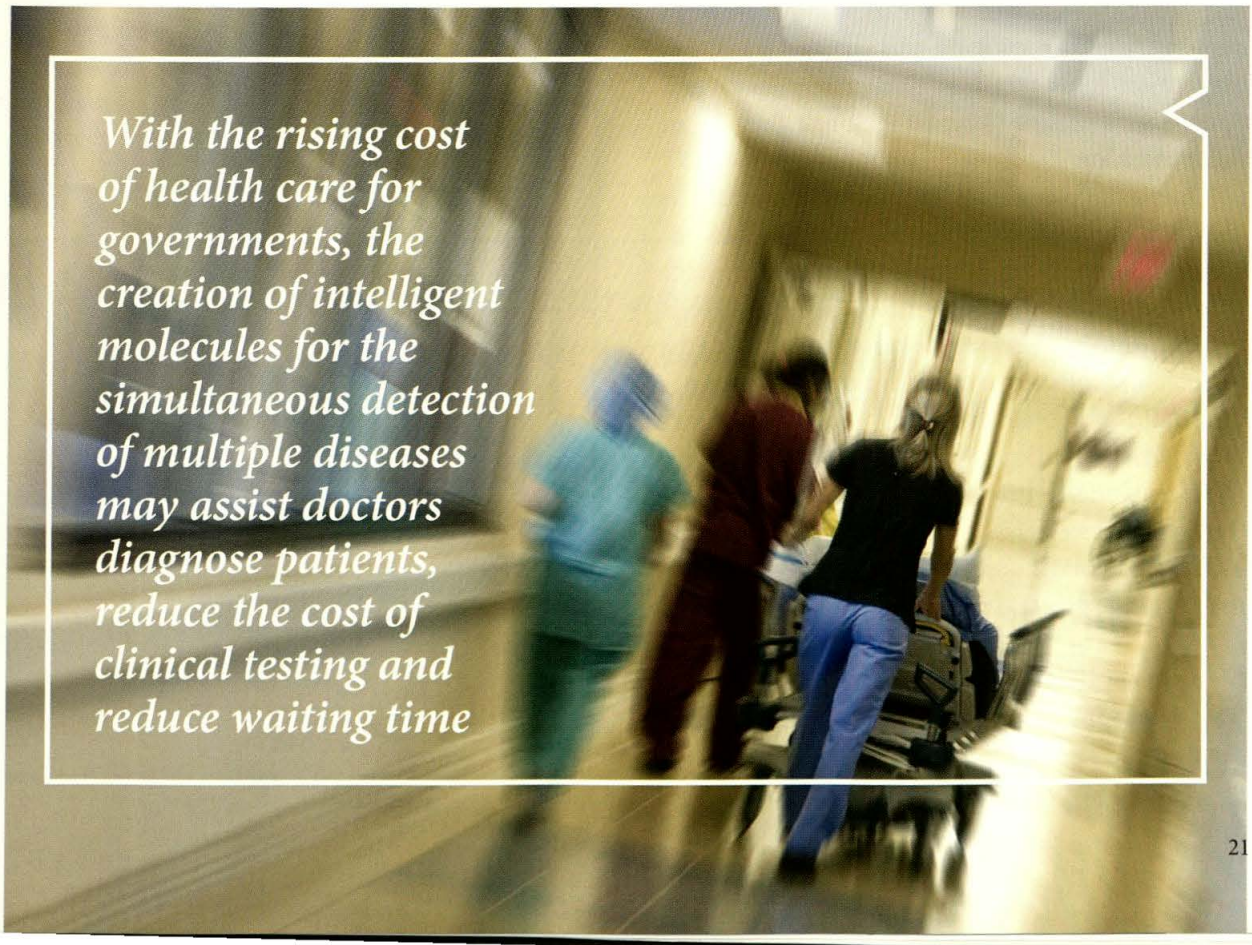
Engineering is normally a discipline associated with building large structures such as towers, bridges and cars. Chemistry is also a discipline associated with building structures, but really tiny ones, at dimensions even smaller than the realm of nanotechnology. Hence, the chemist who builds molecules can be considered a molecular engineer.

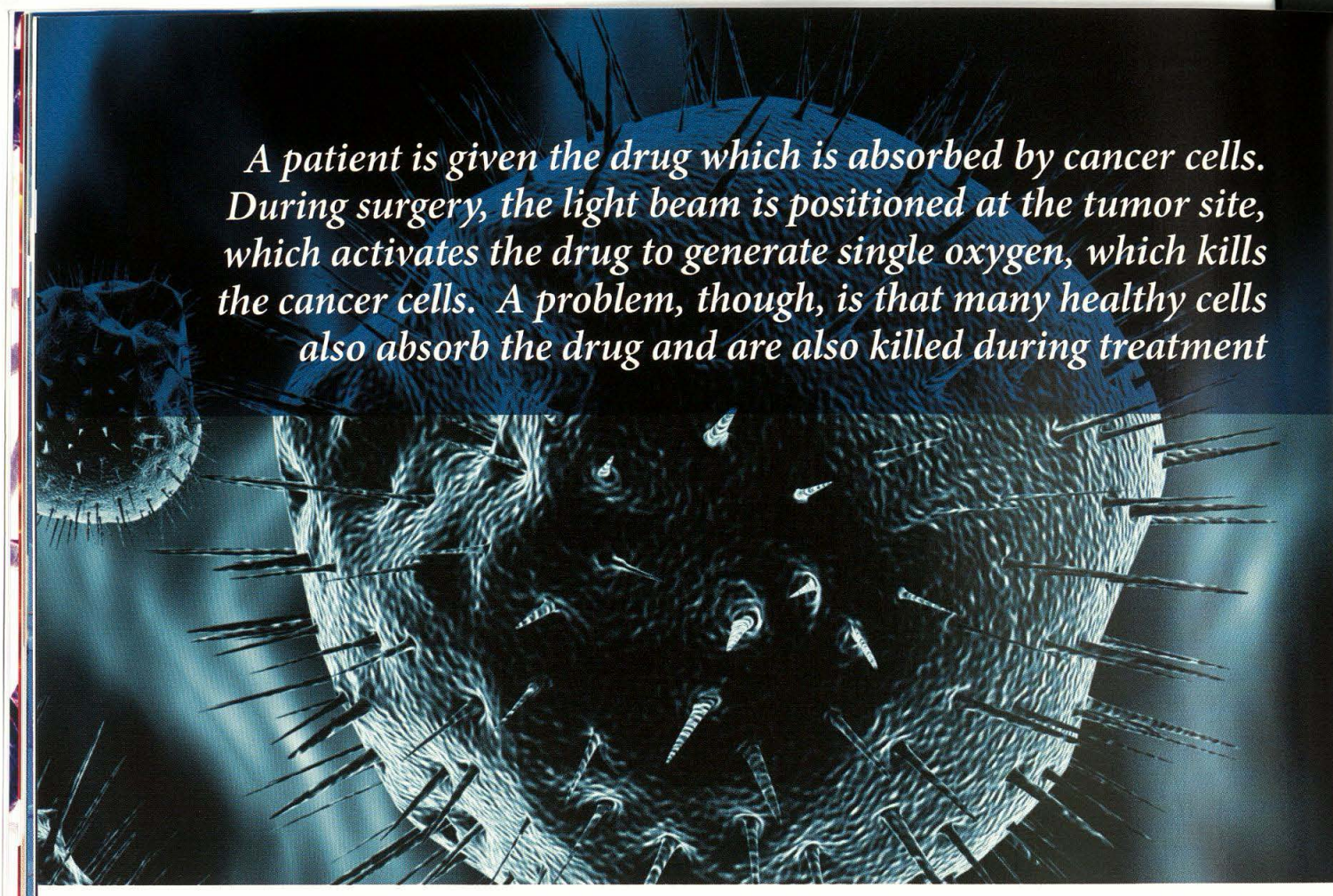
Organic chemistry is the central discipline of making molecules. Molecules are designed and synthesised to have useful functions. As molecular engineers, chemists not only perform chemical transformations-reacting chemicals together to make other chemicals-they spend considerable time planning, designing, studying and testing them too.

An exciting area of frontier research combines ideas from mathematics and computer science with chemistry to engineer intelligent molecules capable of performing calculations and information processing for medical applications. This involves making molecules with built-in logic operations according to Boolean algebraic functions (e.g. YES, NOT, OR, AND etc.). Just as individuals use these commands searching the internet for information, molecules can be designed to retrieve chemical information from a solution in a test tube.

A logic gate is an elementary unit normally associated with digital electronic circuits. Computers based on electric circuits count using binary, the universally adopted number system of 0s and 1s. A YES logic gate has two input states, 0 or 1, and two output states, 0 or 1, just like a working light bulb. When the switch is 'off' (input 0), the light bulb is 'off' (output 0). But when the switch is turned 'on' (input 1), the light bulb turns 'on' (input 1). NOT logic is the opposite of YES logic: an input of 0 returns an output of 1, while an input of 1 returns an output of 0.

AND and OR are examples of two-input logic gates, which have four possible output states. The four possible inputs states for both gates are 0,0; 0,1; 1,0; 1,1. OR logic is not selective as just one input is required to get an output-only the inputs 0,0 result in a 0 output. The other situation 0,1 and 1,0 and 1,1 all result in a 1 output. Choosing between which of two shirts to wear in the morning is a practical example of OR logic. As long as you go to work wearing at least one shirt (although you could wear two shirts, one on top of the other) OR logic is satisfied. AND logic is selective with an output of 1 only when two inputs conditions are satisfied with an input of 1. Love is a classic example of AND logic – it takes two to tango.





A patient is given the drug which is absorbed by cancer cells. During surgery, the light beam is positioned at the tumor site, which activates the drug to generate single oxygen, which kills the cancer cells. A problem, though, is that many healthy cells also absorb the drug and are also killed during treatment

Molecules able to perform these logic functions, and many others, have been reported in the scientific literature. Even more fascinating, though, is that even more complex molecules integrating many of these elementary logic functions have been demonstrated that can add and subtract numbers, play tit-tat-toe against a human opponent and operate as a security keypad lock like that on an ATM machine.

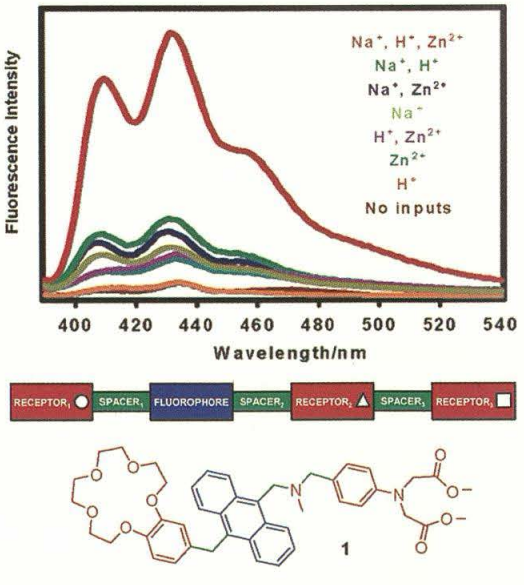
One example of an intelligent molecule is shown in Figure 1. This is an example of a 'lab-on-a-molecule', a tiny molecular device that is capable of detecting sets of at least three chemical species simultaneously. Upon irradiation with light, the intelligent molecule communicates the presence of sodium (Na^+), protons (H^+) and zinc (Zn^{2+}) ions in water by signaling a fluorescence signal. In the absence of one, or two or all three chemical species, the fluorescence light signal is low. However, when all three chemical species are present in solution the molecule gives off a bright light.

Medical applications

The development of a molecule specifically for renal dysfunction (kidney failure) is a realistic

Figure 1

Fluorescence spectra in water or the eight experimental conditions. Only when all three analytes (sodium, zinc and protons) are present at high levels is a high fluorescence light signal observed (spectrum in red).

