Technology Forward Scan: Future applications for digital technology in low and middle income countries

Background Paper

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Pathways for Prosperity Commission
Technology & Inclusive Development

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This paper is part of a series of background papers on technological change and inclusive development, bringing together evidence, ideas and research to feed into the commission's thinking. The views and positions expressed in this paper are those of the author and do not represent the commission.

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What are the prospective future applications for digital technology in low- and middle-income countries?

Section A: Introduction

Humans have been using technology for millions of years. Stone tools made by *Australopithecus*, one of the earliest hominid species, have been found in Kenya and are 3.3 million years old.[1] Although the types of tools we create have obviously changed immeasurably since then, we would certainly recognise something of what was going through those early humans' minds as they fashioned their tools out of stone. This is the drive to make a task easier and more productive through the use of a tool, and by making tasks such as getting food easier, to improve the quality of life. The potential for technology to continue this process that was initiated millions of years ago is unchanged.

Technological trends

Today the use of some form of digital technology is a routine part of everyday life for people all over the world. A few trends have enabled the widespread adoption of these technologies.

Moore's Law

Gordon Moore, the co-founder of Intel, asserted in 1965 that the number of transistors per square inch on an integrated circuit (a computer 'chip') would double approximately every 12 months (revised upwards to every 24 months in 1975). This is perhaps the best summary of how fast digital technology has advanced in the last 50 years.[2] The repercussions of this law have not only been felt in the technology sector, but across the whole global economy.[3] Everyone from technologists, to economists, to anyone involved in any form of economic activity, has been able to rely on the idea that computer chips would be twice as powerful, at the same size and the same cost, every two years, and thus plan their research, investments and product development accordingly. The ability to place more transistors on a chip also underpins the trend towards miniaturisation, such that consumers today have more computing power in their pocket, in the form of their smartphone, than all of NASA's computing capacity in 1969, at the time of the Apollo 11 mission.[4]

Moore's Law could be hitting a plateau, however, and by 2021, transistors may not be able to shrink further. Chip-makers such as Intel and Samsung argue that, at that point, making transistors any smaller would be more expensive than the economic returns it would deliver. This is not necessarily

[1] Joyce, C. (2015) "New Discovery Of World's Oldest Stone Tools", NPR, available at www.npr.org/sections/thetwo-way/2015/04/15/399937433/new-discovery-of-worlds-oldest-tools

[2] Evans, D (2014) "Moore's Law: how long will it last?", Techradar, available at www.techradar.com/news/computing/moore-s-law-how-long-will-it-last--1226772

[3] Bell, L (2016) "What is Moore's Law?", Wired, available at www.wired.co.uk/article/wired-explains-moores-law

[4] Kaku, M (2011) "Physics of the Future: How Science Will Shape Human Destiny and Our Daily Lives by the Year 2100", Doubleday, London, ISBN: 978-0-385-53080-4

a bad thing for digital technology, however – experts have argued that it would increase the incentive to develop technologies such as artificial intelligence (AI). If manufacturers can't continue to rely on computing power to increase exponentially, then they will need to develop more efficient processes that optimise the use of the computing power that is currently available.[5] It remains to be seen what effect newer forms of computing – perhaps those that do not rely on silicon-based transistors, such as quantum computing (see section below) – will have on Moore's Law or any successor.

Widening access to the internet

The internet is the technology that epitomises the information age, and which so many emerging technologies depend on for their development and propagation. It is a networking infrastructure that connects millions of computers together globally, such that any computer can communicate with any other computer as long as they are both connected to the internet. A suite of 'internet protocols' determines the format of different types of internet data and governs how information is sent across the internet, allowing it to be used for email, file transfer, and access to the World Wide Web, for example.

Since its inception in the 1980s, global access to the internet has increased dramatically. According to the most recent figures released by the International Telecommunication Union (ITU), by the end of 2016, 47% of people worldwide were using the internet – up from 30% in 2010. The majority of these internet users are in developed economies – only ~25% of people in Africa were using the internet as of 2016, compared to 79% of Europeans.[6] However, internet use in emerging economies is rising rapidly, driven mainly by young people in these countries. In least developed countries (as per the United Nations definition) up to 35% of individuals using the internet are aged 15–24, compared with 13% in developed countries and 23% globally. In China and India alone, up to 320 million young people use the internet.[7,8]

Greater use of wireless and mobile technology

Technological miniaturisation has allowed the development of faster, more powerful, and more mobile computing and telecommunications devices. More than 7 billion people (95% of the global population) live in an area that is covered by a mobile-cellular network, with almost 4 billion of them (53% of the global population) having access to a 4G Long Term Evolution (LTE) network.[9] The

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[5] Bell, L (2016) "What is Moore's Law?", Wired, available at www.wired.co.uk/article/wired-explains-moores-law

[6] International Telecommunication Union (ITU) (2016) "ICT Facts and Figures 2016", ITU, available at www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf

[7] UN Economic Analysis & Policy Division, LDC criteria, available at www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html

[8] ITU (2017) "ICT Facts and Figures 2017", ITU, available at www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf

[9] ITU (2016) "ICT Facts and Figures 2016", ITU, available at www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf

number of mobile phone users in low- and middle-income countries (LMICs) rose from 2.8 billion in 2012 to 3.6 million in 2016, according to the 2017 GSMA survey.[10] By 2020, we will have more than 6.1 billion smartphone users globally, overtaking landline subscriptions.[11]

Having a communications device in an increasing number of people's pockets has driven the further growth of digital technologies. Mobile is increasingly the method of choice to access the internet and other digital services – in the US, it is estimated that 69% of time spent using digital media occurs via mobile devices.[12] It is arguable that, without the amazing penetration of mobile devices, the growth in social media usage would not have occurred.[13] Nearly 80% of social media time is now spent on mobile devices, with 95.1% of Facebook users accessing the social network via smartphone as of January 2018.[14]

Big data and data analytics

One effect of the increased use of the internet and of mobile devices has been the explosion in the amount of data generated and retained by individuals, governments and companies. It has been estimated that, by the year 2020, about 1.7 megabytes of new information will be created every second for every human being on the planet, meaning that the total amount of digital data in existence will grow to around 44 zettabytes, or 44 trillion gigabytes.[15] This data comes from myriad sources: sensors used to gather climate information, posts to social media sites, digital pictures and videos, purchase transaction records, and cell phone global positioning system (GPS) signals, to name a few. The term 'big data' has been used to describe these large structured or unstructured data sets that are so large or complex that traditional data-processing application software is inadequate to deal with them. The discipline of data analytics has emerged to extract value from and identify patterns in these data. Combining data analytics with advances in computer processing power, storage capacity and additional statistical techniques has underpinned the rise of machine learning, which is the predominant set of AI techniques in use today. The major developments in AI technologies that are exciting so much interest at the moment could not have been made without big data.

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[10] GSMA Connected Women Programme (2015) 'Bridging the gender gap: Mobile access and usage in low- and middle-income countries', available at www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/02/Connected-Women-Gender-Gap.pdf

[11] Marr, B. (2015) "Big Data: 20 Mind-Boggling Facts Everyone Must Read", Forbes, available at www.forbes.com/sites/bernardmarr/2015/09/30/big-data-20-mind-boggling-facts-everyone-must-read/#fcb8b3317b1e

[12] ComScore (2017) "2017 U.S. Cross-Platform Future in Focus", available at www.comscore.com/Insights/Presentations-and-Whitepapers/2017/2017-US-Cross-Platform-Future-in-Focus?

[13] Kendrick J (2013) "Mobile technology: the amazing impact on our lives", ZDNet, available at www.zdnet.com/article/mobile-technology-the-amazing-impact-on-our-lives

[14] Sterling, G (2016) "Nearly 80 percent of social media time now spent on mobile devices", MarketingLand, available at https://marketingland.com/facebook-usage-accounts-1-5-minutes-spent-mobile-171561

[15] Marr, B. (2015) "Big Data: 20 Mind-Boggling Facts Everyone Must Read", Forbes, available at www.forbes.com/sites/bernardmarr/2015/09/30/big-data-20-mind-boggling-facts-everyone-must-read/#fcb8b3317b1e

Cloud computing

Cloud computing is the delivery of computing services – servers, storage, databases, networking, software, analytics and more – over the internet. It has reduced a number of significant barriers to the propagation of digital technology. For example, cloud computing reduces costs by eliminating the need to buy hardware and software, set up and run on-site data centres, and employ technology experts to manage the infrastructure. Moreover, as cloud computing is accessed on demand, there is no need for extensive capital investment in resources that are not being used for any length of time. In global terms, the biggest advantage of cloud computing is that it has allowed the delivery of cutting-edge computing technology to anyone, anywhere with an internet connection.[16]

Alternative interfaces with technology (voice, touchscreen)

As digital technologies have become more widespread, the number of different ways by which we interact with them have increased. Multitouch screens, for example, initially debuted in 1983, but only really took off with the advent of smartphones, where they are now almost ubiquitous. The significance of this technology is that it allows consumers to interact with digital devices more intuitively, lowering the digital literacy threshold that is required to do so. Similarly, voice recognition technology has allowed users to interact with technology in a more natural way. It has allowed those who are unable to read or write, through illiteracy or disability, for example, to access digital technology. It is rapidly becoming a preferred way of communicating with digital devices. Indeed, voice-based uses of search engines increased more than 35-fold between 2008 and 2016, and Andrew Ng, former Chief Scientist at Baidu and at Google Brain, has predicted that, by 2020, 50% of all searches will be made with either images or speech.[17]

This report

These trends have ensured that digital technologies have indelibly changed how humans interact with each other and with the world around them. A lot of research has been carried out on their past and prospective impacts in rich economies, such as in the US and Europe. Less clear are the opportunities and risks of digital technologies, and in particular emerging technologies, when they are deployed in LMICs.

[16] Microsoft Azure. "What is cloud computing?", available at https://azure.microsoft.com/en-gb/overview/what-is-cloud-computing

[17] Search Engine Watch (2016) "What does Meeker's Internet Trends report tell us about voice search?" available at https://searchenginewatch.com/2016/06/03/what-does-meekers-internet-trends-report-tell-us-about-voice-search

We have therefore undertaken a review, supplemented by interviews with technology experts in a dozen countries, of the potential impact of the following seven emerging technologies by 2040 in LMICs:

1. AI
2. Internet of Things (IoT)
3. Augmented Reality and Virtual Reality
4. Drone technology
5. Blockchain and other distributed ledger technologies
6. Quantum computing
7. Brain-computer interfaces

We also review how established 'infrastructure' technologies (data storage, and network connectivity) may change to allow advances in other technologies to be made.

For each of the above technologies, we discuss the potential applications in three areas, which correspond with the Pathways for Prosperity Commission's main focus areas:

- Inclusive economy
- Human development
- Quality government

We have developed a table, ranking the potential applications of each technology according to current stage of development, from those that are already being piloted, to those that are at initial experimental stages, to those that are purely speculative. We also use scenarios to illustrate the applications we describe. These scenarios are fictitious, but are firmly rooted in our research, including the literature review and interviews we have conducted. We are therefore confident that they represent realistic potential applications of these emerging technologies to the Commission's three focus areas.

Section B: Applications of emerging digital technologies

B.1 AI

AI refers to the suite of computer science, engineering, and related techniques that allow computers to solve problems – that is, to take the best possible action in a given situation.[18] It is an umbrella term that comprises 'symbolic AI', or 'good old-fashioned AI', which relies on human-readable representations of problems and logic, as well as machine learning techniques such as deep learning and neural networks, which rely on complex statistical methods to recognise patterns in data, learn from these patterns, and subsequently make predictions.[19] Other terms that fall under this umbrella include predictive analytics and data analytics.

Various superlatives have been used to describe the potential impact of AI, but perhaps the best way of thinking about this technology is that "it's a step change in what we can do with computers".[20] As AI systems become better at sorting data, finding patterns, and making predictions, these algorithms are undertaking an ever-increasing range of tasks, from imitating human interaction in smart personal assistants, to helping ride-sharing apps suggest optimal pick-up points, to identifying fraudulent transactions.[21, 22]

AI research and development in LMICs is multiplying. So far India is the first middle-income country to release its own national AI strategy, where it lists its engineering workforce as an advantage and argues its case as an 'AI garage'.[23] iCog Lab is Ethiopia's first AI lab, where some of the code was written for Sophia – the world's most famous humanoid robot, which was late to its meeting with the Ethiopian Prime Minister this July.[24] Google is opening its first Africa AI research centre later this year in Accra, to bring together academics, engineers and policymakers, and help solve local challenges. Reasons for choosing the Ghanaian capital include fast internet speed, relative political stability, and the high standards of its academic institutions, such as Ashesi University.[25, 26] For now, as many of the examples below will illustrate, China is racing ahead in the AI race. In 2017, the Alibaba Group announced plans to invest more than $15 billion over the next three years in research on technologies including AI.[27]

18 Russell, S J, and Norvig, P, (1995) "Artificial Intelligence: A Modern Approach", Englewood Cliffs, NJ: Prentice Hall.

19 Haugeland, J. (1989) "Artificial Intelligence: The Very Idea", MIT Press; New Ed edition

20 Evans, B. (2018) "Ways to think about machine learning", available at www.ben-evans.com/benedictevans/2018/06/22/ways-to-think-about-machine-learning-8nefy

21 Mitchell, T. (1997) Machine Learning. London, UK: McGraw-Hill Education.

22 Narula, G. (2018) "Everyday Examples of Artificial Intelligence and Machine Learning", available at www.techemergence.com/everyday-examples-of-ai

23 Reddy, S. (2018) "Can India become an AI hub for the developing world?", available at www.bbc.com/news/world-asia-india-44614802

24 Allison, S. (2018) "Ethiopia's Prime Minister got stood up - by a robot", available at https://mg.co.za/article/2018-07-04-ethiopias-prime-minister-got-stood-up-by-a-robot

25 Dean, J. & Cisse, M. (2018), "Google AI in Ghana", available at www.blog.google/around-the-globe/google-africa/google-ai-ghana/

26 Asemota, V. (2018) "'Ghana is the future of Africa': Why Google built an AI lab in Accra", available at https://edition.cnn.com/2018/07/14/africa/google-ghana-ai/index.html

27 Shu, C. (2017) "Alibaba Group will invest $15B into a new global research and development program", available at https://techcrunch.com/2017/10/10/alibaba-group-will-invest-15b-into-a-new-global-research-and-development-program

AI for enhancing agricultural and manufacturing processes

Precision farming, or the management of farms in a way that optimises resources and maximises output, was originally enabled by satellite technology. For example, a GPS-guided tractor is optimally steered to avoid wasting fuel or seed.[28] AI, in combination with other technologies, has the potential to raise efficiency and capacity even further. Ernest Mwebaze's AI research group in Uganda is working towards collecting the most granular data possible from farmers – what they grow now, what they grew last year, the size of their farm and family – with a view to making predictions on and interventions for the individual farmer. Students at Mekelle University, Uganda, are working on an unmanned tractor that will be able to avoid obstacles with the help of sensors. In July 2018, China launched a seven-year autonomous agriculture pilot programme, which includes the testing of unmanned tractors. However, the predominant farm size in many countries is smaller than two hectares; 58% of farms in Uganda are under one hectare, for which individual ownership of (expensive) unmanned tractors may be less applicable.[29] Nevertheless, unlike self-driving cars, tractors rely less on pre-existing reliable infrastructure such as well-marked roads.

