Harnessing Applications of Light and Light-based Technologies for Sustainable Development

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Introduction

People throughout the world and across history have always attached great importance to light. We see this in cultural symbolism, myths and legends, and in the many ways that studying the science of light and applying it in practical applications has shaped the societies in which we live. Light is central to our planet and our existence. On the most fundamental level- through photosynthesis- it is light from the sun which drives life itself; in our daily lives, the light-based technologies of *photonics* give us applications such as internet communications, modern manufacturing, the fabrication of computer chips, and medical imaging.

In recognition of the importance of light in so many areas of life, the United Nations has proclaimed the year 2015 as *the International Year of Light and Light-based Technologies*. This International Year has grown from an initiative of a large consortium of many different partners together with UNESCO, and its overarching objective is to raise worldwide awareness of how important the science and technology of light is for humankind, and the many ways in which photonics provides solutions to problems of global importance.

The world today faces many urgent challenges, such as providing food to a growing population; developing clean sources of energy that can promote growth whilst having low carbon footprint; improving education; reducing poverty and inequality; improving healthcare and quality of life for all. These challenges are of course addressed in the proposed Sustainable Development goals which are expected to frame governmental actions relating to the United Nations Post-2015 Development Agenda. But as discussions of these goals gathers pace in the countdown to their adoption, it is the ideal time to recall that one of the central messages of the International Year of Light is that light science and technologies provide practical and cost-effective solutions to meet many of these challenges.

In what follows we provide an overview of the many ways in which light science can aid sustainable development. The examples below are of course not exhaustive, and a selection of further reading is provided. But we hope that the selection of applications we have chosen highlights just in how many ways light-based technologies can lead to practical solutions that can extend social, medical, and energy generating benefits to billions of people in the world today.

Agriculture and Farming

The food and agriculture sector is essential to sustainable development. Indeed, ending hunger, ensuring food security, and promoting sustainable agriculture are key objectives of the Sustainable Development Goal targets. In many developing countries, agriculture is also the backbone of the economy, and is a key for long-term and inclusive growth due to its strong multiplier impact on other sectors.

Light-based technologies can play an important role in improving agriculture and farming through the area of *agri-photonics*. Lasers and imaging sensors on planes can be used to map soils and crop density, and reflectance data from vegetation can be used to determine very specific information such as the amount of nitrogen present in plants. Lasers and telescopes can be used to monitor evaporation and guide decisions on irrigation, and with appropriate lighting, vegetables and fruits can be grown indoors outside of their normal season, opening up possibilities for crop-cultivation year-round, even in inhospitable regions.

Climate Science

Developing countries are at the frontline of human-induced climate change over the next century. According to the to the IPCC Fifth Assessment Report, throughout the 21st century climate change is expected to lead to increases in ill-health in many regions, and especially in developing countries with low income. Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world.

Light-based technologies are critical for monitoring and predicting the consequences of climate change. They are extensively used to map radiation emitted from the Earth's surface using radiometers, scanners and sensors placed in satellites orbiting our planet. These measurements are transmitted to ground stations where the data is converted to images that provide information on ocean currents or global carbon-dioxide distribution. Of course, mitigating the effects of climate change will also rely heavily on light-based technologies in the field of renewable energy as described below.

Communications

The visible light that we can see is only a small part of the spectrum of electromagnetic radiation that finds important and widespread use in modern society. It is *invisible* microwave electromagnetic radiation that is used in mobile telephone communications and satellite networks, and it is the invisible light from infrared lasers that carries the pulsed signals of optical information under the oceans and across continents via the optical fiber infrastructure of the Internet.