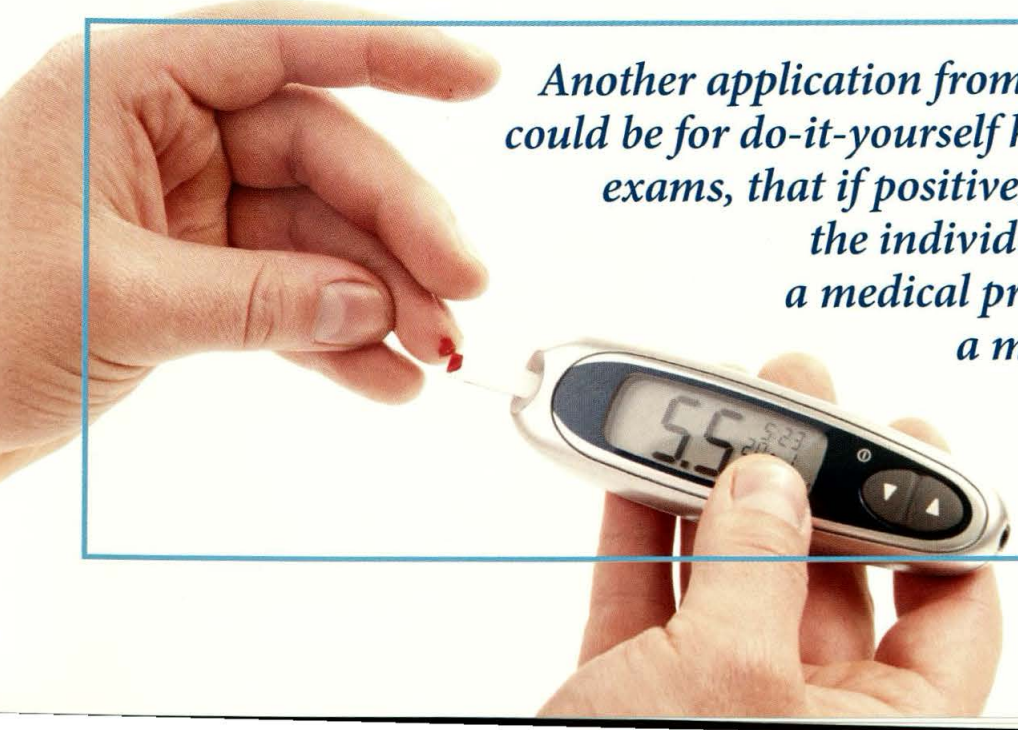


goal for medical diagnostics use as the condition is indicated by high levels of potassium, sodium and urea in the blood. Another application from this research could be for do-it-yourself home medical examinations, somewhat like a pregnancy test, that if positive would allow the individual to consult a medical professional for a more thorough examination.

Another illustration of the potential application of this type of research is in the use of photodynamic therapy (PDT). PDT is a promising treatment for cancer. The treatment requires a light source, a photo-sensitive drug and oxygen. A patient is given the drug which is absorbed by cancer cells. During surgery, the light beam is positioned at the tumor site, which activates the drug to generate single oxygen, which kills the cancer cells. A problem, though, is that many healthy cells also absorb the drug and are also killed during treatment. A research group at Bilkent University in Turkey has figured out a way around this problem using an intelligent molecule. The insides of some cancer cells are known to have higher levels of H^+ and Na^+ ion levels than those of normal cells. The Bilkent group demonstrated a photo-sensitive drug prototype that only worked after detecting high levels of both H^+ and Na^+ ions, according to an AND logic algorithm, so only cancer cells would be killed and not healthy cells. This concept is clearly an improvement over contemporary cancer treatments and could substantial improve the recovery time of patients after PDT treatment.

Carl James Mallia, a graduate student under the supervision of Dr David C. Magri at the University of Malta, is currently working on new 'lab-on-a-molecule' prototypes. Using many standard analytical techniques from nuclear magnetic resonance (NMR) and infra-red (IR) spectroscopy and mass spectrometry (MS), synthesized molecules are accurately characterized to confirm their identity and purity. Then the logic capabilities of the molecules are tested using ultraviolet-visible absorbance and fluorescence spectroscopy.

Molecules with built-in logic functions could have great potential applications for information processing and intelligent medical diagnostics. The use of one test, rather than many separate tests, to detect the presence of many analytes for a disease condition could, therefore, potentially improve the efficiency of v screening and treatment for various medical conditions. In the future, 'lab-on-a-molecule' technology could assist doctors, by not only measuring the analyte amounts, but also by making an intelligent decision on behalf (or in consultation) with the doctor. With the continual rising cost of health care for governments, the creation of intelligent molecules for the simultaneous detection of many analytes corresponding to specific diseases may assist doctors diagnose patients, reduce the cost of clinical testing, reduce waiting time for results and even speed up recovery time for patients. ●



Another application from this research could be for do-it-yourself home medical exams, that if positive, would allow the individual to consult a medical professional for a more thorough examination

STUDYING EARTHQUAKES AND THEIR EFFECTS

The Seismic Monitoring and Research Unit

On Easter Sunday, 24 April 2011, at 3pm, the people of Malta were jolted out of their rest by a magnitude 4 earthquake only 40km east of Malta. This earthquake was the strongest in a sequence of more than 15 shocks that had started the night before and went on until the 27th April, all located within the same epicentral region. No apparent damage was registered and life went back to normal shortly afterwards

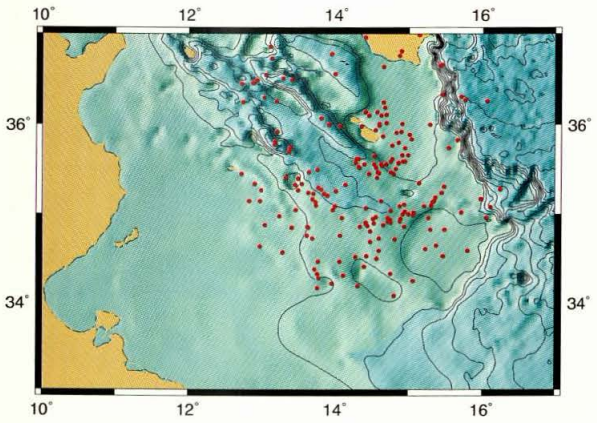
Not so for Dr Pauline Galea, Director of the Seismic Monitoring and Research Unit of the University of Malta, who has made it her mission to record and study earthquakes and other seismic activity, and this period was quite dramatic. Only a few days earlier the world had just learned about the devastation caused by a mega-earthquake and tsunami in Japan, and the Mediterranean area had been recently unstable. A 6.1 magnitude underwater quake had rocked the Mediterranean island of Crete on the 1st of April which was felt also in some parts of Malta. The series of shocks between the 23rd and 27th April had put Malta on edge.

The Mediterranean is one of the world's most seismically active regions, being caught between the slowly northward moving African continent and the Eurasian continent. The interaction of these two large plates has created a wide zone of deformation characterized by a variety of geological processes as well as "hotspots" of elevated seismic activity. Large earthquakes have in the past devastated cities and left thousands of victims. The Maltese islands lie right in the middle of this active region, around 200km south of the Africa-Eurasia boundary segment that passes through Sicily. To monitor activity the Seismic Monitoring and Research Unit was set up in the Physics Department of the University of Malta.

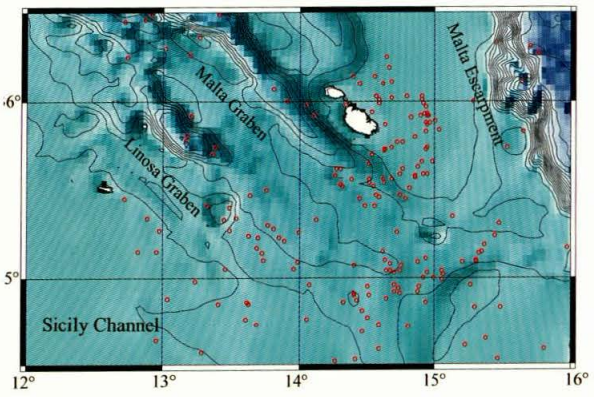
The unit participates in a global network of seismologists. The unit's permanent broadband digital seismograph at Wied Dalam (B'Bugia) is networked in real-time to the Virtual European Broadband Seismic Network (VEBSN). This consists of over 500 such stations in Europe, which in a matter of minutes can collect and process data in order to locate and analyse an earthquake that occurs anywhere in Europe.

This is an important component of a Mediterranean Tsunami Warning System, similar to the well-established one in the Pacific Region.

Closer to home, another of the unit's interests is the study of the tectonic and geodynamic processes occurring in the Central Mediterranean. In particular the stresses set up by the foreland of the African continent as it grinds its way below and against the Italian peninsula and Sicily. These forces have caused the crust of the Sicily-Tunisia platform to break up and stretch, forming the Sicily Channel Rift Zone. By locating earthquakes in this region as accurately as possible, the active faults which facilitate the motion of the crust, and thus generate the earthquakes, are delineated. By studying the waveforms of these earthquakes it is possible to understand the dynamics of these motions. These studies help us understand earthquakes and the damage they case.



Epicentres of earthquakes recorded and located by the SMRU over 5 years. Although hardly any of these earthquakes are felt by the Maltese public, the seismic activity shines a light on the active faulting that is going on underneath the seabed around the islands, and provides clues about the tectonic processes going on due to the interaction between the African and European plates



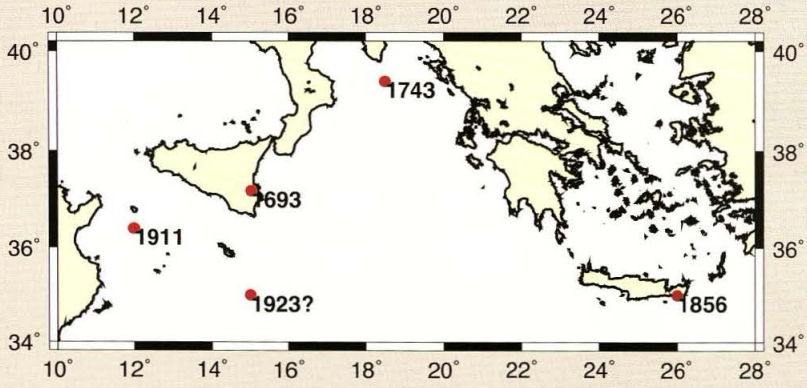
Earthquake epicenters around the Maltese islands located since 2006 by the Seismic Monitoring and Research Unit, using the seismic station WDD at Wied Dalam

Earthquakes provide us with fascinating insights into how the Earth works. The great, magnitude 9.0 Japan earthquake of 11 March 2011, for example, sent seismic wave energy travelling through the whole interior of the planet at thousands of metres per second, so that when it arrived at WDD station in Malta, it produced a seismogram whose every wiggle represented a particular wavepath sampling a different region of the Earth. Collectively these seismograms provide scientists with most of the data needed to decipher the planet's interior structure. Unfortunately, however, whenever earthquakes coincide with populated areas they have the potential to create disaster, mainly through their effects on buildings. If the ground shaking during an earthquake is strong enough, it can cause buildings to collapse, especially if the construction is not up to standard, or if the geological conditions below the building cause the ground shaking to be amplified further. It is therefore the responsibility of seismologists to work towards understanding seismic hazard and risk in urban areas. The SMRU recognizes the need to investigate these effects on the Maltese islands. Even if our islands are not characterized as having a very high seismic hazard, we know that they have suffered various degrees of earthquake damage in the past, and we need to be informed and prepared about how another event would affect today's buildings.