Manual agricultural surveillance is time-consuming and the quantities of data that can be collected are limited, so automating these processes would bring great advantages.[30] For example, cassava roots provide 800 million people globally with their main source of carbohydrate. Researchers in Uganda have developed mCrops, an automated system for combating cassava diseases through surveillance and diagnosis. Instead of farmers having to call and wait days or even weeks for inspectors, it allows them to photograph their plants using cheap smartphones. The system has been trained to spot the signs of the four main diseases that are responsible for ravaging cassava crops, with 88% accuracy.[31] Although illiteracy and smartphone ownership may present more obvious constraints, others are social: while more men own a phone, cassava is often farmed by women.[32] A Vietnamese startup, Sero, has developed a similar tool to help local rice growers, and claims an accuracy rate of 70–90% for 20 crop diseases. Alibaba's ET Agricultural Brain is being used by pig farmers to monitor the animals' daily activities and to alert them to sickness, thus reducing death rates.[33]

In manufacturing, AI can be supported by a network of sensors and devices connected through the IoT. The aim is to fine-tune product quality and optimise operations, for example, by enhancing supply chain management and stock replenishment. AI-enabled predictive maintenance of

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[28] Schmaltz, R. (2017), "What is Precision Agriculture?", available at https://agfundernews.com/what-is-precision-agriculture.html

[29] Lyons, K. (2017) "Only modernised commercial farms will fill Africa's plate, economists warn", available at www.theguardian.com/global-development/2017/oct/10/younger-farmers-and-more-tractors-africa-needs-to-scale-up-says-report

[30] Mwebaze, E. (2015) "Automated monitoring of viral cassava disease", available at www.datascienceafrica.org/slides/dsa15/DeKUT-DataScience-Workshop-Ernest-2015.pdf

[31] Gray, R. (2017) "Treating cancer, stopping violence… How AI protects us", available at www.bbc.com/future/story/20170914-spotting-cancer-stopping-shootings-how-ai-protects-us

[32] Gershgorn, D. (2017) "The most impactful AI research isn't happening in Silicon Valley", available at https://qz.com/1148086/the-most-impactful-ai-research-isnt-happening-in-silicon-valley

[33] Moran, C. (2017) "China Is Spearheading the Future of Agriculture", available at www.realclearscience.com/articles/2018/06/30/china_is_spearheading_the_future_of_agriculture.html

industrial equipment can lower annual repair and inspection costs by 25%, and reduce downtime and scrap rates.[34] AI-driven robotics can help maintain a competitive advantage through increased productivity. Cobots (a robot that works collaboratively with a human) such as robotic arms, take over more dangerous tasks. Despite the often large capital investments required, middle-income countries such as Thailand are turning to automation to boost their economies. For example, Thai food and drinks conglomerate ThaiBev is planning to deploy robots and other automated machinery to boost productivity and support its subsidiaries.[35]

AI-driven robotics will have long-term implications on automation and the future of work. A 2016 report from Citi and the Oxford Martin School highlights that the automation of routine tasks may remove the first rungs of the classic development ladder, where workers shift from agriculture to factory jobs. Low-income countries may no longer be able to follow the path of initially taking advantage of their large pools of cheap, unskilled labour. Ethiopia is currently racing to offer a cheaper alternative to China's increasing labour costs in the manufacturing industry, with the government offering tax breaks and subsidies.[36] And yet 85% of jobs in Ethiopia involve tasks that may be at risk of automation according to the Citi/Oxford Martin School report.[37] Professor Ian Goldin warns that a scenario where people in low-income countries are forced to return to jobs in the agriculture sector due to the automation of manufacturing is not an optimistic model.[38]

AI for improving access to healthcare, education and more

AI may help narrow inequality of access, whether to education, services, or financing. For instance, major barriers to participating in civic life are related to literacy and language. For those who speak an indigenous language, civic participation and writing applications can be difficult when governments operate in a colonial language. Illiteracy continues to be a significant barrier to women – in Afghanistan and Niger, for example, around three times more women than men are illiterate. AI-based automated translation and voice recognition systems could therefore have significant impact in countries with multiple languages. AI interfaces could allow people to interact with bureaucracy through spoken rather than written words.[39] AI analytics could be used to determine which issues are raised more often – on the radio, in village assemblies – as well as whose voices are less likely to be heard.[40]

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[34] McKinsey & Company (2017) "Smartening up with Artificial Intelligence (AI) - What's in it for Germany and its Industrial Sector?", available at www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/Smartening%20up%20with%20artificial%20intelligence/Smartening-up-with-artificial-intelligence.ashx

[35] Zaidani, A. (2017) "Of AI and Robots – Thailand's F&B Giants Investing in Automation to drive Thailand 4.0", available at http://iotbusiness-platform.com/blog/of-ai-and-robots-thailands-fb-giants-investing-in-automation-to-drive-thailand-4-0

[36] Maasho, A. (2017) "Ethiopia bets on clothes to fashion industrial future", available at www.reuters.com/article/us-ethiopia-textiles/ethiopia-bets-on-clothes-to-fashion-industrial-future-idUSKBN1DL1VU

[37] Oxford Martin School (2016) "Technology at work v2.0", available at www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf

[38] Interview with Professor Ian Goldin, 20 June 2018

[39] The Web Foundation (2017) "Artificial Intelligence: The Road Ahead in Low and Middle-Income Countries", available at https://webfoundation.org/docs/2017/07/AI_Report_WF.pdf

[40] Jones, M. (2018) "Artificial Intelligence for Economic Development Conference: Roundup of 27 presentations", available at http://blogs.worldbank.org/developmenttalk/artificial-intelligence-economic-development-conference-roundup-27-presentations

Similarly, AI tools are being developed to ensure that children have access to education, no matter their language, location or economic status. YaNetu is an open source AI-based teaching tablet aimed at African children, which offers avatars teaching built-in curricula in local languages.[41] Companies such as the education technology (edtech) startup Ruangguru (Indonesia) and the education platform Eddi Ü (Mexico) are exploring ways to supplement formal school curricula with their online products.[42, 43] Maletšabisa Molapo, a researcher at IBM, described a pilot project for accelerating the acquisition of English as a second language in South Africa, which is based on peer-learning and peer-assessment to compensate for low teacher-to-student ratios. The tool gives pupils the opportunity to practise, provides automated feedback and assists teachers with grading. Issues the developers have encountered include low access to sufficiently advanced smartphones. AI also has the potential to deliver much more personalised education. It allows students to learn at their own pace, focusing on an individual's needs, and framing learning in a way that each individual will respond to best.

Globally a huge amount of investment is going into the application of AI to healthcare and important advances have been made in several fields. Applications include optimising hospital staff rostering and triage, the analysis of medical scans, and predicting the outbreak of infectious disease.[44] Although developments in this sensitive area will depend heavily on regulation, predictions of future applications include robot surgeons and carers, and a fully personalised healthcare plan. Online consultation service Babyl was set up in Rwanda in 2016; today, 2 million citizens, equating 30% of the adult population, have signed up, and can access records and pick up prescriptions through the app.[45] This kind of tool is available to populations with high levels of smartphone access and ownership, which raises questions about whether it serves to increase health inequalities, rather than reduce them. Healthcare is a highly sensitive sector and there is widespread uncertainty around regulating AI-driven health tools. For example, apps that function as 'online doctors' shy away from being labelled as diagnostic tools, due to potential legal implications in the event of a misdiagnosis.

AI could be a useful tool to help propel access to finance. One advantage of machine learning is its ability to exploit alternative data sources in data-poor environments. Fintech companies are already applying AI to help increase access to financial resources such as credit. Machine learning algorithms could also help reduce gender gaps in access to loans, for example by predicting

[41] iCog Labs (2016) Indiegogo campaign: "Help Us Use Advanced Tech to Disrupt African Education", available at www.indiegogo.com/projects/yanetu-ai-teaching-tablet-for-african-children--3#

[42] Maheshwari, A. (2017) "Indonesia: UOB Venture Management leads Series B fundsing in edtech startup Ruangguru", available at www.uobvm.com.sg/uobvm/assets/pdfs/uob-venture-management-leads-series-b-funding-in-ruangguru.pdf

[43] Eddiu. http://eddiu.com

[44] Fenech, M., Strukelj, N., and Buston, O. (2018) "Ethical, Social, and Political Challenges of Artificial Intelligence in Health" Future Advocacy and Wellcome Trust, available at http://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf

[45] Trick, K. (2018) "The Rwandan project: how Babylon helped rebuild healthcare in a war-shattered country", available at www.standard.co.uk/futurelondon/health/the-rwandan-project-how-babylon-helped-rebuild-healthcare-in-a-warshattered-country-a3885946.html

credit worthiness rather than credit history, which women are less likely to have.[46] Kudi.ai is an AI chatbot that allows its Nigerian users to make payments and send money to friends and family via messaging; it also reminds them to pay bills.[47] Machine learning algorithms can also identify fraudulent firms and flag them to tax authorities. In Kenya however, loan-providing apps have resulted in an increased number of applicants being blacklisted when failing to repay a loan. One reason is that citizens are applying for loans with many platforms simultaneously, a practice that is not being screened routinely.[48]

AI for ensuring national and personal safety

Many LMICs are affected by crises – whether human or natural – that can result in mass migration. AI tools could be used to help predict these movements and shape intelligent solutions, based on relevant factors such as gross domestic product (GDP), population growth, and weighted average of food crops. Other information can be added to train these computational models, creating a complex mathematical relationship between causes and effects. This includes sudden policy decisions to close borders, mobile phone data, (migrants prioritise having access to a means of contact), and migration data from organisations such as UNHCR, the UN Refugee Agency.

If a model predicts imminent famine based on historic data and the climate change trajectory, it can recommend alternative farming methods or food sourcing. Predictions could also be used by non-governmental organisations (NGOs), the UN and others to predict the flow of people in and out of refugee camps. They could then establish safeguards against human trafficking prior to the migration, and co-ordinate the safe passage of people across dangerous terrain and seas. In the long-term, governments could learn more about which social, economic and other pressures play a bigger role than others, as well as the interactions between them, in making a person leave one place for another.[49, 50]

A well-known application of facial recognition is Facebook's tagging of people in photos. The technology also offers ways to help ensure national and personal security. Cases in China include customers paying in shops and restaurants with their face, identifying potential drug abusers at public events and verifying university student entries.[51] South Africa has partnered with Moscow-headquartered AxxonSoft to replace private security guards with facial recognition software in

[46] Jones, M. (2018) "Artificial Intelligence for Economic Development Conference: Roundup of 27 presentations", available at http://blogs.worldbank.org/developmenttalk/artificial-intelligence-economic-development-conference-roundup-27-presentations

[47] Nescafe (2017) "Kudi.ai is helping Nigerians pay bills by chatting with a bot", available at www.konbini.com/ng/lifestyle/kudi-ai-helping-nigeria-pay-bills-via-chat

[48] Mwiti, L. (2018) "Mobile loans crisis as 500,000 get blacklisted", available at www.standardmedia.co.ke/business/article/2001283051/mobile-loans-crisis-as-500-000-blacklisted

[49] Nyoni, B. (2017) "How artificial intelligence can be used to predict Africa's next migration crisis", available at www.unhcr.org/innovation/how-artificial-intelligence-can-be-used-to-predict-africas-next-migration-crisis

[50] Schenkman, L. (2018) "How can we save more lives during a refugee crisis? See it coming before it hits", available at https://ideas.ted.com/how-can-we-save-more-lives-during-a-refugee-crisis-see-it-coming-before-it-hits

[51] Horwitz, J. (2017) "In China, facial recognition is used to buy KFC, board planes, and catch drug users", available at https://qz.com/1067460/in-china-facial-recognition-is-used-to-buy-kfc-board-planes-and-catch-drug-users

housing estates and shopping malls, which can be notified of a criminal entering the premises. Furthermore, the company has developed an algorithm to reduce theft in the retail sector, where cashiers pass goods without scanning them to accomplices posing as customers. The software combines CCTV footage of a cashier's workspace with point-of-sale transaction data, which has reportedly led to numerous arrests.[52] In addition to store security, cameras in public spaces could also detect vulnerable people who are lost, anxious or trafficked.[53]

However, there are justified concerns about the use of facial recognition technologies more broadly, particularly in countries where the checks and balances that protect citizens from intrusive surveillance by the state may not be entirely robust.[54, 55] Furthermore, one well-documented constraint to implementing facial recognition technology is the unintentional bias created by training algorithms on under-representational data sets, that is, predominantly white or Asian. Recent research by the MIT Media Lab showed that facial recognition systems misidentified gender in up to 35% of darker-skinned women.[56]

A further security use for AI was explored by researchers who used machine learning to evaluate the merits of interventions targeting ex-combatants in Colombia. Machine learning allows researchers to consider multiple covariates. In this case, variables including confidence in government, ensuring emotional wellbeing and cutting relations to commanders were measured against risk factors such as employment. The results could be used to help shape policies aimed at preventing a return to conflict.[57] When considering such applications, however, it is important to keep in mind the sensitive socio-political conditions they are being deployed in.

The further future

Today's AI systems operate in narrow domains. They may be better than humans at specific tasks, but are not good at switching tasks. DeepMind's famous AlphaGo agent that beat the world's best 'Go' player Lee Sedol, could never make a cup of tea. Scientists disagree over when, if ever, AI agents will be created that can switch between tasks and outperform a human at any intellectual challenge. Nick Bostrom famously polled AI experts in 2013 asking them when they thought this stage of Artificial General Intelligence would be reached. The average answer was 2040, although

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[52] Hedley, N. (2018) "Is facial recognition technology the end of the security guard?", available at www.businesslive.co.za/fm/fm-fox/2018-02-22-is-facial-recognition-technology-the-end-of-the-security-guard

[53] Lewis, P. (2018) "'I was shocked it was so easy': meet the professor who says facial recognition can tell if you're gay", available at www.theguardian.com/technology/2018/jul/07/artificial-intelligence-can-tell-your-sexuality-politics-surveillance-paul-lewis

[54] NHK (2018) "Facial Recognition Technology Causes Surveillance Worries in China", available at www3.nhk.or.jp/nhkworld/nhknewsline/backstories/facialrecognitiontechnology

[55] Wingfield, N. (2018) "Amazon Pushes Facial Recognition to Police. Critics See Surveillance Risk.", available at www.nytimes.com/2018/05/22/technology/amazon-facial-recognition.html

[56] Goode, L. (2018) "Facial recognition software is biased towards white men, researcher finds", available at www.theverge.com/2018/2/11/17001218/facial-recognition-software-accuracy-technology-mit-white-men-black-women-error

[57] Samii, C. et al. (2016) "Retrospective Causal Inference with Machine Learning Ensembles: An Application to Anti-Recidivism Policies in Colombia", available at https://arxiv.org/pdf/1607.03026.pdf

there was very wide variation, with some saying much sooner and some saying it would never be reached. Bostrom argues that, if this point is reached, then an Artificial Superintelligence could be created soon afterwards that is much more powerful than any human. Bostrom and others have argued that, even if this scenario is fairly unlikely, we should still invest in the research (both technical and philosophical) needed to make sure that such a superintelligence was a force for good.[58]

When it comes to the economy, some authors including Calum Chace, predict that we are only a few decades away from an "Economic Singularity" when most humans will become unemployable because machines (AI systems plus robots) will be able to do anything that we can do – cheaper, faster, and better. Chace doesn't believe that this is necessarily a bad scenario, but he does believe that a huge social and political effort will be required to make this turn out well for humanity.[59]

Challenges

AI relies on high volumes of quality data. However, the sectors in most need of advancement often lack the required quantity and quality of data. For example, one such sector is healthcare, where most data is stored in formats that are not machine readable, and electronic health records are largely unheard of. Latin American countries provide an exception in terms of data management in healthcare: 73% of hospitals across Chile have implemented national electronic health record systems.[60]

Providing an open and secure data environment involves building frameworks that enable the sharing of (sensitive) information with other organisations and sectors. Despite large numbers of internet users, countries such as Kenya and Nigeria still lack data protection and privacy laws.[61] Policymakers will need to create clear legal guidelines on data ownership, transfer and usage. There will also be benefits to harmonising requirements between governments and adopting regional policies. Countries in trade blocs, such as ASEAN, are already well connected in terms of trade and people. A top priority is ensuring the same for cross-border data flows.