The importance of communications for development is stressed by the UN Broadband Commission for Digital Development, who have recently stated how access to mobile devices (phones, tablets and e-readers) with broadband internet connectivity can bring quality education to people everywhere, especially in the world's poorest or most isolated communities. Although it is technology such as fibre to the home (FTTH) that is being emphasized in many developed countries, it is mobile broadband that is perceived as the most practical solutions for many developing countries. The International Telecommunications Union (ITU) reports that mobile broadband is the fastest growing technology in history -

mobile phone subscriptions now exceed the world's total population, and active mobile broadband subscriptions exceed 2.1 billion! Significantly, most of this progress has taken place in developing countries, which account for 82% of net additions of new Internet users globally in the last five years. The UN Broadband Commission and the ITU are pushing hard to ensure that mobile broadband can fulfil its potential to improve education and development. This was expressed eloquently by ITU Secretary-General Houlin Zhao during the 11th meeting of the UN Broadband Commission in February 2015: "For the first time in history, mobile broadband gives us the chance to truly bring education to all, regardless of a person's geographical location, linguistic and cultural frameworks, or ready access to infrastructure like schools and transport."

Education and Training

In addition to the use of light-based technologies to improve educational infrastructure, light science is an ideal subject to stimulate interest in STEM (science, technology, engineering, mathematics) subjects in a classroom context. This has been recognized for many years by UNESCO, the UNESCO Category I Centre ICTP (International Centre for Theoretical Physics) and the International Society for Optics and Photonics (SPIE) who have developed a global programme on Active Learning in Optics and Photonics (ALOP). Inquiry-based, or *active* learning encourages students to construct the knowledge from their own observations, guided by a facilitator whose role it is to lead them from observation to discovery. This is on contrast to the normal classroom scenario in which the teacher lectures and the students passively absorb as much information as they can, which, by itself, is known to be inadequate in developing correct conceptual understanding of the underlying physics. ALOP modules have been developed for many subjects, from the basics to the advanced: Geometrical Optics, Lenses and Optics of the Eye, Interference and Diffraction, Atmospheric Optics, Optical Data Transmission and Wavelength Division Multiplexing. In many cases the cost of material is low, and courses can be adapted to many diverse cultures.

ALOP courses are not aimed at students, however, but are focused on teachers – "training the trainers." This is an essential part of the philosophy, and indeed since 2004, ALOP workshops have reached over 1,000 teachers from 55 developing countries in Africa, Asia and Latin America. The participants are typically lecturers in universities as well as some secondary school teachers of physics. Follow-up activities, in which trained trainers train others locally are an important part of the strategy and this has been very successful in a number of regions around the world. ALOP workshops also provide practical examples of how Interactive Lecture Demonstrations using light-technologies can be used in large classes. One example involves image formation and serves to also illustrate how significant learning gains can be achieved with low-cost materials and without "black-box" solutions which can sometimes be counter-productive. For instance, a cylindrical lens can be designed from a transparent plastic container jar filled with water, using a 9V battery and flashlight bulb as light source.

Energy and Lighting

When one thinks of harnessing light-based technologies for sustainable development, renewable energy through solar power would likely be the first thing that came to mind for most people. After all, many developing countries have abundant solar energy resources (insolation), and the use of solar energy is ideally-suited to providing an off-grid energy supply as a sustainable alternative to the diesel generators which would otherwise be used. There remain many challenges to address, but research is advancing rapidly in the underlying physics and materials science, the development of storage technologies, and in optimising and comparing the technologies of photovoltaics and solar thermal collection. Although the economics of deployment in the energy sector can be complex, the International Energy Agency encapsulated the issues well in its 2011 report when they stated explicitly that solar energy "…will increase countries' energy security…enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments."

Closely coupled to the availability of energy is the availability of lighting. With no reliable source of light, many people in developing communities depend on kerosene lamps for light, which has been estimated to lead to the death of over a million people every year. Providing clean, efficient forms of lighting to developing communities is not only important for health reasons - it is also vital for productivity. Families in rural communities rely on work to provide for the most basic needs of their family, but working hours can be limited due to scarce lighting after sunset. The majority of children in developing countries are also expected to work during the day to help provide for their family. With no, or inadequate, light at night, children are deprived of an education. Although longer term solutions will require clear policies on renewable energy on the regional level, many industries and NGOs and other associations are working on the ground to promote the use of portable solar-powered high-brightness LED lanterns in regions where there is little or no other reliable source of light.