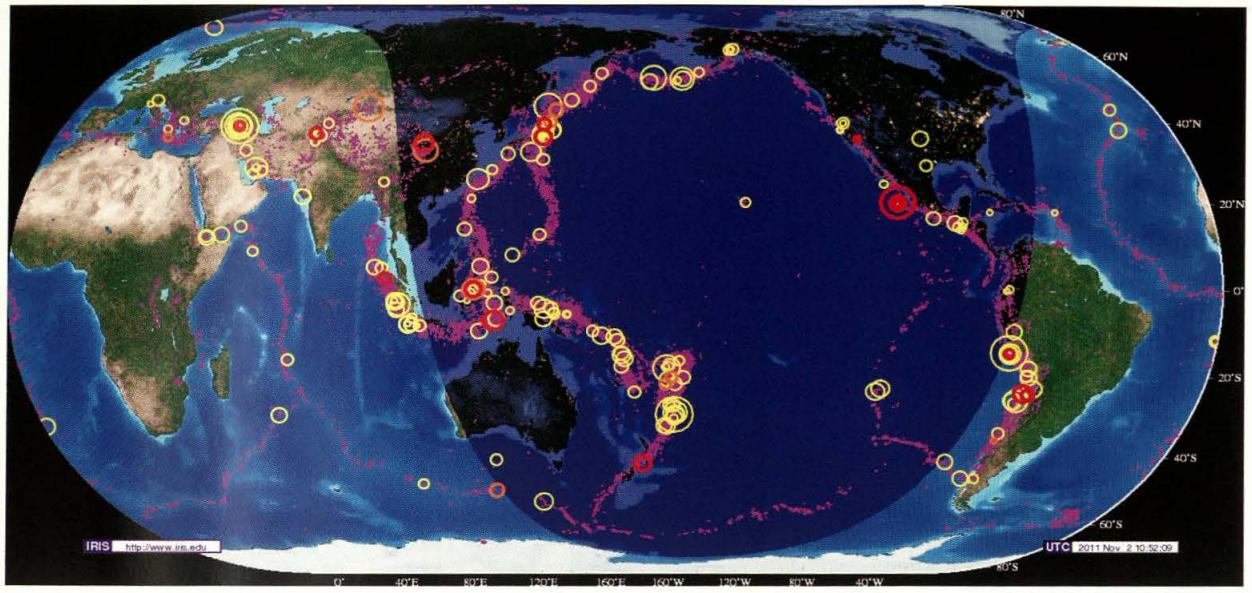
The study of seismic risk is another research interest of the seismic monitoring and research unit. The unit conducts research on the history

When Malta shook

MAJOR TREMOURS IN HISTORY

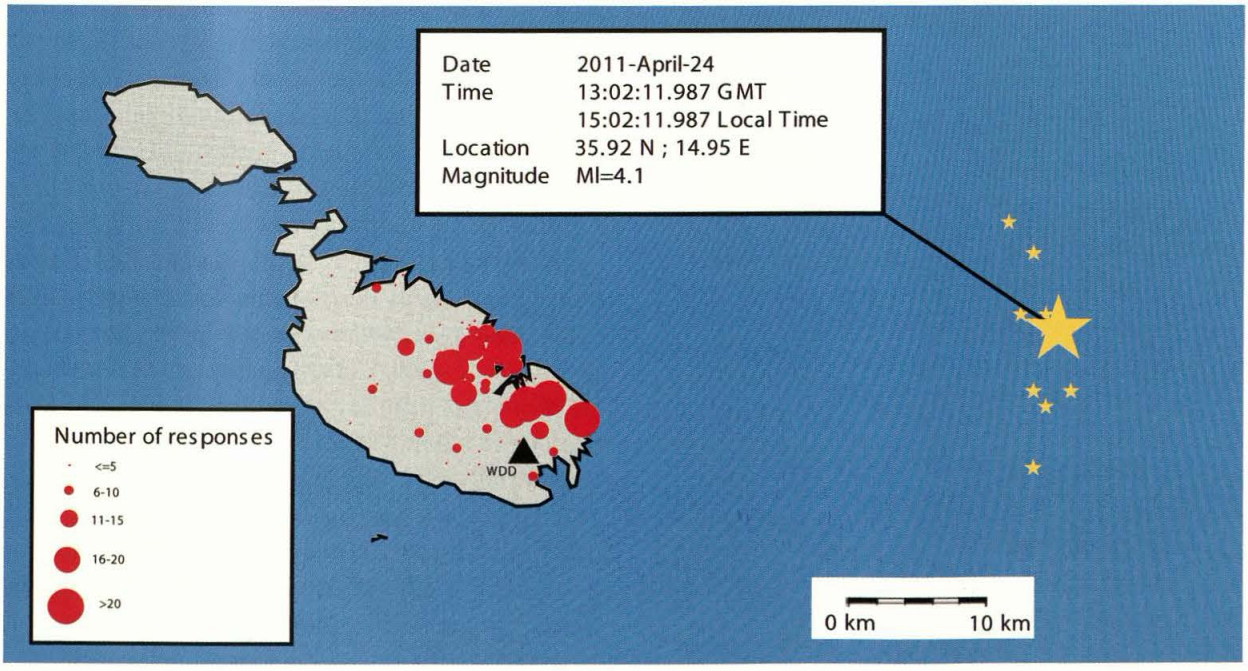


Date	Epicentre	Magnitude	Damage caused
11 Jan 1693	Eastern Sicily	7.4	Most houses in Valletta damaged, some seriously;collapse of several church domes in Malta and Gozo; serious damage to Mdina, partial collapse of cathedral
20 Feb 1743	Ionian Sea	6.9	Damage to Mdina cathedral and numerous other churches
12 Oct 1856	Crete	7.7	Many houses in Malta and Gozo seriously cracked; several church domes and walls damaged
30 Sep 1911	West of Gozo	5.5?	Mostly felt in Gozo, where it produced significant damage to domes and houses; damage to Fort chambray; much less felt in Malta
18 Sep 1923	East of Malta		Mostly felt around harbour area, Malta; non-structural damage to churches and cracks in walls.

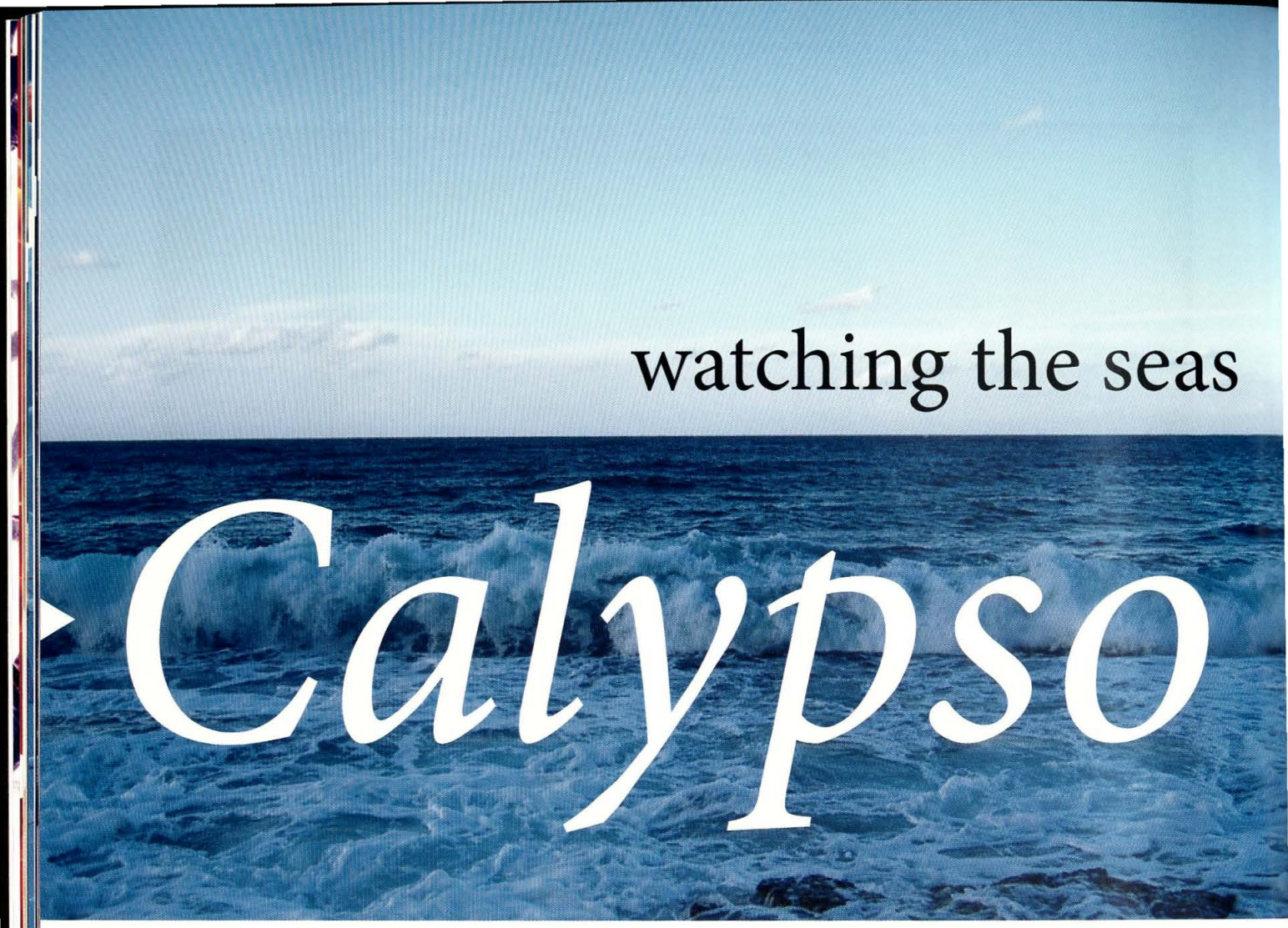


of earthquake effects on the islands and evaluates the probability of seismic hazards. It investigates how sub-surface geology affects movement on the ground surface. The incoming seismic energy is modelled to predict how it travels through the ground, based on theoretical evaluation of an earthquake. Another crucial research activity looks into the way that local buildings would respond to a given type of ground vibration.

Seismically, Malta is an intriguing place to study. It has a long history of activity and potential hazards still need to be mapped. An accurate model can only be built on good data that will yield exciting scientific answers, and probably even more questions. Seismology has an essential societal contribution to prevent building damage and loss of life. ●



Results of the online questionnaire reports following the largest event of the earthquake swarm occurring on the 23rd and 24th April 2011, widely felt on Malta.



watching the seas

Calypso

Some people are convinced that Ogygna is indeed the island of Gozo, within the Maltese archipelago, which consequently is also known as Calypso. Over Ramla bay, the most prominent sandy beach in the Maltese Islands, one finds Calypso's cave, a complex labyrinth which was reputed to extend to sea level in places.

Times have changed but perils still threaten the Mediterranean basin, although their nature is somewhat different from when Homer penned his masterpiece. The risk of oil from marine spillages beaching on shores and hitting important economic resources and causing irreversible environmental damage is a very realistic menace in the stretch of sea between Malta and Sicily. Especially in a small island state like Malta where economic assets are concentrated in space, the damage would be even more devastating. Risk is high because the island are situated along the main shipping lanes of the Mediterranean Sea.

Risks can be highly minimised by using the best tools for surveillance, operational monitoring against pollution threats, as well as a capacity to respond with informed decisions in case of emergency. CALYPSO is a research project that intends to utilise a top-end technology, consisting of an array of High Frequency (HF) radars, to monitor in real-time meteo-marine surface conditions. Like the nymph Calypso, the HF Radars will vigilate on the stretch of sea extending from Malta to the Sicilian shores.

The project is partly financed by the EU under the Operational Programme Italia-Malta 2007-2013, and co-ordinated by Prof. Aldo Drago from the Physical Oceanography Unit of the University of Malta. It brings together 3 other partners from Malta – namely Transport Malta, Civil Protection Department and Armed Forces of Malta – and 4 partners from Sicily – ARPA Sicilia, IAMC-CNR Capo Granitola, Università degli Studi di Palermo (UNIPA) and Università di Catania (CUTGANA). The consortium consists of research entities and also public entities with responsibilities for civil and environmental protection, surveillance, security and response to hazards. The project is a first of its kind

The HF radar data also targets to provide accurate information to monitor and respond effectively to threats from oil spills... Eventually this information can be used to back-track the origin of spills and provide evidence to identify the source of the pollution

in the Mediterranean basin, although the technology has already been put into use in similar exercises carried out in Trieste, Italy and in the Bay of Biscay, in the Basque region of Spain. It was put into use in the 2010 Deepwater Horizon oil spill in the Gulf of Mexico.

The project will set up a permanent and fully operational HF radar observing system, capable of recording (in real-time with hourly updates) surface currents in the Malta Channel. The system consists of HF radar installations on the northern Malta and southern Sicilian shores. The Radars are expected to be installed early in 2012 and the whole system will be operational by mid-2012.

Collected data, combined to numerical models, are intended to primarily support applications to optimise intervention in case of oil spill response as well as endow tools for search and rescue, security, safer navigation, improved metro-marine forecasts, monitoring of sea conditions in critical areas such as proximity to ports, and better management of the marine space between Malta and Sicily.