One way to counter missing regulation is with the use of a regulatory sandbox, or a software-testing environment. Developers can test innovations with real data and customers in a live market, under controlled parameters. For example, Fastcase, a legal research software company based in Washington, DC, launched an 'AI sandbox' for law firms, where they are able to access other data sets as well as test AI analytics tools on their own data.[62] We would suggest that policymakers in LMICs should explore the potential for setting up 'regulatory sandboxes' in their own countries for their own sectors of interest.

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[58] Bostrom, N. (2014) "Superintelligence", Oxford University Press, Oxford

[59] Chase, C. (2016) "The Economic Singularity", Three Cs, London

[60] Corpart, G. (2017) "The Healthcare Data Revolution in Latin America", available at http://globalhealthintelligence.com/ghi-analysis/the-healthcare-data-revolution-in-latin-america

[61] Bizimungu, J. (2018) "Is Africa ready to protect citizens' personal data?", available at www.newtimes.co.rw/news/africa-ready-protect-citizens-personal-data

[62] Ambrogl, R. (2018) "Fastcase Officially Launches Its AI Sandbox and Firms that Will Participate", available at www.lawsitesblog.com/2018/04/fastcase-officially-launches-its-ai-sandbox-and-firms-that-will-participate.html

Interviews with our contributors reinforced the importance of avoiding normative approaches to the opportunities and risks posed by these technologies. Faith Keza, Head of Technology at RwandaOnline, a company tasked with developing an eGovernment platform for the Rwandan government, highlighted that some concerns around data privacy vocalised in high-income countries may not be, by default, shared by people in LMICs (opponents of the Rwandan government might have a different view of course). For example, the conversation around the use of data for AI applications in the US and Europe is dominated by a discussion on the balance between privacy and openness, and whether focusing too much on privacy will restrict the development of AI. It should not be assumed that consumers and citizens in LMICs will reach the same conclusions in such debates as in high-income countries. Rather, these consumers should be empowered to be able to understand the pros and cons of allowing their data to be used for the development of AI tools. There is currently a lack of awareness of privacy issues and of the ways personal data can be misused. This is restricting the ability of citizens of LMICs to meaningfully consider these issues.[63]

B.2 Internet of Things (IoT)

IoT refers to a single device or network of devices that can be monitored and/or controlled from a remote location, and which can transfer data without requiring human-to-human or human-to-computer interaction. Although when the term was first coined in 1999, it was used in the context of supply chain management, today a 'thing' can be a farm animal with a biochip transponder or a car with sensors alerting the driver to low tyre pressure. Among other things, the IoT can generate insights and improvements in healthcare, utility management, industry and environmental protection, and could present many opportunities in LMICs. Its fundamental objective is to achieve the same impact with fewer resources, or to increase the impact with the same resources. Business Insider Intelligence predicts that there will be 24 billion IoT devices on Earth by 2020, and investments in the technology will generate $13 trillion by 2025. In India alone, 4 million application engineers are working on IoT-related ventures.[64–68] Currently, IoT systems function at a local level, whether on one particular farm or in one city. We would speculate that there may come a point when all these systems are safely and reliably interconnected, and the IoT, or a number of IoTs, function at a global scale.

Devices that enable IoT functioning include sensors and actuators. Sensors, or devices that detect and respond to input from the environment, come in various forms and with various functionalities: moisture sensors in fields can inform farmers of their crops' precise water needs, and pressure

[63] Interview with Faith Keza, 6 July 2018

[64] The World Economic Forum (2015) "Deep Shift Technology Tipping Points and Societal Impact", available at www3.weforum.org/docs/WEF_GAC15_Technological_Tipping_Points_report_2015.pdf

[65] Meola, A. (2018) "What is the Internet of Things (IoT)? Meaning & Definition", available at www.businessinsider.com/internet-of-things-definition

[66] Rouse, M. (2018) "internet of things (IoT)", available at https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT

[67] Patel, M. (2017) "How IoT Will Navigate The Future Of Smart Cities In India", available at http://ceoworld.biz/2017/12/27/how-iot-will-navigate-the-future-of-smart-cities-in-india

[68] Miazi, N. et al. (2016) "Enabling The Internet of Things in Developing Countries: Opportunities and Challenges", available at http://wireless.ictp.it/Papers/IoT_Developing.pdf

sensors can monitor traffic flow over bridges. Actuators are devices that can be directed to perform a task, such as opening and closing an irrigation dam.[69] Sensor technologies are improving in terms of miniaturisation, performance, cost and energy consumption. Back in 2014, Spansion Inc. developed sensors that do not need batteries, using chips that can harvest their own energy from the sun, vibration, or heat.[70] In future, smart materials may take over the role of sensors; graphene-based clothing could allow emergency responders to check conditions before entering a hazardous building; 'smart concrete' could alert engineers to wear and tear.[71, 72]

IoT and smart cities: Improving the management of utilities, waste and traffic

A total of 66% of the world's population is expected to live in urban areas by 2050. There is a global need for smart cities as a result of the associated increases in pollution, traffic and energy demand. In Latin America, almost 80% of the population lives in cities, and national and local governments are developing digital strategies to improve connectivity, services and accountability – for example, Uruguay Digital, Colombia's Vive Digital and Mexico's Digital Agenda.[73] US networking giant Cisco is working on smart solutions for cities including Guadalajara, Mexico and Jaipur, India.[74, 75]

In a smart city, a city-wide network of sensors and wifi will help run everything from street lighting to parking, and traffic to waste management, alerting officials to issues before they become problems.[76] Smart sewers will monitor flow levels and manage gates to direct flows to where there is sufficient space, preventing overflow into rivers. Sensors on bridges will enable continuous bridge health monitoring and determine deviations from the target load.[77] The IoT can also help particular population groups. For example, the American city of Louisville distributed 1,000 sensor-equipped inhalers to asthma sufferers, and tracked the data to map where air quality triggered breathing problems. The city planted trees in one of the worst areas and consequently reduced particulate matter by 60%.[78] In future, the concept of smart cities may progress to a country level, where governments are provided with real-time information about economic production and activity.

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[69] International Telecommunications Union (2016) "Harnessing the Internet of Things for Global Development", available at www.itu.int/en/action/broadband/Documents/Harnessing-IoT-Global-Development.pdf

[70] Takahashi, D. (2014) "Spansion goes battery-less with tiny 'Internet of things' chips", available at https://venturebeat.com/2014/06/05/spansion-eliminates-need-for-batteries-in-tiny-internet-of-things-chips

[71] Textile Today (2017) "Graphene to make revolutionary changes in smart clothing technology", available at www.textiletoday.com.bd/graphene-make-revolutionary-changes-smart-clothing-technology

[72] Moruzzi, M (2016) "How smart materials will literally reshape the world around us", available at https://techcrunch.com/2016/09/17/how-smart-materials-will-literally-reshape-the-world-around-us

[73] Santiso, C. (2018) "Going digital: restoring trust in government in Latin American cities", available at www.oecd-forum.org/users/80160-carlos-santiso/posts/29680-going-digital-restoring-trust-in-government-in-latin-american-cities

[74] Gaskell, A. (2017) "Smart Cities And Smart Sewers", available at www.huffingtonpost.com/adi-gaskell/smart-cities-and-smart-se_b_14488630.html

[75] Cisco "Cisco helps turn Jaipur into a Smart and Safer City", available at www.cisco.com/c/dam/en_us/solutions/industries/docs/jda-architecture-case-study.pdf

[76] Ammachchi, N. (2014) "Cisco to Help Transform Guadalajara into a Smart City", available at www.nearshoreamericas.com/guadalajara-turns-cisco-grow-smart-city

[77] Dorsch, L. (2017) "Connected infrastructure: How IoT enables bridge health monitoring", available at https://blog.bosch-si.com/smart-city/connected-infrastructure-how-iot-enables-bridge-health-monitoring

[78] Imaginovation (2017) "How IoT will make Cities Healthier, Safer, More Efficient", available at https://medium.com/@Imaginovation/how-iot-will-make-cities-healthier-safer-more-efficient-c576a21097c7

The IoT also has applications in surveillance and policing, although these can be highly controversial. Data from a central CCTV network, as well as social media and other sources, could be analysed to make accurate crime predictions. LED street lights could dim or brighten according to whether a car or pedestrian is passing. Smart guns could be used by law enforcement. The guns would collect and store data on location and time of fire. ShotSpotter technology uses connected microphones to pick up the audio frequency of gunshots, which can help the authorities pinpoint the location of a shooting in seconds. A judgement in Cape Town this year was the first ever ShotSpotter-linked conviction and sentence.[79]

Chinese networking giant Huawei has developed a network of connected CCTV that uses licence plate and facial recognition technology. Police officers are equipped with special apps that allow them to perform identity and vehicle checks, and assess camera footage. The Chinese district of Longgang, Shenzhen, has reported a drop of 53% in theft and robbery and a 45% increase in crimes solved.[80] Of course, surveillance throws up an array of ethical and privacy issues, so the benefits and risks of using emerging technologies for such purposes should be weighed carefully.

The Industrial Internet of Things (IIoT)

The IIoT refers to the use of the IoT to enhance manufacturing and industrial processes. Two of the IIoT's key attractions are operational efficiency and the predictive maintenance of assets. By using sensors, analytics and real-time data, companies can anticipate equipment failures and respond to emergencies such as leaks or adverse weather. Predictive maintenance can generate additional revenue by avoiding unnecessary shutdown. For example, elevator manufacturer ThyssenKrupp uses networked sensors to avoid service personnel making unnecessary repair trips. Analytics software distinguishes between issues that require immediate attention and those that can wait for scheduled maintenance.[81]

The World Economic Forum has identified four phases of the IIoT. In the short term, there are immediate opportunities around Operational Efficiency (asset utilisation, worker productivity), and New Products and Services (pay-per-use, data monetisation). The long-term opportunities are around an Outcome Economy (pay-per-outcome, selling measurable services), and an Autonomous, Pull Economy (end-to-end automation). In other words, the IoT- enabled industry of the future will be highly automated, and characterised by flexible manufacturing, real-time demand sensing, resource optimisation and waste reduction.[82]

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[79] Isaacs, L. (2018) "Shotspotter technology helps with conviction of manenberg man", available at http://ewn.co.za/2018/06/21/shotspotter-technology-helps-with-conviction-of-manenberg-man

[80] Reichert, C. (2017) "Huawei focuses on making smart cities safe with IoT", available at www.zdnet.com/article/huawei-focuses-on-making-smart-cities-safe-with-iot

[81] The World Economic Forum (2015) "Industrial Internet of Things: Unleashing the Potential of Connected Products and Services", available at www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

[82] The World Economic Forum (2015) "Industrial Internet of Things: Unleashing the Potential of Connected Products and Services", available at www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

IoT for improving healthcare, education, agriculture and transport

The IoT has many promising applications in healthcare. Data can be captured inside a hospital and remotely, allowing healthcare practitioners to monitor patients who return home. Smart beds can modify the bed angle or pressure to increase the comfort of patients who have to rely on nurses to move them. Diabetes apps and wearables can improve self-management, for example, by prompting patients to take their insulin dose. IoT and facial recognition could help paralysed patients manipulate devices such as the air-conditioning, TV or lights.[83] The IoT can also help hospital management determine whether specialist doctors are over- or under-utilising equipment. This could be particularly useful in a resource-poor setting, to establish whether expensive magnetic resonance imaging (MRI) equipment, for example, could be moved around a hospital based on need, making more efficient use of limited resources.[84]

One of the reasons that many children in LMICs go unvaccinated each year is that vaccines get spoiled in transit, due to insufficiently low temperatures. Many of the 200,000 vaccine fridges being used in LMICs are located in extreme and remote places, where maintaining an environment of 2 to 8 degrees Celsius is very challenging. ColdTrace, a real-time monitoring and data analytics platform developed by NexLeaf Analytics, monitors fridge temperatures and sends out alerts by text message to nurses at a clinic in cases of temperature rises. The nurse can respond by checking the latch or turning on the generator. As the system collects the fridge data, patterns can help with diagnosing issues. In case of malfunction, repairs can be carried out remotely, by a mechanic guiding a nurse through the steps over the phone.[85]

Agriculture in LMICs is increasingly faced with the consequences of environmental shocks, lack of proper fertilization, use of excessive chemicals and pesticides, and inefficient crop monitoring systems.[86] Deforestation poses another problem. Projects by the Rainforest Connection in Peru combine acoustic sensors with real-time machine learning analysis. The aim is to curb illegal logging in protected rainforests, by picking up relevant sounds, such as chainsaws and trucks in unauthorised areas.[87]

IoT-enabled precision agriculture can improve crop planning, help keep precise farm records, optimise the consumption of pesticides and reduce environmental pollution. For example, farmers can combine connected tractors and planters with analytics software to apply the optimal mix of seed and fertiliser, at precise depths, to maximise crop yield. Intelligent transmission systems that continuously monitor and analyse data about the route and driver's behaviour can signal when to

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83 Morgan, J. (2018) "8 Ways IoT Can Improve Healthcare", available at https://datafloq.com/read/8-ways-iot-can-improve-healthcare/3066

84 Accenture (2015) "Driving Unconventional Growth through the Industrial Internet of Things", available at www.accenture.com/us-en/_acnmedia/Accenture/next-gen/reassembling-industry/pdf/Accenture-Driving-Unconventional-Growth-through-IIoT.pdf

85 Nexleaf (2017) "IoT for development: Coldtrace", available at http://nexleaf.org/impact/coldtrace-real-time-data

86 Miazi, N. et al. (2016) "Enabling The Internet of Things in Developing Countries: Opportunities and Challenges", available at http://wireless.ictp.it/Papers/IoT_Developing.pdf

87 Kapoor, S. (2018) "Google lends its machine-learning tool to fight deforestation", available at http://houseofbots.com/news-detail/2423-1-google-lends-its-machine-learning-tool-to-fight-deforestation

shift gears, thus conserving fuel and enabling transmissions to last longer. A smart greenhouse can measure and adjust the environmental parameters, such as light, pressure and humidity, eliminating the need for constant manual monitoring. Actuators could automatically turn on the lights or open a window.[88] The IoT could also help policymakers plan for the future production of crops and maintain food security. It is important to note that, not only are many of these proposed applications only at an experimental or even speculative stage of development, but they may be more suitable to larger farms than to the small-scale farms that constitute 80% of farms in Sub-Saharan Africa.[89] Therefore, the applicability of this technology in low-income countries remains to be seen.