Healthcare and Medicine

Optical technologies play a key role in medicine from simple diagnostics and monitoring, to advanced treatment options and research. Photonics appears in very simple and widespread devices: clip-on pulse oximeters use the transmission of light from an LED through a finger to measure oxygen saturation and heartrate, and ear thermometers use infrared light detectors to provide a safe and reliable measurement of body temperature. Imaging and surgery have been revolutionized with the use of endoscopy and laparoscopy, and light-based technologies and lasers find important uses in many medical procedures including neurosurgery, dermatology, dentistry, vision correction, heart surgery, and reconstructive procedures. Many light-based therapies have also proven effective for detecting and treating cancer. One example of a light-based technique to treat cancer is photodynamic therapy, where a patient is given a nontoxic photosensitive drug that is absorbed by cancer cells. During surgery, a light beam is positioned at the tumour site, which then activates the drug to become toxic to targeted malignant cells.

In developing countries, there are of course many challenges in ensuring the best healthcare treatments are available, but the advanced technology of the smartphone promises huge potential to revolutionise medicine in low-resource areas. Such technology-based mobile health can take many forms. For example, a specialised mobile app and lens adapter can convert a smartphone into a device that can take diagnostic-quality images of cataracts. The resulting image can then be sent by email to a remote expert for evaluation and recommendation for treatment, and the ability to geotag results with built-in GPS facilitates record-keeping for field workers. Other examinations possible with a smartphone include retina screening, depth of field tests, colour vision testing, and visual acuity. Beyond testing vision, adaptations to turn smartphones into microscopes are allowing for detection of parasites in blood or stools.

There is, of course, much work to be done in moving from demonstration to large-scale uptake, but the smartphone is one of the most advanced technological devices ever made, with state-of-the-art imaging and communications built-in. It is clear that it has tremendous potential as a portable mobile laboratory. Recent years have seen dramatic strides in the field of telemedicine in general, the use of telecommunication and information technologies to provide access to medical services that would often not be consistently available at a distance. The smartphone may well be showing the way towards the democratization of healthcare in developing countries.

Vision and Seeing

People in developed countries take eyeglasses and good vision for granted. However, worldwide estimates of those who suffer from uncorrected defective eyesight range from the 100's of millions to over a billion adults and children! Far more than just an "inconvenience," the worldwide lack of eyeglasses to correct vision prohibits people from working and taking care of their families and has a negative effect on children's schooling and study. In fact, one 2012 study estimated the loss in GDP due to uncorrected vision was US$ 202 billion annually!

Looking at this objectively, it may seem hard to understand – after all, eyeglasses are a 13th century (!) optical technology, and techniques for their inexpensive mass production have existed for decades. But it is also easy to see how bottlenecks can arise with testing, prescription and distribution. A number of NGOs and industries are therefore working on complementary approaches to solve these problems. One approach uses fluid filled lenses where a user can self-adjust the eyeglasses, allowing a very convenient way to select the appropriate correction. Another idea uses low cost prefabricated lenses and a compact bending machine to create frames from spring steel; this approach can also encourage the establishment of sustainable businesses producing and selling these glasses in local communities.

Water Quality

Water is essential to human health. Despite impressive gains made over the last decades, billions worldwide still suffer from health problems due to the lack of clean water. Although much progress has been made in the use of conventional treatment processes, there is a continuous need for the development of new and complementary technologies to produce high quality water, especially in developing areas. Photonics technologies can significantly help in this regard by improving both water quality assessment and access to clean sources of water. For instance, low-cost water treatment systems powered by solar panels can decompose organic pollutants in water, and solar-powered well pumping has proven to be a sustainable, low-cost solution to provide drinking and irrigation water in off-grid locations in drought-prone regions. Research is also ongoing into the development of LED-based portable systems for point of use purification.