Partners will share experiences and build on existing practices as well as undertake new joint initiatives targeting key problem issues that put at risk the coastal and marine resources especially from oil pollution. The project further envisages the participation of public authorities to enable the full exploitation of the system, improve exchange of information and prepare a common base for joint interventions in the case of accidents and emergencies. The project shall also serve for capacity

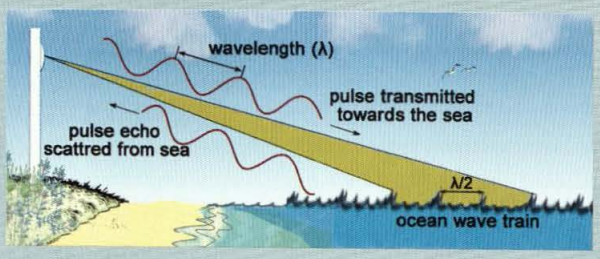
In Greek mythology, Calypso was the daughter of the titan Atlas (also known as Oceanus) and was a nymph living on the magical island of Ogygna. As referred to by Homer in 'The Odyssey', she seduced and imprisoned Odysseus on his journey home from the Trojan war and promised him immortality if he would sojourn permanently with her in the cave. However, after seven years he escaped to return to his beloved wife Penelope.

building in the monitoring of the coastal seas and adjoining resources. The routine acquisition of multi-disciplinary, spatially widespread, long-term data sets of the ocean and coastal seas is expected to trigger an unprecedented leap in the economic value of ocean data and information, and will additionally target multiple applications and users.

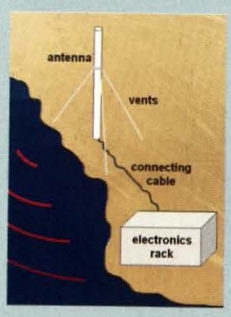
With the support of numerical modelling applications that will be also developed in the project, the HF radar data will provide accurate information to monitor and respond effectively to threats from oil spills. In combination with the Vehicle Tracking System (VTS) this information can be used to back-track the origin of spills and provide evidence to identify the source of the pollution, vital in identifying pollutors. Moreover the HF radar provides an avenue for a wider range of applications including search and rescue, and safer navigation.

The main project targets are to set up a High Frequency radar system with parallel installations in Malta and on the Sicilian coast providing real-time maps and information on sea surface currents in the strip of sea dividing Malta and Sicily. The project will then apply the system for the joint intervention of Malta and Sicily against major oil spill incidents in this high risk and heavily trafficked trans-boundary maritime area.

The project will also establish contacts between Maltese and Sicilian authorities for marine

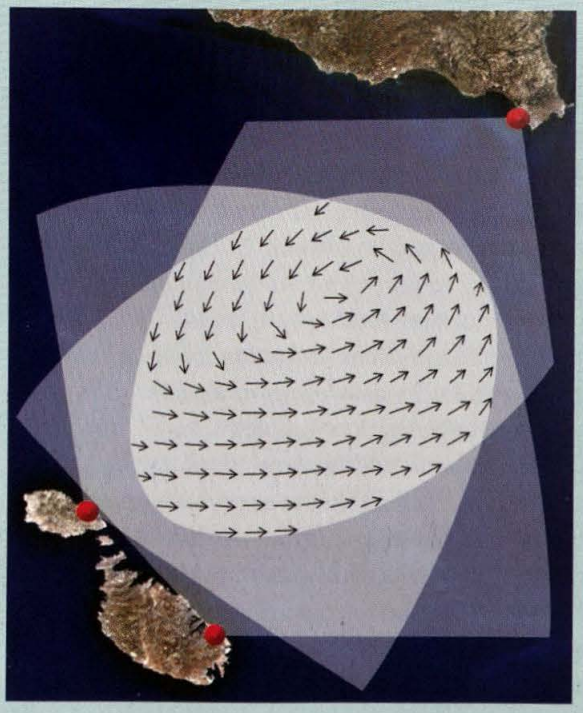


Artist Impression of Radar Installation at Sopu Area, Ta' Qortin, Gozo



Key characteristics for site selection are:

- proximity to the sea
- geographical position
- availability of power supply
- communications to enable the use of internet data flow
- good shelter for the electronics



surveillance and security (especially in connection with marine hazards) and draft common plans for joint and coordinated operations and intervention in case of emergencies especially those arising from oil spillage;

Monitoring the sea between Malta and Sicily with this advanced technology is essential because of the heavy sea traffic. Those ships carry billions of euros worth of goods and thousands of people while providing a crucial link between North Africa and Europe. CALYPSO will save money, lives and provide security, a feat that even Homer might have had difficulty to foretell.

THE PHYSICAL OCEANOGRAPHY UNIT

The Physical Oceanography Unit (PO-Unit) constitutes the research arm of the International Ocean Institute – Malta Operational Centre (IOI-MOC) at the University of Malta. The Unit undertakes oceanographic research, including operational observations and forecasts, specialised data management analysis and participation in international cooperative ventures. The overarching research themes of the PO-Unit cover coastal meteorology, hydrography and physical oceanography with a main emphasis on the experimental study of the hydrodynamics of the sea in the vicinity of the Maltese Islands. The Unit has mainly endeavoured to promote activities in operational oceanography by the installation and maintenance of permanent sea monitoring systems, and the provision of meteo/marine forecasts. Observations include atmospheric parameters, sea level, currents and waves in both delayed and operational mode; forecasts for the same parameters are issued daily for the Central Mediterranean area and in the vicinity of the Maltese Islands on the services website www.capemalta.net. The PO-Unit also acts as a national oceanographic data centre and promotes the IOC/IODE (Committee on International Oceanographic Data and Information Exchange) products and activities in Malta. A main achievement in this field is the online national oceanographic database forming part of the Malta Blue Pages.

Permanent sea monitoring systems will be in place to provide meteo/marine forecasts, including atmospheric parameters, sea level, currents and waves

Understanding fish habitats

Each year around May or June, a small group of Maltese researchers from the Marine Ecology Research Group (MERG), coordinated by Professor Patrick Schembri from the department of Biology, embark on a 10-day research trip on board the Italian research trawler RV 'Sant Anna'

On the vessel the Maltese team joins a group of Italian researchers involved in an on-going study of the seafloor habitats and the overall health of sea deep water fish stock. They are analysing fish population distribution and structure in the Mediterranean. The Maltese researchers are however looking for something more than numbers and trends. Making use of the samples collected during the trawl survey, the MERG scientists study the features that attract fish to habitats and monitor the damage caused by fishing.

In recent years there has been an increasing interest in ecosystem-based fisheries management, since fish stocks should not be considered in isolation but as part of an ecosystem. Such a management strategy requires a good knowledge of the components of the ecosystem and how they interact together. Thus knowledge of the seafloor habitats, known as benthic habitats, and the seafloor assemblages that they support, such as seaweed beds, is essential. These habitats provide feeding and breeding grounds for fish, while the living organisms of that region play an important role in the transfer of biomass from the water column to the seabed and back again. Disruption of the ecosystem disrupts fish stocks.

The BENSPEFISH project aims to address the lack of knowledge that exists on essential fish habitats (in terms of foraging areas, nursery grounds, and spawning sites) for most commercially important fish and other species within the Maltese Fisheries Management Zone.

The main objectives of the BENSPEFISH project are to:

- Locate essential fish habitats and to identify common benthic features that may attract fish and other exploited species to these habitats;
- Characterise in terms of benthic assemblages and physical characteristics of the seabed such benthic habitats including foraging areas, nursery grounds, and spawning areas important for fish and other exploited species;
- Study the physical and biological response of the benthic ecosystem to different regimens of fishing disturbance within existing fishing grounds;

Investigate the use of benthic secondary production on deep water fishing grounds by selected species of fish and other species, both those of direct commercial importance and those that form part of the food chain of exploited species.

BENSPEFISH is a collaborative and ongoing research project between the Marine Ecology Research Group (MERG) at the Department of Biology of the University of Malta, and the Agriculture and Fisheries Regulation Department (previously known as the Malta Centre for Fisheries Studies) within the Ministry for Resources and Rural Affairs. BENSPEFISH forms part of a wider study on the benthic habitats and the assemblages of living organisms within them. The project, operating within the ambit of the three European programmes namely MEDITS, GRUND and MedSudMed, studies actual and potential fishing grounds in the Malta Fisheries Management Zone.

Knowledge of the sea-bed fisheries resources is still poor, although data are now being accumulated through Maltese participation in trawl surveys

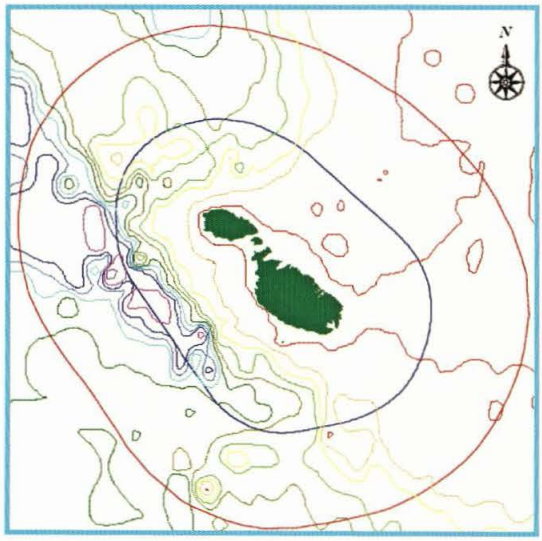
The project is a long-term study involving benthic sampling for faunal and sediment analysis using remote operated sampling gear, as well as analysis of the benthic invertebrates collected from the sea floor during the ongoing trawl survey programmes.

Trawl samples are collected using the standard MEDITS and GRUND gear which consists of a trawl net of width 20m and height 1m. Normally, each trawl haul lasts about 45 minutes, depending on the depth and substratum type, and trawl speed is around 3 knots. The entire faunal component from each haul is sorted into commercial and non-target species, after which fauna of interest are identified, counted, measured and weighted on deck, or are preserved for future study.

The use of benthic secondary production on deep water fishing grounds by selected species of bottom dwelling fish is studied through dietary analysis of stomach contents. This technique helps determine the feeding habits of the selected species, the differences in feeding habits related to size, weight, sex, and maturity stage of the fish, and the differences in feeding habits related to changes in depth and bottom type. Through such studies the effects of fishing intensity on feeding habits of the selected species can be determined.

Current work being carried out as part of the BENSPEFISH project includes the identification and characterisation of the seafloor species within the Maltese Fisheries Management Zone. The project is also studying living organisms of hard inclusions from deep water habitats within the zone, as well as research on the distribution, population dynamics and ecology of select deep water species.

Previous to 2004, Malta operated an Exclusive Fishing Zone that extended to 25 nautical miles from



[Adapted from : Camilleri et al. (2008) MedSudMed Technical Documents 13]

Bathymetry of the Maltese Fisheries Management Zone

Bathymetric depths in metres
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100

12 nautical mile boundary

25 nautical mile boundary

The measures adopted for the management of resources within the Fisheries Management Zone (FMZ) are designed to limit fishing effort and capacity by restricting size and engine power of fishing vessels. In particular, only vessels smaller than 12 m are allowed to fish within the zone since these are considered as boats which practise small scale coastal fishing and which are therefore least harmful to the ecological regime within the zone.