IoT is also being deployed in transport. For instance, driver distraction is one of the major causes of road accidents. Smart devices could collect data on drivers' cognitive responses, their physical and mental health, and the vehicle's safety. They would then alert the driver to issues such as fatigue. They could even intelligently stop the vehicle, thus mitigating road accidents. Smart headwear offers a cheaper alternative to retrofitting a truck cabin with sensors; Ford Brazil is developing a Safe Cap that first vibrates and then uses sounds and flashing lights if head movements associated with fatigue persist.[90] High tech can also be combined with the human touch, as with the Michelin EFFIFUEL service. It uses sensors inside trucks to collect information on fuel consumption, tyre pressure, speed, and so on. Fuel experts then analyse the data to give recommendations to driving instructors, who train employees in how to optimise their driving. In addition, EFFIFUEL clients can pay for tyres on a per-kilometre-driven basis – that is, paying for a product as a service. Companies thus add value to what they offer their clients, by providing information.[91]

Challenges

Although the costs of components such as sensors are decreasing, use and implementation of the IoT can be expensive, especially at a large scale. Where it is used in conjunction with mobile phones, separate contracts may be needed because running costs can accumulate when sensors regularly send text messages. Similarly, once the initial, large capital investment is made to purchase industrial equipment, there may be little incentive to spend more money making the modifications required for the IoT. Another major expense related to the IoT is the cost of skilled staff required to operate and maintain it. The lack of on-the-ground expertise, for example, is one of the many barriers experienced by India's ambitious Smart City Mission.[92]

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88 IoT For All (2018) "IoT Applications in Agriculture", available at www.iotforall.com/iot-applications-in-agriculture

89 Collier, P. and Dercon, S. (2009) "African Agriculture in 50 years: smallholders in a rapidly changing world?", Expert Meeting on How to Feed the World in 2050, Food and Agriculture Organization of the United Nations' Economic and Social Development Department, available at www.fao.org/3/a-ak983e.pdf

90 AFP-Relaxnews (2017) "Hats off to Ford for this smart idea that detects driver fatigue", available at www.malaymail.com/s/1511621/hats-off-to-ford-for-this-smart-idea-that-detects-driver-fatigue

91 Emad (2016) "Michelin: Tires-as-a-Service", available at https://rctom.hbs.org/submission/michelin-tires-as-a-service

92 Sharma, A. (2018) "Demystifying the current state of India's ambitious Smart City Mission", available at www.digit.in/internet-of-things/demystifying-the-current-state-of-indias-ambitious-smart-city-mission-39370.html

Lastly, putting manufacturing plants, equipment, or remote facilities online can make them vulnerable to cyber attacks and data theft. Cybersecurity is therefore essential to building a reliable IoT network. It must be closely monitored, for example, by keeping an inventory of the sensors and devices online, building in failsafe mechanisms to prevent physical harm, and managing legacy systems. This all adds to the expense of this technology, and requires highly skilled operators. Thus, the expenses associated with deploying IoT solutions may be prohibitive to many countries, which have access to various sources of financing, including venture capital firms, development banks, and machinery-related lending.[93, 94]

B.3 Augmented Reality (AR) and Virtual Reality (VR)

VR refers to the simulation of an environment, by generating realistic sensory inputs such as sound and imagery. A simple form of VR is a 3D image on a computer screen, which can be explored by moving the mouse or pressing keys. At the other end of the spectrum, haptic devices, such as gloves that emit vibrations, allow the user to feel the environment.[95] In China alone, 200 startups are working on VR and the country's VR market will be worth an estimated $8.5 billion by 2020.

The potential for VR to be used for good is based on its added dimension of presence. VR can provide a way for the user to walk alongside people who seem different or far away.[96] It also offers a much more transparent medium than social media, for example, for accessing socio-political debates. Perhaps in future, VR will unlock new levels of empathy with marginalised groups, such as women and children, by offering unprecedented access to how they live their lives. By bringing people closer to the 'other', VR could even play a part in fostering peace. In politics, VR could allow new levels of engagement; perhaps people will be interested in a VR experience of being the Mayor or President for the day.

The humanitarian sector is making use of VR for storytelling, as a way to immerse users in a world they will likely never experience, build empathy and gain new donors, as well as show existing donors where their contributions go. *Clouds Over Sidra* is a VR tour of the Syrian refugee camp Za'atari in Jordan, filmed for the UN in partnership with Samsung. By following 12-year-old Sidra as she goes about her life in the camp, the film offers a chance for the voices and experiences of the world's most vulnerable citizens to be amplified, with the aim of bringing them into decision-making processes. The UN has reported higher donation rates and more long-term commitments following screenings of the film.[97, 98] In May 2015, Amnesty International launched its #360Syria

[93] OECD (2017) "Opportunities and Policy Challenges of Digitalisation in Southeast Asia", available at www.oecd.org/southeast-asia/events/regional-forum/Forum_Note_Digital_Transformation_STI.pdf

[94] Parmar, D. (2018) "4 obstacles to IoT adoption & how to fix them", available at https://jaxenter.com/4-obstacles-iot-adoption-fix-146939.html

[95] Rouse, M. (2015) "virtual reality", available at https://whatis.techtarget.com/definition/virtual-reality

[96] Lapowsky, I. (2015) "Oculus' founder on the pros and cons of VR for social good", available at www.wired.com/2015/04/palmer-luckey-social-change

[97] Here Be Dragons, available at www.dragons.org/clouds-over-sidra

[98] UNICEF (2015) "How the United Nations is Using Virtual Reality to Tackle Real-World Problems", available at http://unicefstories.org/2015/10/13/how-the-united-nations-is-using-virtual-reality-to-tackle-real-world-problems

campaign, which used inexpensive VR headsets and led to a 16% increase in people signing up to direct debit donations after one week of fundraising.[99] News services are adding VR to their reporting to show the consequences of human and natural disasters.[100]

AR describes an environment onto which digital information has been overlaid in real time.[101] It differs from VR as users view their actual world. Hardware that can be used to deliver AR applications include head-up displays (HUDs) for windscreens and other screens, smart spectacles such as Google Glass, and standard smartphones. In 2016, Apple CEO Tim Cook stated: "I do think that a significant portion of the population of developed countries, and eventually all countries, will have AR experiences every day, almost like eating three meals a day."[102]

The potential uses for AR are broad:[103]

- **E-governance through AR-enabled devices:** smartphones, smart glasses and in-office displays could leverage a number of accessibility aids, such as translation and graphic instructions, to help citizens complete government forms and applications. These devices could also help people visualise planned public projects, for example, infrastructure, utility facilities, and also to participate in town hall meetings, thus encouraging engagement.

- **Maintenance of city assets:** specialists could give real time expertise and instructions to field workers on how to manage assets, from street lighting to water wells, through head-up windshield displays on maintenance vehicles, smart goggles and hard hat-mounted devices.

- **Emergency response:** AR head-up windshield displays could provide real-time sensor data on dangerous conditions, while helmet-mounted AR visors could help responders navigate through fire or rubble.

- **Public health:** sensors could be combined with AR devices to help citizens decide on the best transport options, in terms of air pollution or carbon footprint.

- **Heritage and tourism:** culturally significant buildings and national resources such as coastlines could be protected by providing an educational experience that would be useful for citizens and tourists alike.

[99] Amnesty International UK (2015) "First use of virtual reality fundraising a hit with members of the public", available at www.amnesty.org.uk/press-releases/first-use-virtual-reality-fundraising-hit-members-public

[100] Gil, L. (2015) "ABC News experiments with VR reporting with coverage of Syria", available at www.wareable.com/vr/abc-news-virtual-reality-video-1699

[101] Rouse, M. (2015) "augmented reality (AR)", available at https://whatis.techtarget.com/definition/augmented-reality-AR

[102] Raymundo, O. (2016) "Tim Cook: Augmented reality will be an essential part of your daily life, like the iPhone", available at www.macworld.com/article/3126607/ios/tim-cook-augmented-reality-will-be-an-essential-part-of-your-daily-life-like-the-iphone.html

[103] Curtin, G. (2017) "6 ways augmented reality can help governments see more clearly", available at www.weforum.org/agenda/2017/02/augmented-reality-smart-government

Occupational uses of AR and VR, including training, health and safety

Seeing a problem virtually can aid understanding and retention, as well as enable people from all corners of the globe to address it together. A highly promising application for AR and VR is therefore education and training.[104] In medicine, for example, VR is already being used to teach students about human anatomy and to research infection-prevention behaviours. Performing a computer simulation of an operation gives students access to a very realistic environment with unobstructed views, and instant feedback.[105–107] In 2017, surgeons from Mumbai and London appeared live as avatars in a single operating room, where they drew virtually on hologram scans of the patient's tumour.[108]

The technologies also have applications in workplace health and safety. Staff can be trained through VR to deal with crowds of shoppers, who may storm the premises of a mall on the opening day of a sale. Oil rig workers can practise fixing equipment in stormy weather. The Greater Stockholm Fire Department used VR goggles to explore the redesign of a district's waterfront. The Department wanted to examine access routes for emergency services, gain an understanding of what firemen should do in an emergency, and provide feedback to the architects.[109] At their plant near Johannesburg, steel and mining company ArcelorMittal is using VR to help screen workers who would deal with maintenance and repairs, for fear of heights. The company has worked with a performance management agency and a gaming company to develop the Blast Furnace Experience, which includes moving platforms that imitate the lift and fans that give the experience of wind speed high up in the air.[110]

AR and VR for business

The modern working environment is increasingly characterised by an on-demand economy and multiple career changes. AR has the potential to revolutionise the workplace, not only in terms of training, but also human interaction. Shop staff can scan a new product and get immediate training, in their chosen language. Immersive product showcases can also strengthen a salesperson's pitch to clients.[111] Participants in a business meeting could point their smartphone at a brochure and

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[104] IT News Africa (2016) "Africa's first interactive digital learning centre launches in South Africa", available at www.itnewsafrica.com/2016/06/africas-first-interactive-digital-learning-centre-launches-in-south-africa

[105] Lung, N. (2018) "NUS Medicine School uses virtual reality to enhance learning of human anatomy", available at www.opengovasia.com/articles/nus-medicine-school-uses-virtual-reality-to-enhance-learning-of-human-anatomy

[106] Clack, L. et al. (2017) "Virtual reality enhanced behaviour-change training for healthcare-associated infection prevention", available at www.frontiersin.org/10.3389/conf.FPUBH.2017.03.00045/4089/3rd_UCL_Centre_for_Behaviour_Change_Digital_Health_Conference_2017_Harnessing_digital_technology_fo/all_events/event_abstract

[107] Ahmed, S. (2018) "Think virtual reality surgery is a thing of the future? Think again…", available at www.jisc.ac.uk/blog/think-virtual-reality-surgery-is-a-thing-of-the-future-think-again-28-feb-2018

[108] Crouch, H. (2017) "Virtual reality connects surgeons from across the globe", available at www.digitalhealth.net/2017/10/surgeons-from-across-the-globe-work-together-virtual-reality

[109] Cousins, S. (2017) "A head start on safety?", available at www.healthandsafetyatwork.com/technology/augmented-reality-virtual-reality

[110] Koolonavich, N. (2018) "ArcelorMittal South Africa Using VR To Test For Fear Of Heights In Staff", available at www.vrfocus.com/2018/05/arcelormittal-south-africa-using-vr-to-test-for-fear-of-heights-in-staff

[111] Sharma, T. (2018) "How augmented reality in the workplace can enhance training", available at www.blippar.com/blog/2018/04/20/how-augmented-reality-workplace-can-enhance-training

an animation would provide further detail. AR technology could act like an informative name tag, providing information on the attendees. VR also allows people to be present in meetings taking place in other locations. For example, a lawyer may not be able to make it to court to represent their client, but could be virtually present instead.[112]

A barrier to investment in businesses based in LMICs is a lack of trust on the part of potential investors – they may not understand the business ecosystem that the company in question developed in, and may not appreciate the local nuances, customs, and challenges associated with business development in the country.[113] VR may help with this by giving potential investors based anywhere in the world an experience of the countries and the people who they are being asked to invest in.

Challenges

VR is currently at a more mature stage than AR. AR tools still present many technical challenges. One such challenge is registration – the problem with misalignment between the virtual avatars and images created by the AR tool, and the 'real world' they are superimposed on. At the very least, this can cause vision fatigue, but it can also have serious implications for contexts that demand total accuracy, such as surgery. AR systems are also unable to satisfy all levels of visual acuity, or eyesight, meaning that some people with poor vision are excluded from using them.

Hardware cost remains a significant constraining factor to scaling up of both technologies: Microsoft's HoloLens, for example, is priced at $3,000. AR and VR also require a lot of bandwidth – 5G connectivity is perceived as critical to ensuring their mainstream deployment. Even when these barriers are overcome, applications need to fit in well with existing systems. In education for instance, tools should complement teaching practices and offer better, cheaper learning methods than what is already provided.[114–119]

112 Speagle, A. "3 Ways VR Technology Will Transform Your Business Meetings", available at www.pgi.com/resources/articles/3-ways-vr-technology-will-create-better-meetings

113 OECD (2009) "Building Trust and Confidence in International Investment", available at www.oecd.org/daf/inv/investment-policy/42446942.pdf

114 Wang, Y. et al. (2017), "Augmented reality with image registration, vision correction and sunlight readability via liquid crystal devices", available at www.nature.com/articles/s41598-017-00492-2

115 Chen, L. (2016) "China's Virtual Reality Market Will Be Worth $8.5 Billion and Everyone Wants a Piece", available at www.bloomberg.com/news/features/2016-05-15/china-s-virtual-reality-market-will-be-worth-8-5-billion-and-everyone-wants-a-piece

116 UNICEF (2016) "Virtuous Reality: Is there a place for VR and AR in the 'for good' space?", available at https://blogs.unicef.org/innovation/virtuous-reality-place-vr-ar-good-space

117 Akl, A. (2017) "Immersive Education Has Promise, but a Long Way to Go", available at https://blogs.voanews.com/techtonics/2017/05/05/vr-education-has-promise-for-developing-world-but-long-way-to-go

118 Augment (2017) "The 3 biggest challenges for augmented reality", available at www.augment.com/blog/3-biggest-challenges-for-augmented-reality

119 Newman, D. (2018) "4 Reasons 5G Is Critical For Mass Adoption Of AR And VR", available at www.forbes.com/sites/danielnewman/2018/03/27/4-reasons-5g-is-critical-for-mass-adoption-of-ar-and-vr/#36c39e2c1878

B.4 Drone Technology

An unmanned aerial vehicle (UAV), or drone, is an aircraft that can fly autonomously or be piloted remotely. Drones were initially intended for military purposes, but there are now numerous civil and commercial applications – for example, cargo delivery, surveying, and more. Drones cause a relatively low degree of disturbance and offer a means to augment distribution networks, by reaching people in remote locations and providing a cheaper and faster alternative to ground activities. However, drones can also threaten air traffic and be used to transport dangerous or contraband goods. Regulations differ from country to country in terms of permitted flight height, drone weight and the licences required; some countries have yet to establish any regulation at all.[120]

The media coverage of promising drone applications mushroomed between 2015 and 2017. Perhaps the most high-profile was Facebook's plan for high-flying drones that would deliver internet, covering 60-mile areas and staying up for months. Although the solar-powered Facebook Aquila achieved a smooth landing following a test flight in 2017, the company recently announced it would no longer be building its own drones, but will work with partners instead.[121, 122]

Drones for filling missing infrastructure gaps

Delivery is the most obvious and common application for drones in countries with poor roads and disconnected communities. Although cargo drones will not replace conventional transport methods, they do allow essential goods to be delivered to remote places, where roads are unlikely to be constructed in the near future. Drones have been delivering blood transfusions in eastern Rwanda since October 2016. The packages are parachuted down, and the shortened delivery time – which can be down from 4 hours to 45 minutes – keeps the supplies fresh and regular. This 'Uber for blood' is the result of a partnership between Zipline, a Silicon Valley robotics company, and the country's health ministry.[123] Similarly, drones are transporting blood samples for HIV tests in remote areas of Malawi, and medical cargo drone flights have been tested in Peru.[124, 125]

120 Wikipedia "Unmanned aerial vehicle", available at https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle

121 Hunter-Hart, M. (2017) "Facebook's Internet Drone Test Goes "Smoothly," Unlike Last Time", available at www.inverse.com/article/33598-facebook-s-internet-drone-test-goes-smoothly-unlike-last-time

122 Satt, N. (2018) "Facebook abandons quest to build its own internet drones", available at www.theverge.com/2018/6/26/17507826/facebook-aquila-internet-drone-project-shut-down