Conclusions

Light-based technologies are pervasive in the everyday lives of people living in affluent areas of the world, but it is our hope that this series of examples illustrates the many applications that can have a real impact on sustainable development. It is appropriate here to quote from the message of Ban Ki-Moon in his message to the Opening Ceremony of the International Year of Light held in Paris on 19-20 January 2015: “As we strive to end poverty and promote shared prosperity, light technologies can offer practical solutions to global challenges.”

In concluding, it is perhaps worth recalling that when the laser was invented in 1960, it was described as a “solution looking for a problem.” Today, however, lasers are part of the everyday lives of billions of people living in affluent areas of the world, from driving the undersea global telecommunications network to the daily tech of barcode scanning at the supermarket. The last decades of research in advanced photonics has created many new technologies that provide practical solutions to problems in developing countries, but a bottleneck has arisen because the scientists and engineers working on the technologies are very often simply not aware of what these problems are. On the other side of the coin, it is often the case that political decision-makers as well as those working in developing regions are just not aware that these solutions may exist. The International Year of Light asks the scientific community to work to bridge this gap in knowledge and understanding, and it is our hope that this article takes a positive forward step in achieving this.

Further Reading

Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland (2014).

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Solar Energy Perspectives. Organisation for Economic Co-operation and Development and International Energy Agency, OECD Publishing (2011)

Technology, Broadband and Education, Advancing the Education for All Agenda, A report by the Broadband Commission Working Group on Education, ITU & UNESCO, January 2013 www.broadbandcommission.org

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Author Biographies

John Dudley (@johnmdudley) is Professor at the University of Franche-Comte in Besancon, France. He has published over 500 contributions in journals & conference proceedings, and delivered over 120 invited talks at major conferences. He regularly speaks on topics including: his own research in nonlinear optics; global research trends in photonics; extreme events in nature; public outreach & education; career development. He is Fellow of OSA, the IEEE and the European Optical Society. He served as the President of the European Physical Society for a two year term from April 2013-March 2015, and currently chairs the Steering Committee of the International Year of Light & Light-based Technologies 2015 (IYL2015).

Jorge Rivero González (@jorgegrivero) is a science communicator working at the European Physical Society (EPS) as the EPS IYL 2015 Outreach Officer. He is also editor of the IYL2015 blog. Before that he spent four years living in Munich while he was doing his PhD in Astrophysics at the University Observatory Munich. Since 2009 he is a member of the GalileoMobile project, a science education programme that brings astronomy closer to young people around the world, and has given him the possibility to share the wonders of astronomy with children in Bolivia, Peru and Brazil in 2009 and 2014.

Joseph Niemela (@joeniemela) is a senior researcher at the Abdus Salam International Center for Theoretical Physics (ICTP) in Trieste (Italy). Niemela conducts research in fluid dynamics and low-temperature physics, heads the ICTP Office of External Activities, organizes the annual ICTP Winter College on Optics, and serves as the global secretariat for IYL2015. He has a PhD in physics from University of Oregon (USA).

Figure Captions

Please note we have ensured we have permission to use all figures.

Image 1.jpg

Symon from Zomba Malawi trying new glasses provided by the onedollarglasses initiative. (Credit: Wolfram Cüppers)

Image2.jpg

A low power LED lighting system can give children in developing regions enough light to read, helping them with their schooling. Credit: SolarAid/Kat Harrison

Image3.jpg

Laser has been used to treat millions children affected by disfiguring birthmarks by selectively heating and destroying specific tissue. Credit: George Morgan / Vietnam Vascular Anomalies Center.

Image4.jpg

Optics is a field of science that promotes enquiry-based learning by doing for students of all ages.
Credit: James Webb Space Telescope

Image5.jpg

Since 2004, Active Learning in Optics and Photonics (ALOP) workshops have reached over 1,000 teachers from 55 developing countries. Credit: Evvy Kartini/ BATAN (Indonesia)

Image6.jpg

The message from Ban Ki-Moon being read at the Opening Ceremony of the International Year of Light at UNESCO HQ in Paris on 19 January 2015 (Credit: Dan Curticapaen)