Publications from BENSPEFISH

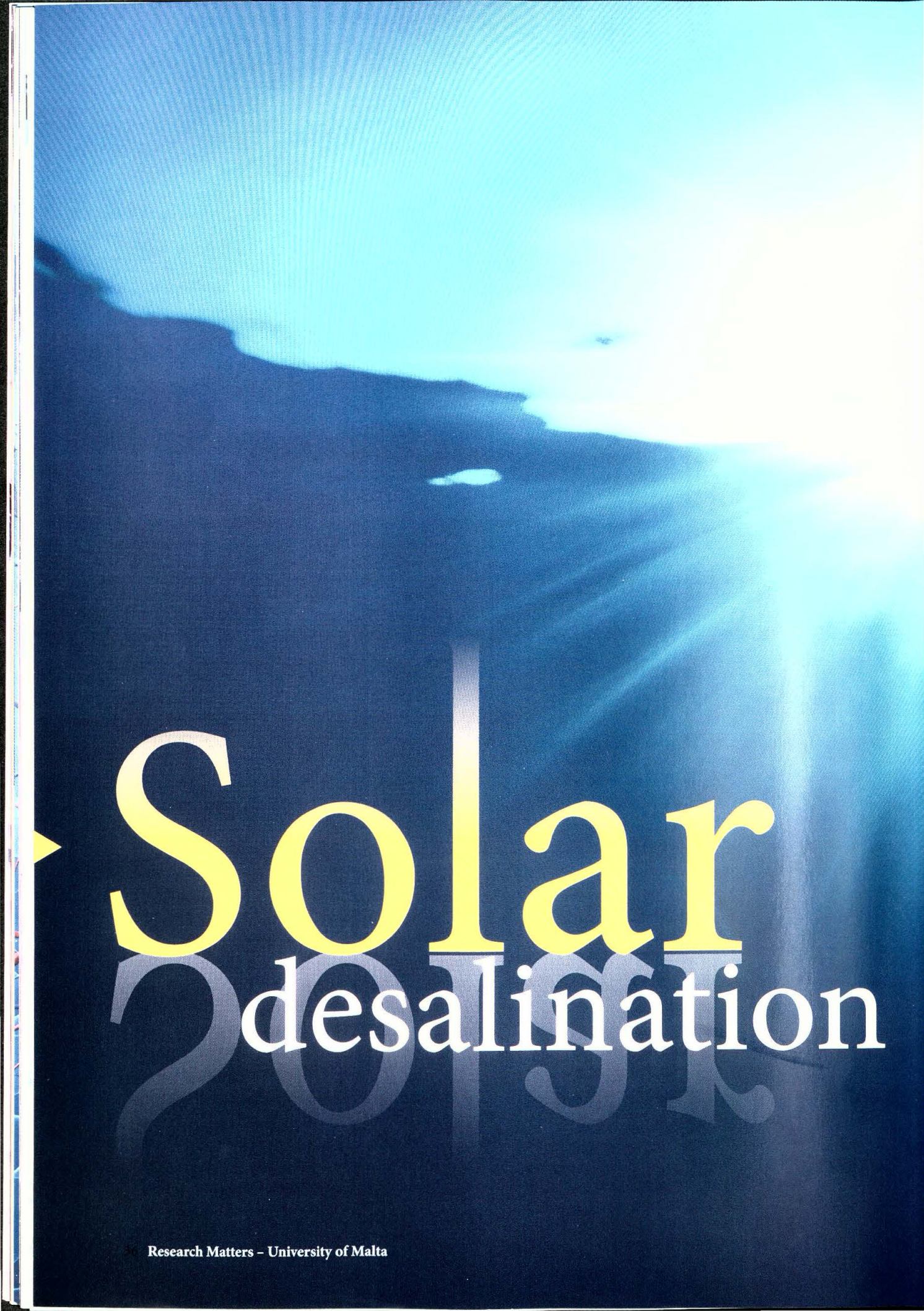
- Feeding habits of the small-spotted catshark Scyliorhinus canicula (L., 1758) in the Central Mediterranean.
- Deep-water Corallium rubrum (L., 1758) from the Mediterranean Sea: preliminary genetic characterisation.
- Fishers' perception of a 35-year old Exclusive Fisheries Zone.
- Differences in demersal community structure and body-size spectra within and outside the Maltese Fishery Management Zone (FMZ).
- Role of environmental variables in structuring demersal assemblages on trawled bottoms on the Maltese continental shelf.
- Demersal assemblages on deep water trawling grounds off the Maltese islands: Management implications.
- Litter as a source of habitat islands on deep water muddy bottoms.
- Deep-water corals in Maltese waters.

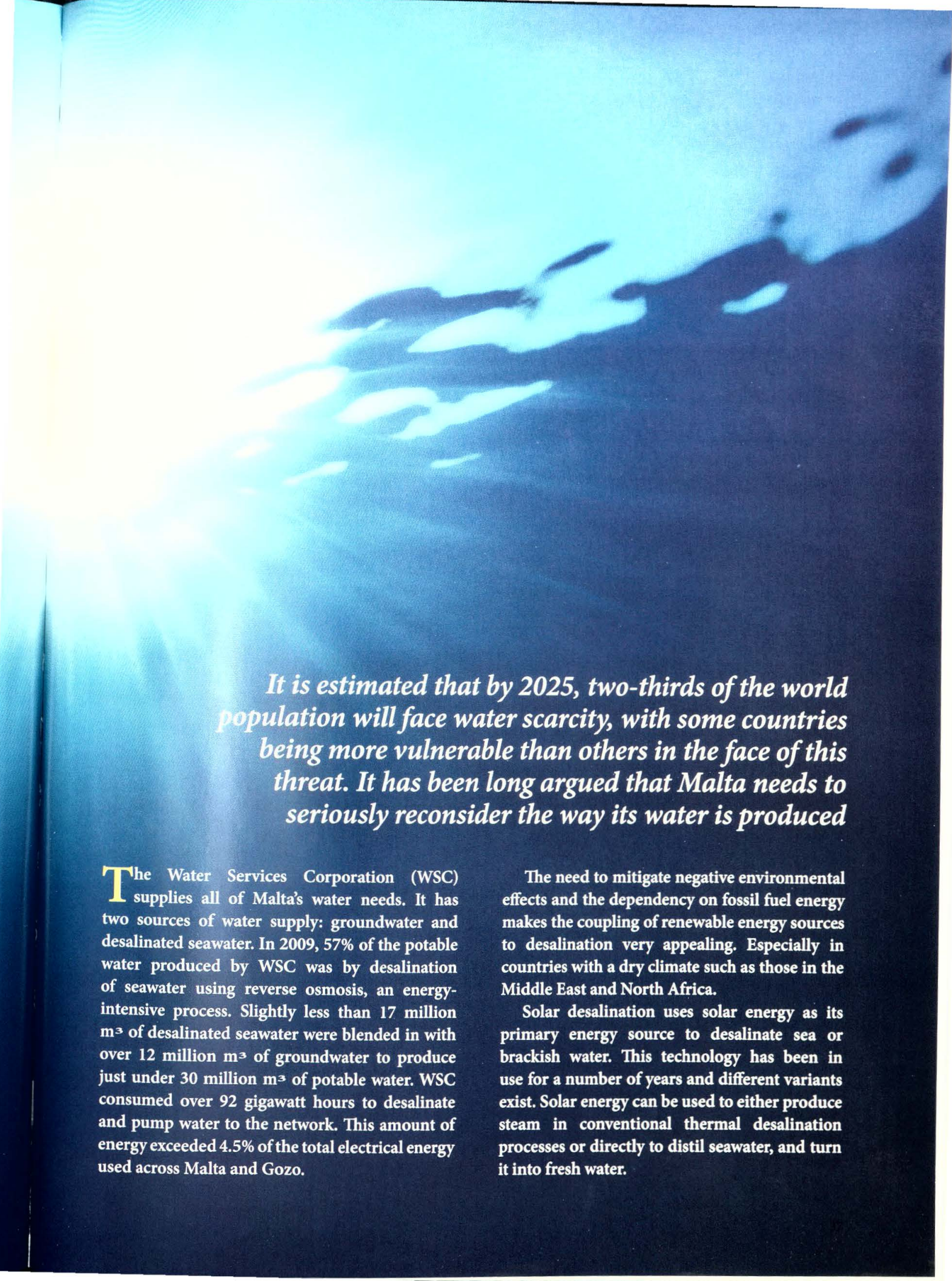
The project involves a long-term study involving benthic sampling for faunal and sediment analysis using remote operated sampling gear, as well as analysis of the benthic invertebrates collected during the ongoing trawl survey programmes

the baselines of the Maltese Islands. With the entry of Malta into the European Union, this zone was maintained as a Fisheries Management Zone. Due to the management regime operated by Malta within the previous EFZ since the early 1970s, seafloor and close-to seafloor resources have suffered little fishing pressure, and the new management regime now operating in the Malta FMZ is designed to continue to conserve the fisheries resources within the area. However, knowledge of the demersal fisheries resources within this area is still poor, although data are now being accumulated through Maltese participation in trawl surveys (MEDITS and GRUND, since 2000) and in the FAO programme MedSudMed. Through the latter programme, information on benthic assemblages within this area has been collected since 2003.

The key aim of the Malta FMZ is to protect the fisheries resources of Malta's sea area and the ecosystems on which they depend. During the accession negotiations, Malta presented to the EU a number of studies showing the negative effects that purse-seining and industrial long-lining (two very intensive fishing methods), as practised by EU fishers, would have in the Maltese EFZ area if this was opened up to these fishery types. The EU recognized the conflict that exists between these fishing methods and the less intensive passive fishing operations practised to that date by the Maltese fishing fleet, and a Fishersies Management Zone was set up.

The ecosystem within Malta's waters needs to be understood to better manage the area. Otherwise, the decline or loss of a species might go unnoticed. Malta's fishing resource needs to be retained for our artisan fishing economy to survive, for our beautiful villages to retain their character and for our children.


Solar
desalination



It is estimated that by 2025, two-thirds of the world population will face water scarcity, with some countries being more vulnerable than others in the face of this threat. It has been long argued that Malta needs to seriously reconsider the way its water is produced

The Water Services Corporation (WSC) supplies all of Malta's water needs. It has two sources of water supply: groundwater and desalinated seawater. In 2009, 57% of the potable water produced by WSC was by desalination of seawater using reverse osmosis, an energy-intensive process. Slightly less than 17 million m^3 of desalinated seawater were blended in with over 12 million m^3 of groundwater to produce just under 30 million m^3 of potable water. WSC consumed over 92 gigawatt hours to desalinate and pump water to the network. This amount of energy exceeded 4.5% of the total electrical energy used across Malta and Gozo.

The need to mitigate negative environmental effects and the dependency on fossil fuel energy makes the coupling of renewable energy sources to desalination very appealing. Especially in countries with a dry climate such as those in the Middle East and North Africa.

Solar desalination uses solar energy as its primary energy source to desalinate sea or brackish water. This technology has been in use for a number of years and different variants exist. Solar energy can be used to either produce steam in conventional thermal desalination processes or directly to distil seawater, and turn it into fresh water.

The University of Malta has been conducting research in the desalination of sea and brackish water by solar energy since 2004. In the summer of 2005, a German research institution, CUTEC donated a solar desalination unit to the University. This was installed on the roof of the Water Services Corporation (WSC) at Tigne'. Maltese students undertook summer projects at Clausthal technical university. They learnt how the units functioned and more importantly the system of MCR (Measure-Control- Regulate) technology which can transmit operating data.

In 2006, the University of Malta developed a series of prototypes specifically designed to function in the Mediterranean climate. Once the potential benefits of this technology were confirmed, attempts were made to identify a local investor that was willing to enter into partnership with the University and WSC. The aim was to manufacture solar desalination units in Malta. 'Ecologic Ltd', a Maltese company showed particular interest in this initiative and formed a consortium.

Having managed to tap funds from the National R & I Programme, the consortium embarked on a solar desalination project in 2008 which is now in its third and final stage. Soon it will soon deliver the first optimised prototype ready for marketing by Ecologic Ltd. The project is coordinated by Dr. Ing. Stephen Abela from the Department of Metallurgy and Materials Engineering.

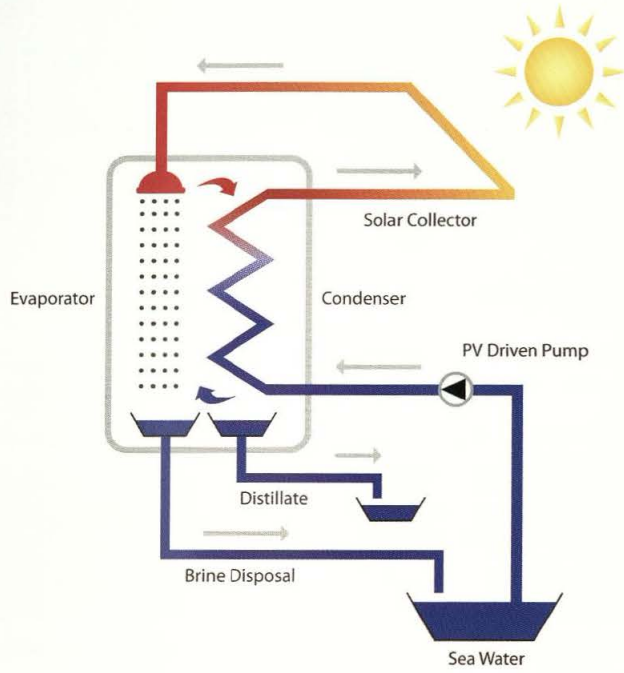
Using local materials, the project established the influence of Maltese atmospheric conditions on the desalination unit. During this process the project identified the optimal parameters for the Mediterranean climatic conditions. The design and development of these units optimises their thermodynamic efficiency and economic competitiveness, while being easily manufactured in Malta.