123 McVeigh, K. (2018) "'Uber for blood': how Rwandan delivery robots are saving lives", available at www.theguardian.com/global-development/2018/jan/02/rwanda-scheme-saving-blood-drone

124 Mbah, F. (2017) "UNICEF uses drones in Malawi to speed up HIV diagnosis", available at www.trtworld.com/mea/unicef-uses-drones-in-malawi-to-speed-up-hiv-diagnosis-389506

125 Meier, P. (2017) "Cargo drones deliver in the Amazon rainforest", available at http://robohub.org/cargo-drones-deliver-in-the-amazon-rainforest

Drones for humanitarian applications

UNICEF is collaborating with the government of Malawi on the first Drone Corridor for UAVs and humanitarian aviation in the world, launched in June 2017. The corridor allows global companies to work with local experts to build and test drones with a focus on humanitarian and development use. Solutions must follow the UNICEF innovation principles – that is, open source, open data, sharable, and designed for scale. The focus is on three main areas: imagery (for example, situation monitoring during a mudslide), connectivity (such as extending wifi signal), and transport (for example, vaccine delivery).[126] To maximise the benefits to local communities, such technologies can be paired with actions such as printing the detailed maps produced by the drone cameras onto waterproof material, and sharing them among community leaders.[127]

Humanitarian drone response has also been tested elsewhere, such as in Peru following floods and the displacement of communities. Understanding impact typically requires inspection on the ground or by flying light aircrafts, and both methods are slow and expensive. In November 2017, Peru Flying Labs demonstrated the applicability of drones for this purpose to national and local government representatives, who in turn are responsible for activating the Peruvian armed forces on the ground. This was a clear example of drones augmenting the response operations, while maintaining community trust.[128] WeRobotics is developing AI and machine learning software to automate the analysis of aerial imagery of disaster-affected areas.[129]

Air Shepherd, a pioneering group of conservationists, entrepreneurs and researchers, is using a high-tech combination of drones and AI to fight poaching. The drone's software is trained to identify images of poachers and animals. Air Shepherd has worked in South Africa, Zimbabwe, Malawi and Botswana, but hopes to expand to any location targeted by illegal poaching. The company has reported that flying drones does deter poachers.[130] In addition, the drones can benefit the rangers by providing additional protection during a potentially dangerous operation. Where conservation organisations can afford such technology, the rangers and drone team must be well co-ordinated, be able to make arrests, and save the animals.[131, 132]

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[126] UNICEF (2017) "Africa's first humanitarian drone testing corridor launched in Malawi by Government and UNICEF", available at http://unicefstories.org/2017/06/29/africas-first-humanitarian-drone-testing-corridor-launched-in-malawi-by-government-and-unicef

[127] UNICEF (2017) "Flying high over Malawi: My time working with drones", available at https://blogs.unicef.org/innovation/flying-high-malawi-time-working-drones

[128] WeRobotics (2017) "Peru Flying Labs Responds to Peru Floods with Aerial Robots", available at https://blog.werobotics.org/2017/12/13/peru-floods-response

[129] WeRobotics "Artificial Intelligence for Automated Data Analysis", available at https://werobotics.org/portfolio/artificial-intelligence-for-automated-data-analysis

[130] Worland, J. (2018) "Drones Are Helping Catch Poachers Operating Under Cover of Darkness", available at http://time.com/5279322/drones-poaching-air-shepherd

[131] Nuwer, R. (2017) "High Above, Drones Keep Watchful Eyes on Wildlife in Africa", available at www.nytimes.com/2017/03/13/science/drones-africa-poachers-wildlife.html?_r=0

[132] defenceWeb (2018) "UDS's Air Shepherd launches new operations in southern Africa", available at www.defenceweb.co.za/index.php?option=com_content&view=article&id=52008&catid=74&Itemid=30

Drones for agriculture and healthcare

Drones can fly low over crops and provide data such as warnings of plant stress to farmers through near-infrared sensors, thus preventing crop losses and improving food security.[133] Seeding, irrigation, diagnosing diseases, assessment of crop, soil and animal health, measuring plant number and height and estimating yield are just some of the agricultural activities a drone is well-suited to help with.[134] Apps alert farmers to insufficient water, the presence of pests and a crop performing poorly.[135] Drones are not as limited by geographical features as traditional forms of transport, such as road vehicles, and they can be used for small and fragmented land.[136] In February 2018, the African Union published a Decision, requesting Member States to harness drones for agriculture.[137] FAO in Myanmar is promoting the use of drones in agriculture to update maps, measure fields and crop health, with the objective of managing and reducing disaster risk.[138]

Other agricultural applications may be much more country or region specific. For example, Sudan is facing extreme desertification, resulting in population displacement as communities seek habitable lands. Two Sudanese developers have invented a drone capable of planting the seeds of acacia trees, whose roots prevent massive sand movement. The drone's other capability is remote agricultural sensing for plant health assessment. Unfortunately in this instance, the developers have cited sanctions against Sudan as barriers to obtaining equipment and technical support for the project.[139]

The Sterile Insect Technique is an insect pest control method that deploys radiation, genetic modification, or some other method to sterilise male mosquitoes and reduce the population. The method has the benefit of not having to use pesticides, although there are concerns about releasing modified animals into the wild, especially more recently with genetic modification. Drones offer the possibility of large-scale and cost-efficient releases, also over densely populated areas. This application could be used to stop the spread of viruses such as Zika and dengue fever, for which Aedes aegypti, or the yellow fever mosquito, is responsible. Such a scheme has been tested in Brazil.[140]

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[133] van Vark, C. (2015) "Drones set to give global farming a makeover", available at www.theguardian.com/global-development/2015/dec/26/drones-farming-crop-problems-uavs

[134] ibid.

[135] Opudo, D. (2018) "South African Aerobotics to Help Farmers in Disease Prevention and Yield Increase", available at www.techinafrica.com/south-african-aerobotics-help-farmers-disease-prevention-yield-increase

[136] Pudasainee, A. (2017) "Food security with the help of UAVs", available at www.fao.org/cfs/cfs-home/blog/blog-articles/article/fr/c/1027524

[137] FAO (2018), "African Union embraces drones technology for agriculture", available at www.fao.org/e-agriculture/news/african-union-embraces-drones-technology-agriculture

[138] FAO (2017) "FAO Myanmar promotes the use of drones to enhance disaster risk reduction", available at www.fao.org/e-agriculture/news/fao-myanmar-promotes-use-drones-enhance-disaster-risk-reduction

[139] Child, D. (2018) "From Kigali to Khartoum: Africa's drone revolution", available at www.aljazeera.com/indepth/features/africa-drone-revolution-180123090528801.html

[140] Reagan, J. (2018) "How Drones Are Sterilizing Deadly Mosquitoes", available at https://dronelife.com/2018/04/25/how-drones-are-sterilizing-deadly-mosquitoes

Drones for mapping, monitoring, surveillance, and discovery

Mapping land boundaries is an important step in helping citizens register ownership. In many parts of Africa, boundaries are marked by planting hedges. Drones allow aerial mapping to be performed at a much higher spatial resolution than previously possible, and to capture frequent changes in land use.[141] A project funded by the European Commission, its4land, is testing drones for this purpose in Kenya, Rwanda and Ethiopia. The plan is to expand to other African nations, and two pilots per country have been trained in France. The project is hoping to help distinguish between private, public or community land to foster economic growth and development, for example, by allowing landowners to get loans and for governments to tax them correctly.[142] It is important to note that land ownership can be a highly sensitive issue in many countries, especially in the context of land redistribution.

Drones can be used for monitoring purposes, in ways that ensure funds are being spent appropriately and that help project managers stick to their schedule. In the Gauteng province, South Africa, drones are being used to monitor construction projects and dissuade workers from overstating supplies or ignoring safety regulations. The province has planned 340 community infrastructure projects for the next three years. They will be spending £250 million, and so are using the technology to help stay on schedule.[143] The use of drones and other technologies may help reduce the cost of corruption, which places an estimated 40% 'inefficiency premium' on the price of any project.[144]

The potential applications for drones are multiplied when used in conjunction with other technologies, for example, AI. Researchers from Cambridge, UK and India are developing an autonomous drone surveillance system to identify violent individuals in public areas in real-time. Video footage is analysed by an algorithm trained to pick up 'violent' poses (currently strangling, punching, kicking, shooting and stabbing). The aim is to develop the algorithm further to avoid violent attacks altogether. The researchers report a 94% accuracy rate of detecting the poses, but this falls as the number of individuals in the frame increases. Furthermore, the technology was tested on volunteers who exaggerated their poses – in reality, the footage may be blurry and results less accurate. As with any surveillance application, questions are raised as to who will have access to the footage and permission to act on it.[145]

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[141] Stroeven, C. (2018) "UAV flight permission breakthrough in Kenya", available at https://its4land.com/uav-flight-permission-breakthrough-in-kenya

[142] Wayumba, R. (2017) "Drones are taking to the skies above Africa to map land ownership", available at https://theconversation.com/drones-are-taking-to-the-skies-above-africa-to-map-land-ownership-87369

[143] Gauteng Department of Infrastructure Development (2018) "Gauteng government launches its ambitious drone programme to help monitor delivery of construction projects", available at

www.gauteng.gov.za/media/Statements/Gauteng%20Government%20launches%20its%20ambitious%20programme%20to%20help%20monitor%20delivery%20of%20construction%20projects.pdf

[144] Heathcote, C. (2018) "African roundtable on good infrastructure governance", available at www.corruptionwatch.org.za/first-african-roundtable-good-infrastructure-governance

[145] The Wire (2018) "Drones That Can Spot 'Violent Behaviour' in Crowds to Be Tested in India", available at https://thewire.in/the-sciences/drones-ai-violent-behaviour-india-test-nit-warangal

As drones become smaller, cheaper and more self-organising, they will be able to fly around in large groups, like a flock of birds. Drone swarms are already being tested, particularly within the context of autonomous weapons, but they could be used to pollinate plants, monitor pipelines, and check confined spaces for survivors in the aftermath of an earthquake. While swarming drones are currently still in their infancy, researchers foresee them becoming as common to our environment as insects.[146] At the other end of the size spectrum, large drones could be used to transport humans; companies, including Airbus, are testing 'electric vertical take-off and landing' vehicles, capable of carrying five passengers.[147]

Challenges

News of planned initiatives exploring applications of drone technology appeared to climax in 2017, but there has been a notable lull this year. It may be that pilot studies have hit cost and regulatory barriers, preventing the scaling up from pilot stage of development to widespread use.[148]

Drone technology is yet to be regulated by most countries around the world. This year, the Kenya Civil Aviation Authority released regulations for the commercial use of drones that are more than 2kg in weight, fly over 50 feet above the ground and are not fitted with a camera. The rules include obtaining and renewing a drone and pilot license.[149] Since 2017, the Civil Aviation Administration of China (CAAC) has been giving the go-ahead for delivery companies to start sending packages to certain rural areas.[150]

Trust in the technology is another issue, as people are wary of drones taking photos or films. To address this, the Zipline team in Rwanda has been attending town hall events to assure citizens that their drones are for delivery purposes only, and that cameras are only installed during test flights to map out routes.[151]

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146 Hambling, D. (2017) "The next era of drones will be defined by swarms", available at www.bbc.com/future/story/20170425-were-entering-the-next-era-of-drones

147 Reichert, C. (2017) "Dubai begins testing drone taxi service", available at www.zdnet.com/article/dubai-begins-testing-drone-taxi-service

148 Interview with David Sangokoya, 15 June 2018

149 Wamathai, J. (2018) "You need a license to import & operate a drone in Kenya", available at https://hapakenya.com/2018/03/05/you-need-a-license-to-import-operate-a-drone-in-kenya

150 Lyu, D. et al. (2018) "China Is on the Fast Track to Drone Deliveries", available at www.bloomberg.com/hyperdrive

151 Kuo, L. (2017) "Africa is now the world's testing ground for commercial drones", available at https://qz.com/1003810/the-worlds-first-commercial-drone-delivery-operates-from-a-hill-in-rwanda

B.5 Blockchain and other distributed ledger technologies

Blockchain was invented in 2008 and refers to a digital ledger that records value transactions as blocks. Once recorded, the data in a given block cannot be altered retroactively without alteration of all subsequent blocks. The database is not stored in a centralised location, which protects it from corruption by a hacker, and means the network operates on a peer-to-peer basis. The blockchain was initially invented to serve as the public transaction ledger of the cryptocurrency bitcoin, but applications have spread to governance, identity management and more.[152, 153]

Blockchain technology presents an opportunity to record assets, transfer value and track transactions in a decentralised manner. This can be particularly relevant for countries characterised by weak institutions, a lack of proper documentation and a low trust in government.[154, 155] Records cannot be changed or deleted and the trail of transactions can be used for law enforcement and auditing purposes. Blockchain also presents an opportunity to fill gaps in missing infrastructure and to provide other services at a lower cost by cutting out the middleman.

A number of countries around the world have been proactive in exploring blockchain technologies in the past few years. On the African continent, Rwanda partnered with Swiss-based cybersecurity company WISeKey to establish its Blockchain and IoT Centre of Excellence in early 2017. It has since announced a collaboration with Microsoft. Uganda recently announced the creation of a task force, whose role will be to explore potential applications of the technology.[156] The Democratic Republic of Congo is aiming to launch a pilot scheme to track cobalt's journey from artisanal mines. The aim is to ensure that the cobalt – a battery component of products such as iPhones – has not been mined by children. Each sealed bag of cobalt would get its own digital tag and be entered onto a blockchain with a mobile phone, together with details of weight and time, and so on. This process would be repeated at each stage of the supply chain, and the scheme would initially be closely monitored by various organisations.[157] Businesses are looking at cryptocurrencies as an alternative medium for carrying out cross-border trade, or in response to unstable domestic economies. For example, BitPesa allows Africans living abroad to send money home at a cheaper rate.[158] However, the likelihood of widespread adoption is low, in part because cryptocurrencies cannot be converted into local currencies.[159]

152 Blockgeeks (2016) "What is Blockchain Technology? A Step-by-Step Guide For Beginners", available at https://blockgeeks.com/guides/what-is-blockchain-technology

153 ibid.

154 Santiso, C. (2018) "Can blockchain help in the fight against corruption?", available at www.weforum.org/agenda/2018/03/will-blockchain-curb-corruption

155 Schmidt, K. & Sandner, P. (2017) "Solving Challenges in Developing Countries with Blockchain Technology", available at http://explore-ip.com/2017_Solving-Challenges-in-Developing-Countries-with-Blockchain-Technology.pdf

156 Kiprop, V. (2018) "East Africa: Blockchain Platform to Ease Service Delivery in East Africa", available at http://allafrica.com/stories/201806010658.html

157 Lewis, B. (2018) "Blockchain to track Congo's cobalt from mine to mobile", available at https://uk.reuters.com/article/uk-mining-blockchain-cobalt/blockchain-to-track-congos-cobalt-from-mine-to-mobile-idUKKBN1FM0YI

158 Sheffield, H. (2015) "Bitcoin is being used by African migrant workers to send money home", available at www.independent.co.uk/news/business/news/bitcoin-is-being-used-by-african-migrant-workers-to-send-money-home-10098169.html

159 Schmidt, K. & Sandner, P. (2017) "Solving Challenges in Developing Countries with Blockchain Technology", available at http://explore-ip.com/2017_Solving-Challenges-in-Developing-Countries-with-Blockchain-Technology.pdf

Blockchain for registering land and identity documents

Two of the most popular applications to date are for property registries and basic legal digital documents. Many people in LMICs do not have an identity document, which can prevent them from setting up a bank account or voting. A birth certificate can facilitate an individual's access to education and inheritance. This and other identity documents also provide assurance for government departments and aid charities – for example, as a way to verify that funds are being given to the right person. They are also able to collect data about individuals and communities, and direct resources accordingly, even in remote areas.[160] Blockchain is already being trialled for the delivery of international aid, to help ensure that funds reach the right beneficiaries. In 2017, Disberse, a fund management platform, distributed funds from a UK NGO to a Swazi NGO, and then on to four local schools. The donor saved 2.5% on transfer fees, which translated into schooling three more girls for one year. In 2017, the World Food Programme ran a pilot scheme in Pakistan where two pieces of information were recorded on a private blockchain to distribute funds to refugees: their entitlement; and a unique identification number, linked to biometric data. The platform removes the need for an intermediary bank; money therefore does not need to be sent in advance, and a large proportion of fees are eliminated.[161]

In 2016, the Republic of Georgia began trialling a blockchain-based database for registering land titles. The partnership with cryptocurrency technology company, Bitfury, now covers the sale of land titles and the registration of new ones, as well as mortgages, rentals and notary services.[162] Transactions can be executed in a matter of minutes via smartphone app at the property in question, consequently reducing operational costs by up to 90%.[163] Each land title has its own unique identification code, which is uploaded to multiple public databases. A change to the original document would therefore mean mismatching copies, triggering an alert. The legal owner has sole access to the key that can be used to transfer ownership; the blockchain industry and regulators still need to decide on a standard procedure in the event of a lost key.[164, 165] Prior to the initiative, only 25% of land in the country was registered, and property disputes were common in the chaos that followed the fall of the Soviet Union. There are now more than 1 million uploaded documents, and Georgia's National Agency of Public Registration is looking into implementing smart contracts.

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160 ibid.

161 GSMA (2017) "Blockchain for Development: Emerging Opportunities for Mobile, Identity and Aid", available at www.gsma.com/mobilefordevelopment/wp-content/uploads/2017/12/Blockchain-for-Development.pdf

162 Nimfuehr, M. (2017) "Blockchain application land register: Georgia and Sweden leading", available at https://medium.com/bitcoinblase/blockchain-application-land-register-georgia-and-sweden-leading-e7fa9800170c

163 Schmidt, K. & Sandner, P. (2017) "Solving Challenges in Developing Countries with Blockchain Technology", available at http://explore-ip.com/2017_Solving-Challenges-in-Developing-Countries-with-Blockchain-Technology.pdf

164 Jardine, B. (2018) "Georgia stakes place on wild frontier of blockchain governance", available at https://eurasianet.org/s/georgia-stakes-place-on-wild-frontier-of-blockchain-governance

165 Mearian, L. (2018) "Solving a blockchain conundrum: Biometrics could recover lost encryption keys", available at www.computerworld.com/article/3273429/blockchain/solving-a-blockchain-conundrum-how-biometrics-could-recover-lost-encryption-keys.html

Similar projects are underway in African countries, with plans to expand in the next 5 years.[166] In Ghana, the startup Bitland has begun helping farmers register their land online, following interviews with them, their neighbours and chiefs to determine ownership. Prior to this process, 80% of Ghanaian landowners lacked title, and oral agreements were the norm. A Blockchain Masterclass initiative in Ghana aims to grow awareness of the technology and its benefits with regards to solving land challenges in Africa.[167] Real estate company, Land LayBy Ghana, is seeking to scale and develop the solution with other partners.

Kai Schmidt and Philipp Sandner, authors of the article *Solving Challenges in Developing Countries with Blockchain Technology*, identify various benefits for citizens who register their real estate, including using it as collateral, and being incentivised to invest in their property. This in turn indirectly lowers fertility rates and improves child education levels. Clear ownership allows companies and governments to contact the owners of real estate when, for example, building a facility nearby. The financial impact on business and individuals is thus considerable. Before any of this can be implemented, however, disputes over ownership must be resolved; other technologies such as satellite imagery and drones can help with this.[168]

Some other blockchain applications include:

- **Budget-tracking** could help tackle corruption at a local level. Although money can be redirected, blockchain monitors all the transaction details, from the transaction amount and time to the receiver. At a government level, ministries would be able to track expenditure and analyse budgets, providing a more detailed overview of impact.[169]

- **Microfinance through peer-to-peer lending** helps to tackle financial exclusion. Small and medium-sized enterprises (SMEs) can represent the vast majority of a country's businesses – 96% in Nigeria for example – but new entrants and startups find it incredibly difficult to access loans from banks. In 2017, German peer-to-peer (P2P) lender, Bitbond, and Bitcoin-based mobile payments provider, BitPesa, announced an initiative connecting individuals and investors with small businesses in Kenya, Nigeria, Tanzania and Uganda.[170]

- **Smart contracts** provide programmable agreements, with predefined rules and penalties, which make automatic payouts between two parties once certain criteria have been met. These contracts are secured in the blockchain as 'self-executing contractual states', which eliminates the risk of relying on others to follow through on their commitments. For

[166] Wafula, D. (2018) "Crypto in Africa: Domestic crypto market shows great prospects", available at https://coingeek.com/crypto-africa-domestic-crypto-market-shows-great-prospects

[167] Ayemoba, A. (2018) "Land LayBy Ghana Launches Debut Land Management Blockchain Masterclass", available at www.proshareng.com/news/Property%20&%20Real%20Estate/Land-LayBy-Ghana-Launches-Debut-Land-Management-Blockchain-Masterclass/40093

[168] Schmidt, K. & Sandner, P. (2017) "Solving Challenges in Developing Countries with Blockchain Technology", available at http://explore-ip.com/2017_Solving-Challenges-in-Developing-Countries-with-Blockchain-Technology.pdf

[169] ibid.

[170] Parker, L. (2017) "BitBond and Bitpesa target P2P loans for African Businesses", available at https://bravenewcoin.com/news/bitbond-and-bitpesa-target-p2p-loans-for-african-businesses

example, a smart contract can be set up between a council and a local tradesman who is responsible for repairing a pothole. The tradesman would receive payment automatically upon uploading a photo of the completed project. However, challenges include working out how the system reads the criteria – in this case how it would distinguish between a poorly- or well-repaired pothole, and how to allow for renegotiation.

-Distributed governance, where digital voting circumvents obstacles such as distance and election fraud. Individuals would have their own anonymous key that allows them to cast a vote.

Lucas Zaehringer, a blockchain enthusiast based in Germany, has set up Positive Blockchain. This is a database of 500 projects that use blockchain technologies to generate positive social impact, and a platform to link various stakeholders, from startups to governments and NGOs. He is confident in blockchain's capacity to become mainstream in the next five to ten years, as the technology relies on pre-existing infrastructure, namely mobile phones and the internet.[171]

Challenges

For citizens to be incentivised to use blockchain solutions, they must first understand the benefits of registering land or the birth of their child. This may be tricky if populations have survived, and even thrived, without such documentation for generations.[172] Nairobi-based real estate firm Land Layby Group envisages rewarding correct entries of land registration with tokens, although these would only have nominal value at present.[173] Such initiatives may need to be upgraded to actual monetary payment if the technology is to gain any traction.

As with most new digital technologies, blockchain relies on accurate data, digitalised registries and reliable digital identities. The information uploaded on the blockchain in the first place must be accurate, so it is reasonable to suggest that mechanisms for data validation are necessary. Some would argue, however, that demanding regulatory oversight in the form of data entry vetting negates the very feature that makes the blockchain so attractive, namely the lack of a central regulator. Developing governance models that balance blockchain's decentralised and private nature with overseeing standards such as data vetting remains a challenge.

171 Interview with Lucas Zaehringer, 12 June 2018

172 Schmidt, K. & Sandner, P. (2017) "Solving Challenges in Developing Countries with Blockchain Technology", available at http://explore-ip.com/2017_Solving-Challenges-in-Developing-Countries-with-Blockchain-Technology.pdf

173 Mwanza, K. & Wilkins, H. (2018) "African startups bet on blockchain to tackle land fraud", available at www.reuters.com/article/us-africa-landrights-blockchain/african-startups-bet-on-blockchain-to-tackle-land-fraud-idUSKCN1G00YK

The lack of regulatory oversight means that cryptocurrencies can be a risky investment. For example, Central Banks do not offer any recourse to investors who lose money on cryptocurrencies. Finally, the running of the complex algorithms associated with cryptocurrency mining require large amounts of computational power; the energy spent on mining Bitcoin alone in 2017 surpassed the average electricity consumption of 159 countries.[174–176]

B.6 Quantum Computing

Of the technologies discussed in this paper, quantum computing is perhaps at once the most speculative and the most potentially paradigm-shifting. Quantum computers are devices that solve problems using the counterintuitive rules of quantum physics, such as superposition and entanglement (Box 1). Unlike ordinary classical computers – which only store information in 'bits' that are zeros or ones – quantum computers use 'qubits' that can be a mixture of both one and zero at once, thanks to superposition and entanglement. This theoretically allows a quantum computer to process a vast number of calculations simultaneously, as the qubits responsible for the calculations can use ones, zeros, and 'superpositions' of ones and zeros. Therefore, certain difficult tasks, long thought to be impossible for classical computers, could be achieved quickly and efficiently by a quantum computer.[177]

[174] Business Day (2018) "Bitcoin is not a currency, says Reserve Bank", available at www.businesslive.co.za/bd/national/2018-05-25-bitcoin-is-not-a-currency-says-reserve-bank

[175] Wall, L. (2016) ""Smart Contracts" in a Complex World", available at www.frbatlanta.org/cenfis/publications/notesfromthevault/1607

[176] Marr, B. (2018) "The 5 Big Problems With Blockchain Everyone Should Be Aware Of", available at www.forbes.com/sites/bernardmarr/2018/02/19/the-5-big-problems-with-blockchain-everyone-should-be-aware-of/#2005c36a1670

[177] "Quantum Computing 101", University of Waterloo Institute for Quantum Computing, available at https://uwaterloo.ca/institute-for-quantum-computing/quantum-computing-101#Superposition-and-entanglement

Box 1: A brief explanation of the physics behind quantum computing

Niels Bohr, the Nobel prize-winning Danish physicist who is known as the 'Father of the Atom' for his seminal work on atomic structure and quantum physics, famously said: "Anyone who is not shocked by quantum theory has not understood it." To this day, quantum physics retains an air of impenetrability to the lay observer, even though its strangest predictions have been repeatedly experimentally proven.[178] Briefly, quantum theory is the theoretical basis of modern physics that explains the nature and behaviour of matter and energy on the atomic and subatomic level. On these scales, particles exhibit properties that cannot be observed at the larger scales human beings normally experience.

One such property is that of superposition. This refers to the statistical concept that, at the quantum scale, particles exist across all possible states (in terms of their position, speed, or energy level) at the same time, with a probability associated with each state. This superposition of states exists until the particle is 'observed' or 'measured'. A well-known analogy that has been used to discuss the implications of superposition is that of Schrödinger's cat.[179] It is superposition that allows the qubits in quantum computers to be in both a '0' and a '1' state at once.

Another property is entanglement. Dismissed by Albert Einstein as "spooky action at a distance", quantum entanglement refers to the fact that, if two quantum systems interact, it becomes impossible to measure the features of one system (such as its position, momentum and polarity) without instantly observing the same features in the other, even if the two systems are separated across a distance of thousands of light years. In quantum computers, entanglement allows a number of qubits to exist in strongly correlated states, increasing their computational power.

The potential applications of such a step change in how computing occurs are vast, but it is important to emphasise that there are significant scientific, theoretical, and engineering challenges that need to be overcome before this potential is realised. However, many in the field are confident that these applications will begin to come on stream by the 2040s.

There are four main areas of application for quantum computing. The one that receives most attention is cryptography. The fact that it is extremely difficult for a classical computer to find the prime factors of a very large number forms the basis of much present day cryptography. For example, credit card number encryption relies entirely on the fact that this factoring problem is difficult.[180] Quantum computation could allow the development of novel encryption techniques, as well as allowing the cracking of traditional encryption methods, with implications for cybersecurity and intelligence. In fact, work is already underway to develop so-called 'post-quantum' cryptography protocols that would be resistant to decryption attempts by quantum computers. Such protocols, when developed, will likely entirely replace the existing major protocols (Transport Layer Security [TLS] and its predecessor, Secure Sockets Layer [SSL]).

Another complex problem that would benefit from the development of quantum computers is the modelling of chemical reactions. Classical supercomputers struggle with modelling the behaviour of complex molecules (such as proteins) or dynamic processes over time (such as reactions). On the other hand, quantum computing could allow us to model, and thus better understand, complex chemical reactions, leading to the development of new industrial chemicals and new medicines.

178 Orcel, C. (2015) "Three Experiments That Show Quantum Physics is Real", Forbes, available at wwww.forbes.com/sites/chadorzel/2015/07/20/three-experiments-that-show-quantum-physics-is-real/#1b963a431ae5

179 Gribbin, J. (2011) 'In Search of Schrodinger's Cat: Quantum Physics and Reality", Random House Publishing Group, p.234. ISBN 0307790444

180 Beall, A. and Reynolds, M. (2018) "What are quantum computers and how do they work?", Wired, available at www.wired.co.uk/article/quantum-computing-explained

Quantum sensing is another potential application of this technology. Quantum physics allows the development of entirely new modalities of sensors, such as detectors that can be placed *within* living cells and measure magnetic field and temperature without affecting the cell's function. Such sensing abilities could open up whole new areas of research and improve understanding of biological processes in hitherto unimaginable ways.

Another area of quantum computing is quantum communication, or quantum networking. Through the entanglement of qubits *across* quantum computers, rather than within a single computer, whole networks of such computers could be created, allowing the development of a 'quantum internet'. One immediate opportunity for this is the generation and instant sharing of certifiably random numbers, which have multiple applications in computing, such as in encryption.[181, 182]

B.7 Brain-computer interfaces (BCIs)

BCIs – also known as brain-machine interfaces or neural-control interfaces – are devices that convert messages carried by an individual's nervous system into commands that can control external software or hardware such as a computer or robotic arm.[183] These interfaces can be invasive, where electrodes have to be surgically implanted in the recipient, or non-invasive, where sensors that detect brain activity are placed on the scalp. A lot of BCI research thus far has focused on restoring function to people who have severe motor or sensory disabilities. In Stanford, a BCI has been developed that allows researchers to 'see' the movement intentions of paralysed patients from their brain signals, allowing them to control a tablet device wirelessly and to type messages on it.[184] Bidirectional communication with BCIs is also possible. Researchers at the University of Pittsburgh, for example, have developed a system that uses signals recorded inside the brain to control a robotic arm, as well as allowing the user to experience the sensation of touch when they are picking up objects.[185] Very early versions of bionic eyes for people with severe vision impairment have been

[181] Carrel-Billiard, M., Garrison, D., and Dukatz, C. (2017) "Think beyond ones and zeros: Quantum Computing Now", Accenture, available at www.accenture.com/t20170628T011725Z__w__/us-en/_acnmedia/PDF-54/Accenture-807510-Quantum-Computing-RGB-V02.pdf#zoom=50

[182] Nanalyze (2017) "What is a Quantum Random Number Generator (QRNG)?" available at www.nanalyze.com/2017/02/quantum-random-number-generator-qrng

[183] Akeredolu, F. (2018) "How the CBN regulatory sandbox can support financial inclusion", available at https://link.springer.com/chapter/10.1007/978-1-84996-272-8_1

[184] Goldman, B. (2017) "Brain-computer interface advance allows fast, accurate typing by people with paralysis", available at https://med.stanford.edu/news/all-news/2017/02/brain-computer-interface-allows-fast-accurate-typing-by-people-with-paralysis.html

[185] The McGowan Institute For Regenerative Medicine (2017) "Prosthetic Arm + Brain-Computer Interface = 2016 #1 Innovative Idea", available at https://www.mirm.pitt.edu/medical-devices/prosthetic-arm-brain-computer-interface-2016-1-innovative-idea

deployed commercially, and improved versions are undergoing human trials.[186, 187] Although the technology has made phenomenal strides forward in the last 50 years, it is important to remember that a lot of research and improvements are still needed before its use becomes more widespread. For example, bionic eyes offer very low-resolution vision and when BCIs produce movements, they are currently much slower, less precise and less complex than what able-bodied people do easily every day with their limbs.