Competitiveness of solar desalination technology

Comparisons of costs of water produced by different technologies have to be seen in the light of the steadily increasing fuel and labour costs; the impact which some production methods have on the environment; and the importance of this recourse to man and particularly to those living in regions, like Malta where water is in very short supply and becoming increasingly more so. Furthermore production technologies such as reverse osmosis have been adapted to large scale production, whilst solar desalination plants have only been developed for small scale water production. However, in the future, technological developments, environmentally pressing issues and necessity are likely to tip the scale in different directions.

In order to compare reverse osmosis-technology with commercial solar desalination units it is necessary to consider the smallest reverse osmosis unit available on the market. This unit typically

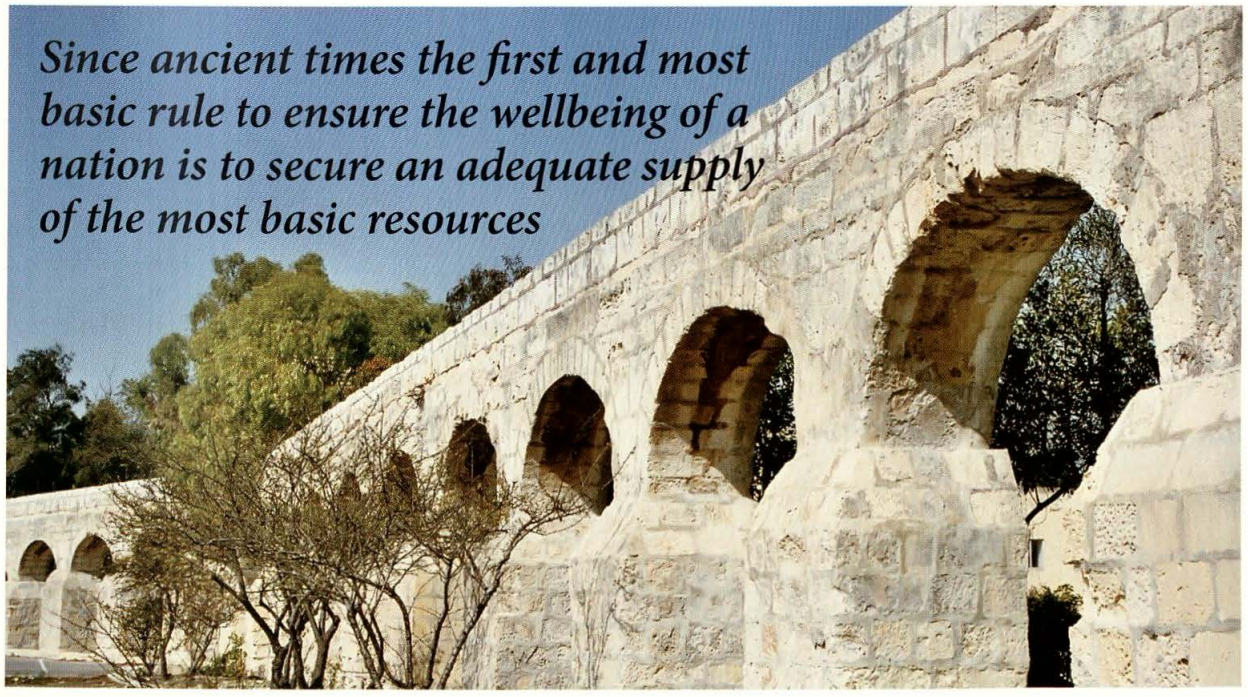
The first optimised prototype which is ready to be marketed



Using local materials, the project established the influence of atmospheric conditions typical of the Maltese islands and the Mediterranean region on the desalination unit. During this process the project has been able to identify the optimal parameters for the Mediterranean climatic conditions

produces 5000 Litres per day and is equivalent to 43 solar desalination units or over 400 humidity collectors.

Security is a world in common use in today's jargon. Water is essential to security. Since ancient times the first and most basic rule to ensure the wellbeing of a nation was to secure an adequate supply of resources. Water is a basic resource. Being a small densely populated island surrounded by salt water, Malta is extremely vulnerable to fluctuations of fossil fuel oil supply, as this will invariable lead to a shortage of drinking water. If fuel runs low, Wind and Solar are the only technologies which can ensure uninterrupted water supply to the Maltese islands. In this context reverse osmosis technology cannot even compete with alternative technologies. There will always be a need for alternative sources to ensure the secure the supply of the indispensable commodity. ●



IMPROVING RUNWAY

For the last six years the University of Malta has been conducting research into the development of an effective method and system that alerts the pilots to avoid collisions.

Runway incursions, when an aircraft erroneously enters a runway, pose a major threat to safety in civil aviation. They introduce the risk that two aircraft may collide on a runway resulting in a fatal or catastrophic accident. With over 50 million flights operating annually worldwide, it is not surprising that an average of two runway incursions occur daily in the United States.

Although most of these do not lead to a significant risk of a collision, several events have led to fatal accidents or to near misses that compromise the safety record of commercial aviation. Over the years there have been numerous initiatives to mitigate the risk of incursion, within both the United States and Europe. These range from awareness campaigns and improved signage to air traffic control alerting tools that are used in order to advise the air traffic controller of a runway incursion. Whilst these initiatives have undoubtedly provided improved levels of safety and contributed to the reduction of the numbers of incidents, up to now, they have not mitigated

the problem. In fact the United States National Transportation Safety Board (NTSB) still keeps the topic of runway incursions in its top ten most wanted safety improvements list.

Research carried out to date has indicated that runway incursions are preferably mitigated through surveillance equipment installed on board aircraft. Such systems would directly alert the crew to take positive action to ensure that an accident is avoided. It is conceptually favourable to advise pilots that a runway is about to be entered erroneously before they do so, thus essentially avoid causing a runway incursion. However, it is well known that as long as humans remain in-the-loop flying and controlling aircraft, human error will continue to remain an ever-present limitation and runway incursions will continue to occur. It is for this reason that a system that monitors the developing situation and alerts the pilots in the event of a runway conflict will continue to be of value in making commercial aviation even safer. The value of such alerting equipment in the cockpit is further emphasised by the fact that air traffic is expected to double in the next twenty years, which will raise the risk of runway collision.

Since 2005, the University of Malta has been conducting research into the development of an effective method and system that alerts the pilots in a way to ensure that a collision can be effectively avoided. Contracted initially to conduct research in the area by the European Commission under Framework Programme 6 as part of the FLYSAFE project, the €0.6 Million activity has led the University to file for UK and US patent applications in 2008. Since then, the University has been granted its first foreign patent with the granting of the UK patent in 2010. The US patent is currently pending award.

The major research contribution to the industry has been in the alerting strategy, designed specifically to ensure pilots will take the best action to ensure that a collision is avoided once a runway conflict is detected. Addressing the problem by thinking 'out of the box', an approach that the research team has become accustomed to adopt, the solution identified was to monitor aircraft movements on and in the vicinity of the runway in question, identify whether a risk of collision exists and, in such an event, determine the safest manoeuvre the pilots should conduct to avoid an accident. The system then alerts the crew accordingly. The value of the work has been in the identification of the alerting strategy and the system determining the safest manoeuvre. The identification of such a solution was achieved through the application of rigorous industrial processes and required the application of a broad range of multi-disciplinary skills and know-how in engineering, ranging from flight deck operations, to aircraft performance engineering, electronic system design, human factors and air traffic management.

Both the identification of the safest way to mitigate a conflict situation and the selection of the alerting philosophy posed major challenges. Whilst both are significantly affected by rigorous civil aviation certification requirements, the former required very accurate and robust aircraft performance prediction in a highly dynamic environment, whilst the latter required compatibility with current flight deck operations and alerting philosophies. Besides, both aspects are required to work in unison as part of a process

The major research contribution to the industry has been in the alerting strategy, designed specifically to ensure pilots will take the best action to ensure that a collision is avoided once a runway conflict is detected

chain that involves the pilot-in-the-loop in the eventual successful mitigation of the conflict. This implies that the alerting technique, that utilises both aural and visual alerting methods, needs to be sufficiently assertive and timely to ensure the pilots take quick and correct action. This is fundamental considering that, particularly in take-off, one or two seconds can make all the difference between a resolvable conflict and an accident.

The system developed by the University of Malta was done in continuous consultation with industry. Besides working with research and industrial partners within the FLYSAFE project, such as Airbus, Thales, BAE Systems, NLR and Cranfield University, inputs from American organisations, including, in particular, Boeing, RTCA and Mitre Corporation have also been taken into consideration. Operators have been involved throughout the development life cycle as early as the conceptual design stage and line pilots have been involved in extensive simulator evaluations that have been conducted to assess the effectiveness and performance of the developed system. This has resulted in a much applied downstream research activity that is very industry oriented and a concept that has been matured to Technology Readiness Level 4, in preparation for potential industrialisation of the concept to effectively contribute towards improved safety in commercial aviation.

High speed multi-vision

a new industrial tool

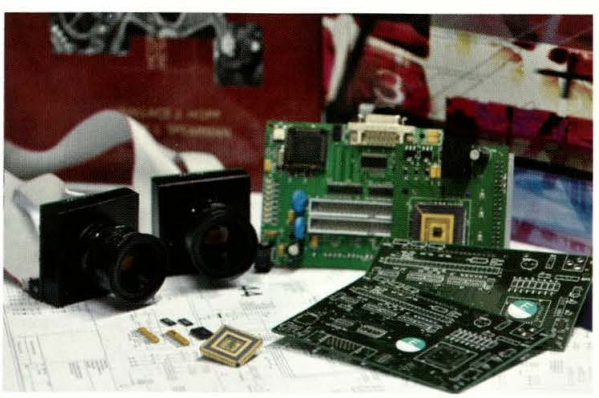
Have you ever wondered what it would be like to observe the first micro-second after a bullet hits bullet-proof glass? How about peering inside the cylinder of a Diesel engine running at 6000rpm… and it is now possible in full high definition 3D

High speed multi-vision is a technology that captures images moving at extremely high speeds, using several cameras, and rendering it in 3D. It is an important research and diagnostic tool in many industries and can lead to a better understanding of important physical and industrial processes. For example, visualizing the combustion wave front in a diesel engine, as it propagates through the hot gasses can help engineers figure out new ways of designing piston crowns and fuel injectors to ensure cleaner operation. This will increase fuel efficiency. However, 3D imaging of such ultra-fast events is no trivial matter.

Multivision technology involves the use of two (for stereovision) or more cameras working in tandem to capture objects or events from multiple angles. This is important to create 3D representations of the said objects of events, in a method not too different from the way the human visual system works. Fast events require the cameras to be synchronised in order to capture the same instant accurately and the closer they need to be synchronised, the harder the solution.

Research Engineer Marc-Anthony Azzopardi from the Faculty of Engineering of the University of Malta has conducted research that brought such new capabilities to the area of high speed vision which was previously only possible using cumbersome beam splitters and complex optics.

As part of an FP6 European project consortium called "*SENSATION*" the University has developed a method for synchronising multiple high speed cameras with exceptional accuracy. This provides the capability of taking simultaneous digital snap-shots of an object or event from several different angles with a synchronisation error well within a tenth of a billionth of a second using purely electronic means of relative simplicity and low cost. Such technology is compact and practical and has widespread application in a number of industries.



Marc Anthony Azzopardi

The method involves using a symmetric camera design, using matched CMOS (complementary metal-oxide-semiconductor) image sensors, which when operated under a specific set of closely controlled conditions result in highly reliable, synchronous image capture. The images from all cameras are combined at source using a carefully designed data concentrator and can then be transferred as a composite image to a computer via a single standard cable with no loss in synchronisation and very little delay.

The University is actively exploring the commercial potential of this technology and this may well serve as a model for transforming further home-grown research and innovation into useful products which benefit society at large. The big step of transferring technology from the research lab into the industrial park is notoriously challenging, but it is the key for making further research financially sustainable. For this, the University of Malta has secured the technology though a patent and has engaged Isis Innovation Ltd. the technology transfer subsidiary of Oxford University, to aid in its commercialization activities of this technology.

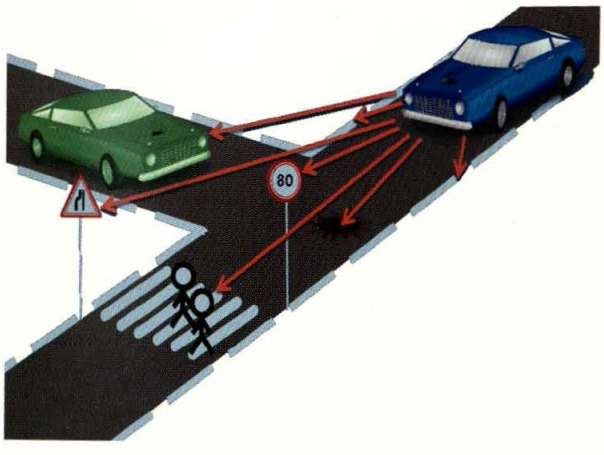
Priority for this invention was established in Malta in September 2008, then through the World Intellectual Property Organisation (WIPO) it also became the first truly international patent application for the University of Malta. It spans most of the industrialised world with coverage in over 30 countries. These include the United States, Germany, France, Italy, the United Kingdom and Japan. Such coverage is an important first step to commercialise a product.

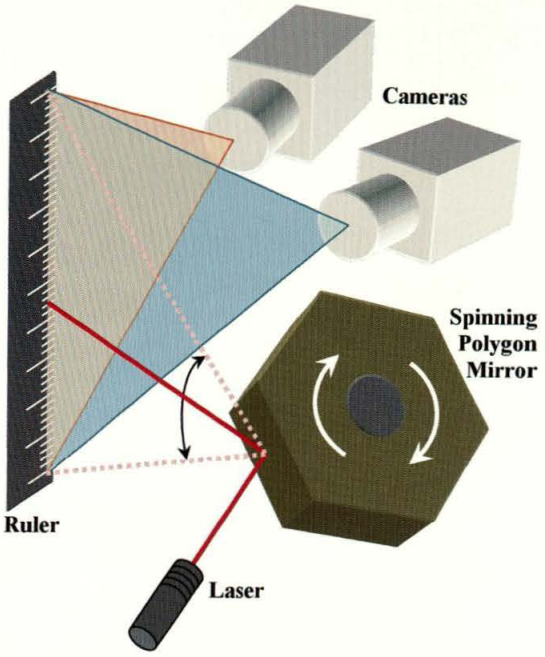
Demonstrating the high performance of the system was another challenge. A direct way to demonstrate high synchronization consists of the simultaneous capture of fast moving objects against

The technology guarantees high synchronisation at lower cost than the alternatives

a reference background. But the synchronisation accuracy is so high that a speeding projectile travelling at several times the speed of sound is still unable to generate a measurable distinction between images (of the projectile) captured by the multiple cameras. For adequate sensitivity, the object has to be travelling at many kilometers per second. One practical method is a laser scanner. This involves reflecting a high intensity collimated laser beam off a rapidly spinning polygon mirror onto a ruled surface.

A high degree of camera synchronisation simplifies the development of camera systems for car vision. This is one of the fastest growing applications of multi-camera machine vision for the general consumer. The technology guarantees high synchronisation at low cost. It also aggregates multiple synchronised video streams onto fewer cables. The set of conceivable automotive camera applications is an ever-growing list, with some market research reports claiming over 10 cameras will be required per vehicle. The list includes driver vigilance and drowsiness monitoring, intersection assistance, road surface condition monitoring, blind spot warning, adaptive cruise control, pedestrian detection, lane departure warning, collision warning/avoidance, accident recording and others. Many of these applications rely on multi-vision and hence require synchronization of pairs or triplets of cameras.





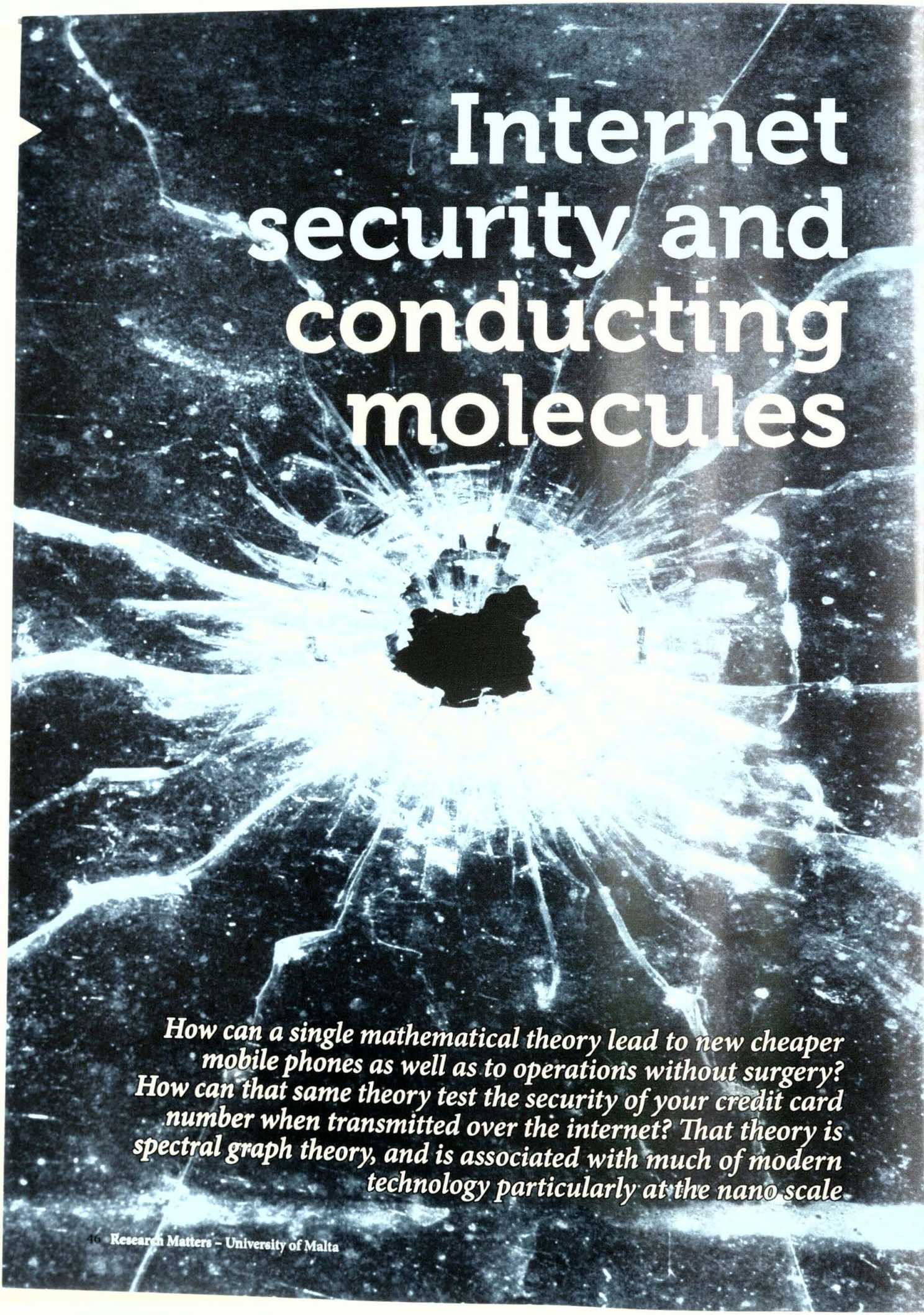
Scientific instrumentation is another key area. There are several instances where the ability to image high speed processes synchronously from multiple angles can make the difference in a scientist's ability to understand an important process. Supersonic air flow and turbulence in wind tunnels; cavitation induced erosion; ice formation on the leading edge of aircraft wings; micro-meteorite impact deflection on spacecraft; insect and bird flight dynamics; shockwave lensing in shape charged armour piercing shells... the list is endless.

Other sectors of application include crash testing; high speed industrial machine vision; high speed metal machining; medical imaging; gaming; and sports motion/gait analysis.

Such a long list of applications shows the prudent step in patenting this technology. Not every patent will lead to substantial profits, but the new intellectual property laws will encourage a lot more applications. Products from research at the University of Malta will soon be hitting our shelves, advancing medical equipment and even getting into our cars. ●

The technology can be applied to detect driver vigilance and drowsiness, blind spot warning, pedestrian detection, collision warning/avoidance and accident recording

Internet security and conducting molecules



How can a single mathematical theory lead to new cheaper mobile phones as well as to operations without surgery? How can that same theory test the security of your credit card number when transmitted over the internet? That theory is spectral graph theory, and is associated with much of modern technology particularly at the nano scale

Research in spectral graph theory by Prof. Irene Sciriha at the Mathematics Dept. of the University of Malta established a niche between the interplay of algebra and geometry. It has also enabled researchers in usually alien disciplines to device materials that save millions of euro. The keyword is nanotechnology. Components on the nanoscale are lighter, cheaper to produce and transport, less prone to damage and can store larger amounts of information at an incredibly fast rate.

The explosion in growth and popularity that nanotechnology is enjoying was triggered by the discovery, in 1985, of a new form of carbon, called fullerenes, by three scientists, Kroto, Smalley and Curl and students O'Brien and Heath. The first three were awarded the Nobel Prize in 1996. Up to 1985, we used to learn that carbon can exist as diamond, graphite and amorphous soot or coal. Smalley's laboratory produced carbon vapour by a laser beam directed at a rotating graphite disc. Then it was cooled by allowing it to flow with He (helium) gas at 10 atm, making clusters of a new carbon form, composed of spherical Carbon 60 molecules.

Carbon 60 molecules are hollow spherical cages 1.1 nanometres in diameter, about 1000 times thinner than a human hair. Nanotubes of carbon with one atom thick walls are 50 times stronger than steel and half as dense as aluminium. They are already proving to be the constructing material for bullet proof vests, electronic devices, light luggage bags, houses and medical instruments.

In his famous 1959 speech, `There is Plenty of Room at the Bottom', the physicist Richard Feynman predicted a different world where devices are so small that the enormous computers they had at that time could be held in one hand. He argued that in principle this was possible, today forty years later he was proven right. He had claimed: `Atoms on a small scale behave like nothing on a large scale, for they satisfy new laws, those of quantum mechanics'. Mathematics has supported his claims and industry is waking up to this new potential.

It is expected that nanotechnology will be the future manufacturing technology that will make most products incredibly smaller, lighter, stronger, cheaper, more environmentally friendly and more precise. It is causing today's `gold' rush. There is a frantic drive in the mobile phone and computer industry to reduce the size and weight of electronic components. Scientists and engineers are already using single molecules as electronically active elements.