Looking to the future, many researchers are working to develop BCIs that augment human capacity, rather than simply assist it. Perhaps the most famous startup that has this goal is Elon Musk's Neuralink, which has the stated aim of helping human beings merge with software to keep pace with advancements in AI.[188] Braintree co-founder Bryan Johnson has founded Kernel, a startup that is attempting to develop chips that can be implanted in the brain. Although the technology is likely to be many decades away, their first goal is to reverse the effects of neurodegenerative diseases such as Parkinson's disease and Alzheimer's disease, and ultimately to increase the memory and processing capacity of the brains these chips are implanted in.[189, 190] Even more speculatively, one can envisage a situation where human operators use BCIs to operate complex machinery situated very far away, perhaps even on a mining mission on the moon or on Mars. This may revolutionise space exploration.

B.8 Data Storage

Novel methods of data storage are being developed to deal with the problem of the exponential rise in the amount of data being generated by human beings. Greater capacity and performance are constantly required, alongside lower running costs and less physical space occupied by the storage devices. Clearly, any technology that significantly reduces the costs of storing data may be of significant benefit to emerging economies.

Helium-filled hard drives have lately been pushing the capacity boundaries of hard drives, which are typically filled with air. Helium provides less resistance to the spinning of the hard drive than air, meaning that helium-filled drives use less power and run cooler. In 2015, Western Digital announced the world's first 10TB hard drive, made possible through the use of helium.[191] Although in development for some time, the technology is still comparatively expensive, costing around $0.068 per GB compared to around $0.03 per GB for standard hard drives.

[186] Second Sight (2016) "How Is Argus® II Designed To Produce Sight?", available at www.secondsight.com/how-is-argus-r-ii-designed-to-produce-sight-en.html

[187] Oxford Biomedic Research Centre (2016) ""Bionic eye" to feature on ITV documentary", available at https://oxfordbrc.nihr.ac.uk/bionic-eye-to-feature-on-itv-documentary

[188] Satt, N. (2017) "Elon Musk launches Neuralink, a venture to merge the human brain with AI", available at www.theverge.com/2017/3/27/15077864/elon-musk-neuralink-brain-computer-interface-ai-cyborgs

[189] Wise, J. (2017) "Brain-Computer Interfaces Are Already Here", available at www.bloomberg.com/news/features/2017-09-07/brain-computer-interfaces-are-already-here

[190] Richardson, J. H. (2017) "Inside the race to hack the human brain", Wired, available at www.wired.com/story/inside-the-race-to-build-a-brain-machine-interface

[191] Anthony, S. (2014) "Western Digital unveils world's first 10TB hard drive: Helium-filled, shingled recording", available at www.extremetech.com/computing/189813-western-digital-unveils-worlds-first-10tb-hard-drive-helium-filled-shingled-recording

Shingled magnetic recording (SMR) is another development of hard drive technology.[192] Data tracks on the drive are recorded closer together, overlapping one another like shingles on a roof, allowing more data to be written to the same space. Importantly, traditional reader and writer elements can be used for SMR, meaning that this technology does not require significant new production capital to be used in a product, keeping costs low. The trade-off at the moment is in performance, as SMR drives are currently slower than traditional drives.

Perhaps the strangest new storage technology of the future is DNA. In 2012, researchers at Harvard were able to encode DNA with digital information, including a 53,400-word book in HTML, 11 JPEG images, and one JavaScript program.[193] The main advantages of DNA as a data storage medium are its superior storage density (2.2 petabytes per gram, which means that a DNA hard drive about the size of a teaspoon could fit all of the world's data on it), and its stability, which translates into longevity.[194] The technology is currently too expensive, and the reading/writing processes take too long, for it to be used routinely.

Other researchers are attempting more prosaic approaches to reducing the costs of running data centres. Microsoft recently announced Project Natick, which involves situating a data centre underwater off the Scottish coast.[195] It is hoped that the sea will provide a natural coolant. For this attempt, the data centre comprises 12 racks with 864 servers and 27.6 petabytes of storage, and researchers aim to have it in place for 5 years. The longest Microsoft have maintained an underwater data centre thus far is for 5 months, so this would represent a significant improvement in the technology.

Besides the costs of data storage, those of data transfer also need to be kept in mind. These include maintenance of the required infrastructure, employing skilled maintenance staff, and the cost of the electricity needed to transmit data. The latter is a frequently underappreciated cost. Google's Cloud infrastructure alone used 260 million watts in 2011, more than the whole of Salt Lake City in the same period.[196] A smartphone streaming an hour of video on a daily basis uses as much electricity as a new refrigerator.[197]

192 Seagate "Seagate SMR- Increase Drive Capacity", available at www.seagate.com/gb/en/tech-insights/breaking-areal-density-barriers-with-seagate-smr-master-ti

193 Church, G. et al (2012), "Next-Generation Digital Information Storage in DNA", available at http://arep.med.harvard.edu/pdf/Church_Science_12.pdf

194 Murphy, M. (2015) "Scientists say all the world's data can fit on a DNA hard drive the size of a teaspoon", available at https://qz.com/345640/scientists-say-all-the-worlds-data-can-fit-on-a-dna-hard-drive-the-size-of-a-teaspoon

195 Warren, T. (2018) "Microsoft sinks a data center off the Scottish coast", available at www.theverge.com/2018/6/6/17433206/microsoft-underwater-data-center-project-natick

196 Glanz, J. (2011) "Google Details, and Defends, Its Use of Electricity", available at www.nytimes.com/2011/09/09/technology/google-details-and-defends-its-use-of-electricity.html?_r=0

197 Mills, M. (2012) "The Cloud Begins with Coal", available at www.tech-pundit.com/wp-content/uploads/2013/07/Cloud_Begins_With_Coal.pdf?c761ac

Although the patchwork nature of internet infrastructure makes exact measurements difficult, it is clear that data transfer costs have fallen by 15% to 50% year-on-year over the last two decades. Nowadays, most reports place the estimated cost of moving data over existing infrastructure in high-income countries at less than $0.01 per gigabyte.[198]

The picture in LMICs is less clear. We have found no evidence that any novel methods of data transmission are being developed at the moment that LMICs could capitalise on to bring costs down. Our recommendation to policymakers would therefore be to invest in reducing the costs of electricity generation and of the maintenance of existing infrastructure, in order to bring down the costs of data transmission for their areas.

B.9 Novel Forms of Connectivity

One of the consequences of more widespread dissemination of the IoT is a massive increase in the amount of unstructured data that will be generated and carried by networks across the globe. This will also happen as more people – including in LMICs – become connected to the internet. Therefore, mobile and other networks around the world will need to be upscaled in order to cope with this increase in transmitted data.

There are various approaches to increasing the capacity of consumer mobile, standard internet, and internal enterprise networks. In traditional networks, the functionality of the network mainly depends on its hardware, such as switches and routers. Therefore, the performance of the network depends almost exclusively on the performance of the hardware. Working on the network thus involves highly skilled technicians, who are trained in the use of network hardware devices from multiple different vendors, manually configuring multiple devices on a device-by-device basis. This is time-consuming and prone to error. Moreover, this configuration approach makes it much more complex for an administrator to deploy a consistent set of policies across a large network (as individual technicians working on their own part of the network may implement their own 'fixes'). As a result, organisations are more likely to encounter problems such as network failure and security breaches. Lastly, the addition of new devices to traditional networks, such as smart IoT devices, is a major undertaking. The simplest option is to allow any new device that is added to have access to the whole network. However, this carries security implications, as smart IoT devices are targets for hacking, and if one such device is breached, then the whole network is breached. A solution is to implement network segmentation, such that new devices added to the network are only given access to part of the network, but this is difficult to configure in traditional networks because of the reliance on multiple individual pieces of hardware to deliver network functionality.[199]

Software-defined networking (SDN) is an emerging technology that may help overcome these difficulties. In essence, the 'overall control' of the network is not disseminated among multiple hardware devices as in traditional networks, but is 'abstracted' to a centralised software application.

[198] BroadBand Now (2016) "How Much Does Data Really Cost an ISP?", available at https://broadbandnow.com/report/much-data-really-cost-isps

[199] Ocedo, "Traditional vs Software-defined networking", available at www.ipknowledge.net/wp-content/uploads/2014/12/SDN.pdf

Thus, the hardware simply deals with transferring data from one site to another, while the software determines where the data is sent. Because the control of the network is centralised and is based on software, it becomes much easier for network technicians to manage. Rather than configurations being executed on a manual, device-by-device basis, SDN allows the automation of this process, enabling an administrator to manage the entire network as if it were a single device. This increases configuration accuracy and consistency, and allows administrators to change configurations much quicker. Rather than having a network with multiple patches and fixes applied to different hardware appliances by different technicians over the lifetime of the network, SDN allows a standardised approach to be used across the whole network. This has allowed the development of cloud data centres.[200]

Moreover, SDN allows control of data flow via multiple paths across the network from source to destination. The central control software allows the data flow to be split across multiple nodes, meaning that network performance and scalability can be enhanced.[201]

An alternative, but related, approach is network function virtualisation (NFV).[202] The concept of server virtualisation has been around since the 1960s. At the most basic level, it involves the use of a type of software called a 'hypervisor' to run multiple operating systems and applications on a single physical server. Thus, multiple servers exist and function on a single physical machine. This allows a single physical server to deal with multiple types of workload at the same time – such as databases, file sharing, graphics virtualisation and media delivery. As a result, many different network equipment types can be consolidated onto industry-standard high volume servers, switches and storage. This circumvents the problems created by the large and increasing variety of proprietary hardware network appliances.[203]

SDN and NFV can help address the problem posed by increased capacity demand of mobile traffic. Moreover, by reducing the reliance on multiple expensive proprietary hardware platforms, they reduce capital expenditure and operational costs. Many mobile operators and internet service providers have recognised this potential, and investments in SDN and NFV technologies worldwide are projected to increase by 54% between 2018 and 2030, eventually reaching over $20 billion.[204]

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[200] Pate, P. (2013) "NFV and SDN: What's the Difference?", available at www.sdxcentral.com/articles/contributed/nfv-and-sdn-whats-the-difference/2013/03/

[201] Ocedo, "Traditional vs Software-defined networking", available at www.ipknowledge.net/wp-content/uploads/2014/12/SDN.pdf

[202] Kerravala, Z. (2018), "SDNs and NFV are complementary and core components of modernized networks", NetworkWorld, available at www.networkworld.com/article/3278278/lan-wan/sdns-and-nfv-are-complementary-technologies-that-are-core-components-of-a-modernized-network-unders.html#tk.drr_mlt

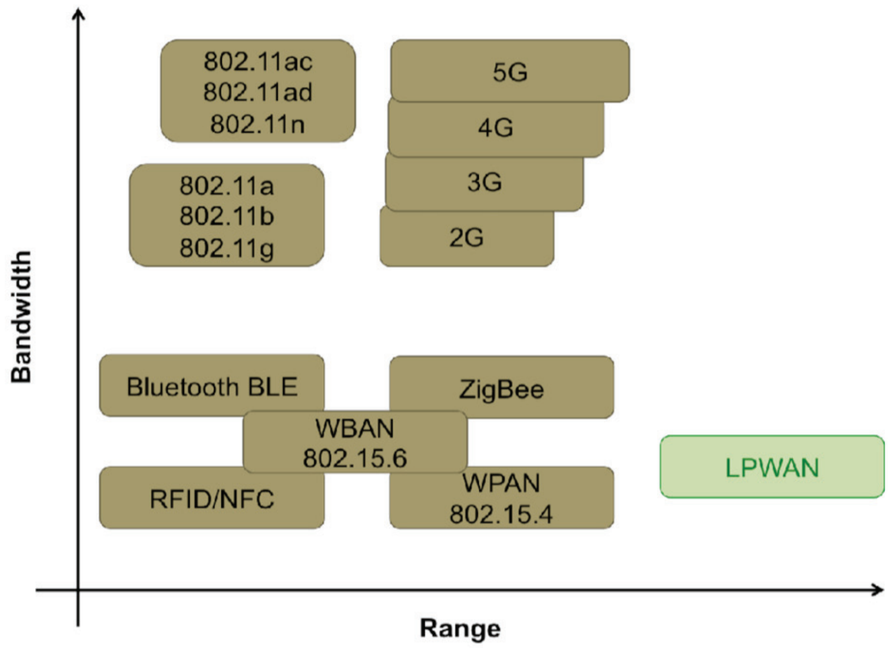
[203] Postscapes (2018) "IoT Technology Guidebook", available at www.postscapes.com/internet-of-things-technologies/#communication

[204] SNS Telecom (2017), "The SDN, NFV & Network Virtualization Ecosystem: 2018-2030.– Opportunities, Challenges, Strategies & Forecasts", available at https://thebusinesstactics.com/342753/the-sdn-nfv-network-virtualization-ecosystem-is-expected-to-reach-usd-2350-million-at-a-cagr-of-54-by-2030-opportunities-challenges-strategies-forecasts-2018-2030/

Ultra wideband (UWB) – also known as digital pulse wireless – is a wireless technology for transmitting large amounts of digital data over a wide spectrum of frequency bands with very low power for a short distance. UWB radio can carry a huge amount of data over a distance up to 230 feet at lower power than standard radio transmissions. It also has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and at a higher power.[205] UWB has potential applications in voice and data transmission, as it allows low-powered and relatively low-cost signals to carry information at very high rates within a restricted range. It can also be used in applications involving radar, in which the signal penetrates nearby surfaces but reflects those that are farther away, allowing objects to be detected behind walls or other coverings.

The requirements of IoT have also driven the emergence of another new wireless communication technology: low-power wide area network (LPWAN). Its main characteristics are low-power, long-range, and low-cost communication, meaning it is gaining popularity in industrial and research communities. LPWAN provides long-range communication up to 10–40 km in rural zones and 1–5 km in urban zones, but at the cost of low bandwidth: most LPWAN technologies can only send less than 1,000 bytes of data per day or less than 5,000 bits per second. A comparison of LPWAN and other wireless networks, in terms of their bandwidth and range, is provided in Figure 1. These promising aspects of LPWAN have prompted recent experimental studies on its performance in outdoor and indoor environments. The studies have found that this technology is highly suitable for applications that only need to transmit tiny amounts of data in long range.[206]

Figure 1: How does LPWAN technology compare to other wireless networks in terms of bandwidth and range?



Source: Image adapted from McClelland, C. (2017)[207]

205 Postscapes (2018) "IoT Technology Guidebook", available at www.postscapes.com/internet-of-things-technologies/#communication

206 Mekki, K. et al. (2018) "A comparative study of LPWAN technologies for large-scale IoT deployment", available at www.sciencedirect.com/science/article/pii/S2405959517302953

207 McClelland, C. (2017) "LPWAN - The Benefits of LPWAN Technology vs. Other IoT Connectivity Options", Leverege, available at www.leverege.com/blogpost/lpwan-benefits-vs-iot-connectivity-options

As seen in Figure 1, LPWAN is ideal for situations where devices need to send small data bundles over a wide area.[208]

An interesting development in mobile telephony is 'Long Term Evolution (LTE) Direct'. LTE is a well-established 4G mobile communications standard that smartphones use to communicate with mobile network towers. With LTE Direct, phones are now able to communicate directly with other mobile devices and with 'beacons' located in shops and other businesses. This technology has a range of up to 500 meters, far more than either wifi or Bluetooth. It may allow smartphones to automatically discover nearby people, businesses, and other information, meaning that it can potentially allow new means of delivering targeted promotions or advertising. A beacon installed in an airline check-in desk, for instance, might offer information on delays to people nearby who are booked on an affected flight. LTE Direct could also help solve the problems that occur when a large number of mobile devices are trying to connect to the same mobile network tower.[209]

B.10 Classification of Applications

Table 1 classifies the potential applications of each technology described in this report according to their stage of development:

> **i.) Pilot or early stage:** application at initial phases of testing in real world situations (we have tried to limit examples to LMICs and not developed countries);
> **ii.) Experimental:** application technically feasible and/or undergoing initial, experimental testing;
> **iii.) Speculative:** application not currently technically feasible but likely to be so in ten or more years.