Nanotubes of carbon with one atom thick walls are

50 TIMES STRONGER

than steel and half as dense as aluminium

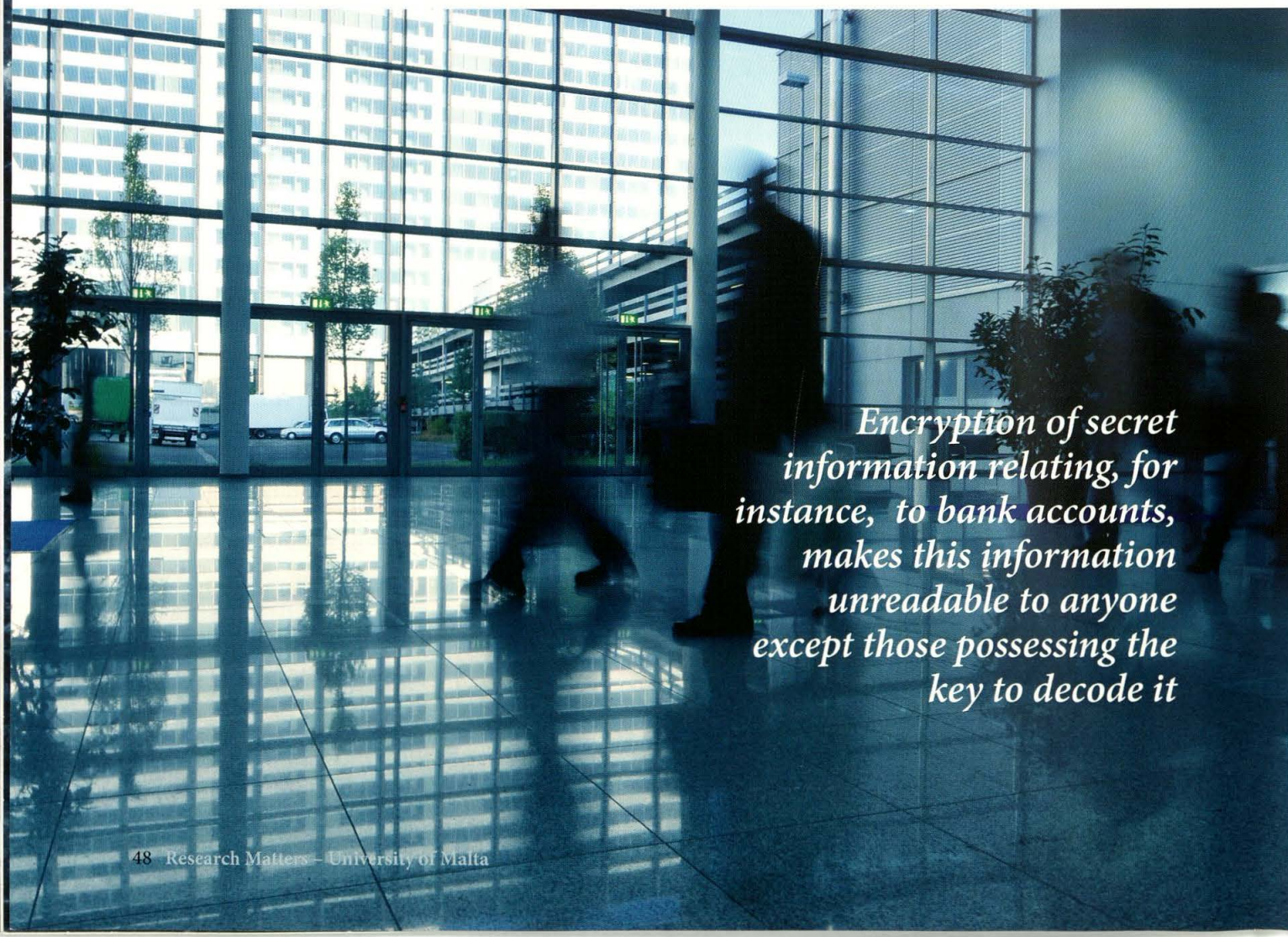
Although these devices are still experimental, Prof. Sciriha has pioneered mathematical theory that will allow mathematical theory scientific discoveries in the future. Electric circuits with a carbon molecule as a component have recently become a desirable feature. Terminal connections to any two atoms of an omni-conductor give rise to a current even at a very small bias voltage whereas conduction is barred between two atoms of an omni-insulator. This beckons the question: which molecules can be used? Theoretical chemists working with π-systems such as unsaturated carbon molecules were searching for a robust theory that would design these types of molecules. Prof Sciriha

had been exploring the structural properties of singular graphs, since 1993. Her discoveries provided a theory, revealing the properties of omni-conductors and omni-insulators, that fitted like a glove. She classified vertices in a singular graph as core vertices, that allowed prediction of weak core-forbidden vertices and strong core-forbidden vertices, that allowed predthe particular molecular structures that conduct electricity.

This research is also relevant to scanning tunnelling microscopy, smart solar panels, fast exciting computer games, virtually indestructible motorcycle helmets and nano-sensors detecting impurities such as salmonella. All these apparently unrelated technologies and many more would be greatly improved with micro circuits using a single molecule as a component.

The University of Malta in collaboration with theoretical chemist Patrick Fowler and his team at the University of Sheffield are using spectral graph theory, to design the structure of molecules that conduct at small bias voltages. The aim is to establish a strong theory facilitating the understanding of known chemical discoveries related to molecular electronic devices where current ows ballistically through a molecule incorporated into a circuit, as well as to predict the structure of molecules having desirable properties.

A nut molecular fullerene graph is a singular graph that in the appropriate charge state has a half-occupied non-bonding orbital. It would be predicted to have non-zero spin density at all sites, and so would have markedly different reactivity from the more usual types of radical, where the spin density at some sites vanishes. The concept of nut graphs, which emerges as an underlying theme in the theory of singular graphs, contributes to a clear understanding of the interaction between molecular structure and reactivity. Moreover the well developed theory of nut graphs can be used to predict the synthesis of nut fullerenes from basic repeated motifs or from the coalescence of smaller nut molecular graphs.



Encryption of secret information relating, for instance, to bank accounts, makes this information unreadable to anyone except those possessing the key to decode it

Sciriha's publications have influenced optimization in design. They have attracted the attention of the American linear algebra think-tank sponsored by AIM3, CBMS4 and NSF5 who periodically invite her to contribute to the theme 'The mutually beneficial relationship of matrices and graphs' in intensive work shops. As a result highly motivating joint papers and monographs are published.

Why has spectral graph theory found so much favour with chemists, engineers and computer scientists? A graph is another name for a network. It may bond atoms in a carbon molecule as already described or it may link websites in the design of a search engine such as Google establishing the indicators to rank them.

The University of Malta is also collaborating with the Universities of Aveiro and Coimbra of Portugal to NP completeness using non-conventional techniques. In a recent publication a new more tractable method of finding whether a network has a Hamiltonian Cycle was developed. A Hamiltonian Cycle visits each city in a network once in a round tour. The Hamiltonian Cycle problem is one of a group of very hard yet unsolved problems termed NP hard. Solving one would have a cascade effect on the solution of others.

Hamiltonion Cycle problems are used in encryption to transform secret information, relating for instance to bank accounts, to make it unreadable to anyone except those possessing the key to decode it. Determining whether or not it is possible to solve these problems quickly, is one of the principal unsolved problems of computer science. If successful, this would pose huge problems for cryptography which requires codes that are almost always hard to decode, with solutions that cannot be approximated in polynomial time. The success of security relies on the large amount of time, billions or trillions of years, using the best computing power available today, to decode. So whereas finding faster ways of solving problems saves society a great deal of money it could have huge repercussions on the security of intelligence systems.

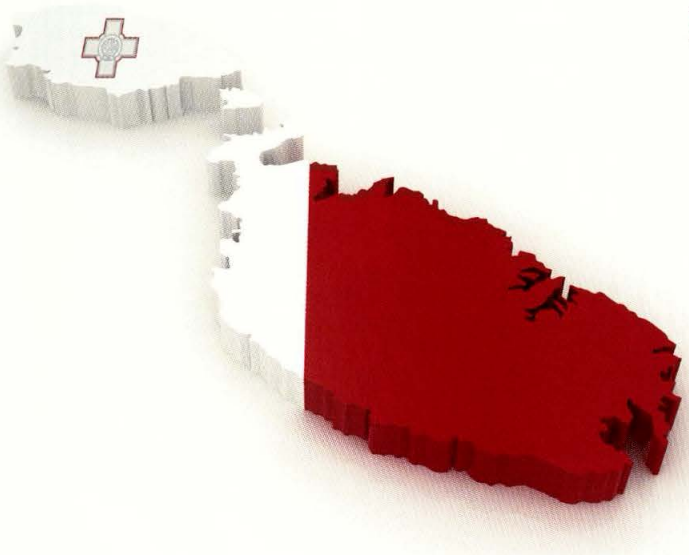
The high applicability of spectral graph theory has led to new avenues of research. The University of Malta has set up collaborations with the University of Belgrade, focused on specific eigenvalues in the spectra of graphs. The index or largest eigenvalue of the adjacency matrix and the minimum positive eigenvalue of the Laplacian matrix, among graphs of the same order, have wide applications in the power method used in sociology, principal component analysis used in fingerprint and face recognition, page ranking which is the basis of the Google search engine, and wavelet theory useful in seismology and medical cardiac studies. Other eigenvalues contribute to the study of virus spreading, epidemic systems as well as the good connectivity or restrictive bottlenecks in networks. There are also studies of Boolean matrices and the unique colourability of graphs going on with the University of Messina geometry group that mirror aspects of computer engineering.

A graph is another name for a network. It may bond atoms in a carbon molecule or it may link websites in the design of a search engine such as Google establishing the indicators to rank them

The chemist Ivan Gutman recognised the power of mathematics and read for two doctoral degrees, one in each subject. In his article 'What chemists cannot see without mathematics', he epitomizes the symbiotic interaction between mathematics and scientific discovery. Mathematics is the back-bone of innovation in industry. Moreover, mathematics has a powerful lateral angle, indispensable for progress in technology. It is the instrument to simulate a mobile phone as well as a jumbo jet, human behaviour as well as the stock exchange, DNA sequencing as well as the growth of a plant. Its power lies in elucidating seemingly complex processes using simple clear logical concepts. We are humbled by its power and like little children admire its vastness in awe. ●

MIND YOUR LANGUAGE

How Information and Communication Technology helps keeping a vulnerable language alive



The Maltese language – an official EU language since 2004 has survived the test of time and has, during its existence, gone through a continuous process of renewal. Time and again the Maltese language faced the threat of becoming irrelevant, which would have led to its subsequent extinction, a fate experienced by other 'small' languages across the world

For a language to remain alive and valid, and most importantly for a small language to do so, it has to be supported by resources that continue to provide new knowledge about the language itself, while preserving the inherent knowledge with the objective of keeping the components that make up a language – words, grammar, literature – valid and contemporary.

Over the past few years, the Institute of Linguistics, in collaboration with the Department of Intelligent Computer Systems of the University of Malta have been working on constructing a number of electronic, machine-readable language resources for the Maltese language. The core resource is a large ***corpus*** of texts (or transcribed speech) from various genres. The research team behind this project is made up of Dr Albert Gatt, Prof. Ray Fabri and Ms Claudia Borg from the Institute of Linguistics, together with Mr Mike Rosner from the Department of Intelligent Computer Systems).

Such a resource is valuable for research on all aspects of Maltese language use, for both linguists and professionals working with the Maltese language (such as translators). One common use of ***corpora*** is to identify word uses in different contexts; this has become the standard method used by lexicographers in constructing dictionaries, where contextual information can help to distinguish the different meanings of a word.

The corpus is also useful to build statistical models for Natural Language processing, a theoretically motivated range of computational techniques for analyzing and representing naturally occurring texts at one or more levels of linguistic analysis for the purpose of achieving human-like language processing for a range of tasks or applications.

Statistical language models use large amounts of data to estimate the likelihood of particular patterns or structures in a language. These are being used in a variety of applications, from Machine Translation (where the translation of a source text is often built in part by identifying the most probable translations for its components in a parallel text corpus), to parsing sentences and generating them.

Apart from the corpus itself, which is now close to 100 million tokens in size, the research team is also working on a number of computational tools that explicitly make use of the corpus data. In particular, they are developing part-of-speech tagging: A part-of-speech tagger takes sentences as input and labels each word in them with their grammatical information (e.g. the verb *harget*

Statistical language models use large amounts of data to estimate the likelihood of particular patterns or structures in a language. These are being used in a variety of applications, from Machine Translation (where the translation of a source text is often built in part by identifying the most probable translations for its components in a parallel text corpus), to parsing sentences and generating them

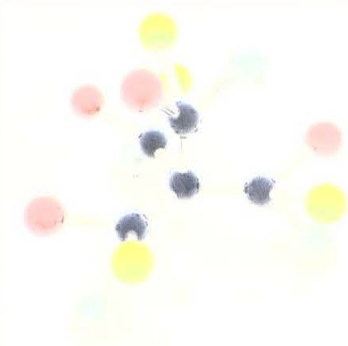
would be labelled as a verb in the third person singular feminine, perfective). The research team has also developed software that would enable the tagging.

Given that there is as yet no standard spellchecker for Maltese, the research team is currently developing a statistical spellchecker, to enable the context-sensitive correction of orthographical errors. This uses a statistical language model constructed from the corpus to estimate the most probably correction for a mis-spelled word, given its context.

The Maltese Language Resource corpus is an opportunistic text collection of nearly 100 million tokens, mostly created from publicly available documents, as well as a limited amount of user-contributed material in a number of categories such as academic, law, literature (and literary criticism), transcripts of parliamentary debates, press articles and press releases, speeches, and web documents in Maltese.

Apart from the corpus the Maltese Language Resource Server hosts a compilation of verb roots, compiled by researcher Michael Spagnol. This is an exhaustive database of roots and verbal patterns in Maltese, which was compiled using Serracino-Inglott's (1975-1989) monolingual dictionary, Aquilina's (1987-1990) bilingual dictionary, and Mifsud's (1995, Loan Verbs in Maltese. NY: Brill, pp. 272-295) list of loan verbs that have been fully integrated into the root-and-pattern system of Maltese. It contains around 2000 consonantal roots and over 4000 verbs.

The corpus, and related resources, is available online from the Maltese Langauge Resource Server at http://mlrs.research.um.edu.mt. ●



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