We have included applications that are in experimental or speculative stages of development in high-income countries, but not in widespread use. Furthermore, while we have named countries where the applications may be found, the lists are not exhaustive.

[208] Note: 802.11x, 802.15.x: wireless network standards created and maintained by the Institute of Electrical and Electronics Engineers LAN/MAN Standards Committee; 2G to 5G: 'generations' of mobile telecommunication standards; BLE: Bluetooth Low Energy; RFID: radio-frequency identification; NFC: near-field communication; WBAN: wireless body area network; WPAN: wireless personal area network.

[209] Simonite, T. (2014), "Future Smartphones Won't Need Cell Towers to Connect", MIT Technology Review, available at www.technologyreview.com/s/530996/future-smartphones-wont-need-cell-towers-to-connect

Table 1: Potential technology applications according to development stage

	Timeframe		
Technology	*At pilot or early stage*	*At experimental stage*	*At speculative stage*
AI	Economy • Unmanned tractors (China, Uganda) • Crop and livestock monitoring systems (China, Uganda, Vietnam) • AI-driven creditworthiness assessment (Dominican Republic, Nigeria, Kenya) • Automated warehouses (China)	Economy • Automated fruit pickers (US, UK) • Autonomous vehicles on roads (cars, lorries)	Economy • Responsive, iterative, automated development and deployment of economic policy
	Human development • Personalised education tools (South Africa) • AI-based health assessment tools, e.g. Babyl (Rwanda)		Human development • Personalised healthcare based on genomic analysis • Fully autonomous robotic care workers
	Quality of government • Facial recognition technology in policing (China, South Africa) • Machine learning for anti-recidivism policy (Columbia)	Quality of government • AI-based automated translation and voice recognition systems (also relevant to 'Economy' and 'Human development') • AI-based crisis prediction and management, e.g. impact on expected migration flows, food supply	Quality of government • Automated sentiment analysis of social media for ongoing polling
The Internet of Things	Economy • Industrial IoT (China)	Economy • IoT-enabled precision agriculture • Infrastructure management, e.g. bridges	Economy • Country-scale IoT: real-time information about economic production/activity
	Human development • Smart cities (Mexico, China, India – also relevant to 'Economy') • Solid waste management (India) • Pollution, air quality management (India, China) • Utilities management (China) • Traffic management (India, China) • ColdTrace vaccine refrigerator (Mozambique)	Human development • Smart hospitals and clinics • Smart homes • Smart greenhouse • Smart vehicles • Smart water and sewage system for tracking disease, water quality	Human development • Global-scale IoT • Smart materials
	Quality of government • ShotSpotter gunshot detection (South Africa)		
Augmented & Virtual Reality	Economy • AR- & VR-enabled training and education, e.g. surgery, engineering (South Africa) (also relevant to 'Human Development')	Economy • AR-enabled maintenance of city assets • AR- and VR-enabled tourism • AR-enabled business interaction	
	Human development • VR-enabled humanitarian awareness & funding (Jordan, Syria)	Human development • AR-enabled emergency response tools • AR-enabled public health tools, e.g. choose cleanest transport option	Human development • VR-enabled empathy with groups, e.g. women and children • VR-facilitated peacekeeping by introducing the 'other'
		Quality of government • E-governance through AR-enabled devices • VR-President for the Day experience	Quality of government • AR-enabled civic participation, e.g. town hall meetings

Drones	Economy • Cargo delivery (China) • Crop monitoring (Myanmar) • Monitoring of construction projects (South Africa)	Economy • Drone-enabled internet access (also relevant to 'Human development') • Drone-enabled crop planting (Sudan) • Drone taxi (Dubai, USA)	Economy • Swarming drones, e.g. for crop pollination, emergency response
	Human development • Crisis monitoring and response (Peru, Malawi) • Pest control (Brazil) • Delivering medical supplies e.g. Uber for Blood (Peru, Rwanda)		
	Quality of government • Anti-poaching monitoring (South Africa, Zimbabwe, Malawi, Botswana) • Land boundary mapping (Kenya, Rwanda, Ethiopia) • Surveillance e.g. of crowds (India)		
Blockchain	Economy • Cryptocurrency (Kenya) • Microfinance, e.g. peer-to-peer lending (Kenya, Nigeria, Tanzania, Uganda)	Economy • Smart contracts	
	Human development • Mineral tracking (Republic of Congo)		
	Quality of government • Land registry (Georgia, Ghana)	Quality of government • Budget-tracking for governments • Identity documents, e.g. register birth via smartphone	Quality of government • Distributed governance, e.g. digital voting
Quantum computing			Economy • Quantum cryptography (also relevant to 'Quality of Government') • Modelling of chemical reactions • Quantum sensors (also relevant to 'Human development') • Quantum communication
Brain-computer interfaces			Economy • Remote control of machinery in mining, search and rescue, space exploration
		Human development • Restoring function to people who have severe motor or sensory disabilities (US)	Human development • Reverse the effects of neurodegenerative diseases such as Parkinson's disease and Alzheimer's disease (US) • Increase memory and processing capacity of human brains
Data storage	Economy • Underwater data centres (California, Scotland)	Economy • Helium-filled hard drives • Shingled magnetic recording	Economy • DNA storage technology
Novel forms of connectivity	Economy • Software-defined networking • Network function virtualisation • Ultra wideband • Low-power wide area network		

Section C: Conclusion and Recommendations

"It is difficult to make predictions, especially about the future." — Niels Bohr
"The best way to predict the future is to create it." — Peter Drucker

For this paper, we undertook a detailed literature review, and conducted interviews with experts including academics, entrepreneurs, and policymakers. Our aim was to understand what the potential applications for digital technology are in LMICs.

In Section B, we discussed the main applications of seven emerging technologies in these countries, and outlined whether these are at pilot stage (where the application has moved beyond initial experiments and is being trialled 'in the field' at small scale), experimental (where the application is technically feasible, and/or is undergoing initial testing), or speculative stage (where the technology does not yet exist to develop this application).

Recommendation 1: Problem-focused approach

The aphorisms attributed to Niels Bohr and Peter Drucker above demonstrate the challenges inherent in such a task, as well as a potential way forward for policymakers faced with choices on which technologies to explore on behalf of their countries. We would urge policymakers to avoid focusing exclusively on the technical capabilities of a technology; it is important not to lose sight of the people who the technology was designed to help, and their needs. Many of our contributors repeated the need to customise applications for the local context, and to avoid parachuting in less relevant solutions from developed countries. For example, ride-sharing platforms, such as Uber, offer a good mobility solution, as many people in LMICs cannot afford to buy their own car. Self-driving cars however, may be less suitable, as they rely on infrastructure such as straight, well-marked roads, which are often lacking.

We would suggest that policymakers:

1. **Take the challenges that their country and people face as the starting point and focus on addressing these problems.** Understanding citizens' problems is obviously 'bread and butter' for politicians and civil servants. So, it could appear that it is more important to keep falling in love with the 'problem', rather than falling in love with the 'solution'.

2. **Identify the existing technologies that can be applied to solving identified problems.** Policymakers can also explore how to adapt existing technologies to be able to solve these problems (rather than vice-versa) .

3. **Understand and tackle the challenges that prevent the application of these technologies at scale.** This way, policymakers can create the ecosystem in which the potential benefits that may follow from the use of these technologies are maximised.

Recommendation 2: Focus on the most impactful and most mature technologies

We have described more than 80 potential applications of seven emerging technologies in this paper, at varying stages of development. In order to assist policymakers in determining which of these applications are likely to achieve high levels of impact, and which are also more feasible, we have undertaken a semi-quantitative ranking exercise. The three authors independently scored all 83 applications in three domains ('number of people impacted by field'; 'significance of impact of field on human wellbeing'; and 'importance of this application within the field').[210, 211] A mean score was calculated for each domain. A mean was then calculated for these three domain scores, giving an impact rating ranging from 1 (least impactful) to 3 (most impactful) for each application (see Appendix 2). For likelihood, the scoring was based on the assessment outlined in Table 1.[212] Therefore, each application was given two scores, one for impact ranging from 1 to 3, and one for likelihood ranging from 1 to 3. We used these scores to clearly identify three important categories of application: high-impact pilot applications, high-impact experimental, and high-impact speculative. We have listed the top 15 applications in Table 2.

Table 2: The top 15 applications

High-impact pilot applications	**High-impact experimental applications**	**High-impact speculative applications**
• AI-based crop and livestock monitoring • AI-based personalised education via online/digital tools • AI-based health assessment tools, e.g. Babyl • IoT-enabled smart cities • Drone-enabled land boundary mapping • Drone-enabled crop monitoring	• IoT-enabled smart hospitals and clinics • IoT-enabled precision agriculture • IoT-enabled smart water and sewage system for tracking disease, water quality • AI-based crisis prediction and management, e.g. impact on migration flows, food supply • AI-based automated translation and voice recognition systems • Blockchain-supported identity documents	• AI-based responsive, iterative, automated development and deployment of economic policy • AI-based personalised healthcare based on genomic analysis • Country-scale IoT: real-time information about economic production/activity

[210] The term 'field' in this context refers to a broad field of human activity, eg agriculture, healthcare, manufacturing.

[211] Each application was scored from 1 to 3 in each domain, where 1 denoted least significant/impactful, and 3 most significant/impactful.

[212] An application in pilot phase was scored 3, in experimental phase scored 2, and in speculative phase scored 1.

The majority of these applications are in the fields of healthcare and agriculture. This reflects the significant gains that can be made in LMICs by the use of technology in these often underdeveloped and critical sectors. In these cases, we predict that technology could help significantly increase productivity and efficacy of healthcare and agricultural methods, leading to better overall health and well-being in these populations (although, as noted previously, some applications may be less well-suited to small-scale farming). Secondly, the majority of these applications use AI, reflecting the relative maturity of this technology and its readiness to deliver significant impact in these countries.

Recommendation 3: create an enabling environment by tackling overarching challenges

We have detailed the specific challenges that stand in the way of the application of each of the seven emerging technologies. However, a number of overarching challenges emerge from our analysis of the use of technology in LMICs. Some of these challenges are more technical in nature, while others are more socio-political.

Data

Data is a driver for development, and it has been a constant reference throughout this report, especially as a challenge to various technologies. To reiterate, as we continue to generate increasing volumes of data, various gaps need to be filled. Individuals are both consumers and producers of data, and tensions around control and ownership should be addressed. Individual concerns around privacy and consent need to be balanced with human rights, national security, and other issues. Data collection, flows, and storage must be promoted, managed and protected by policy frameworks, safeguards and impact assessment. This requires capacity building, sharing of expertise and some degree of experimentation. A comprehensive approach is needed for the long-term sustainability of the data ecosystem.[213]

Variable availability and speed of internet

Access to the internet varies by geography, gender, socio-economic status, and other determinants. For instance, South-East Asia is the world's fastest growing region for internet access and an estimated 125,000 new users come online each day,[214] and 90% of 15- to 24-year-olds have at least five years' experience of using the internet.[215] But there are stark differences between countries: while 80% of Singaporeans accessed the internet in 2016, only 25% of people in Laos and Myanmar were able to do the same.[216]

[213] World Economic Forum (2015) "Data-Driven Development Pathways for Progress", available at www3.weforum.org/docs/WEFUSA_DataDrivenDevelopment_Report2015.pdf

[214] Duchatellier, C. (2017) "Asia must overhaul its education systems for the new reality of work", available at www.weforum.org/agenda/2017/05/asia-must-overhaul-its-education-systems-for-the-new-reality-of-work

[215] Pimple, M. (2017) "Social media can help young people reclaim their human rights. ASEAN governments should embrace this", available at www.weforum.org/agenda/2017/05/social-media-can-help-young-people-reclaim-their-human-rights-asean-governments-should-embrace-this

[216] OECD (2017) "Opportunities and Policy Challenges of Digitalisation in Southeast Asia", available at www.oecd.org/southeast-asia/events/regional-forum/Forum_Note_Digital_Transformation_STI.pdf

One of the reasons for these variations is cost, which remains high in many LMICs. In Zimbabwe for example, mobile internet is provided predominantly through $1 daily data bundles of around 250MB. According to the Alliance for Affordable Internet, 1GB of mobile data "costs nearly 45% of a citizen's average income".[217] Efforts to expand access are crucial to avoiding a scenario where only wealthy citizens who own smartphones can benefit. According to an Oxford Martin School and Citi report, the divergence in penetration rates of technology adoption can account for 82% of the increase in the global income gap since 1820.[218]

Apart from the costs inherent to technology, such as providing the necessary infrastructure, some countries are adding to the costs through the fiscal system. For example, Ugandans must now pay an upfront daily levy of 200 Ugandan shillings ($0.05, £0.04) to access Over The Top (OTT) services, which include Facebook, WhatsApp and Twitter. While officials have cited over-reliance on donor funding as justification for the new social media tax, Amnesty International has described it as "a clear attempt to undermine the right to freedom of expression". A further 1% tax is also being applied to mobile money transactions. At the end of 2016, a 1GB mobile broadband plan in Uganda cost more than 15% of average monthly income.[219–221]

As many of our contributors have noted, many of the technologies and the applications we discuss in this paper rely on internet access. Therefore, addressing the challenges of unequal access to this resource, and variable speeds in different regions, is crucial to ensure the widest possible application of these technologies.

Trust

Distrust of digital tools remains a barrier. Only 3% of Indonesians are aware of mobile money as a concept and the majority of smartphone users in Vietnam rely on pre-downloaded apps, instead of searching for and accessing new apps themselves.[222, 223] Farmers have shown suspicion of data-gathering technology, as information about their harvests may be used to trade against them.[224]

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217 Karombo, T. (2018) "Zimbabwe is trying to transform itself into a leading tech hub with China's help", available at https://qz.com/1306520/zimbabwe-needs-china-for-its-tech-and-ict-ambitions

218 Oxford Martin School (2016) "Technology at work v2.0", available at www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf

219 Muhumuza, R. (2018) "Uganda Just Rolled Out a 5-Cent Daily Tax to Access Social Media. People Aren't Happy", available at http://time.com/5328463/uganda-social-media-tax/

220 Busari, S. (2018) "Uganda government sued over social media tax", available at https://edition.cnn.com/2018/06/01/africa/uganda-social-media-tax/index.html

221 Alliance For Affordable Internet (2016) "Mobile Broadband Data Costs", available at http://a4ai.org/mobile-broadband-pricing-data

222 Schonhardt, S. (2015) "Mobile Banking Struggles to Gain Traction in Indonesia", available at www.wsj.com/articles/mobile-banking-struggles-to-gain-traction-in-indonesia-1437507127

223 Ahanonu, K. et al. (2013) "Mobile Brand Interaction in Southeast Asia: a Comparative Study", available at www.mmaglobal.com/files/vol8no2/vol8no2-1.pdf

224 World Economic Forum (2015) "Industrial Internet of Things: Unleashing the Potential of Connected Products and Services", available at www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

Digital security is another concern. Indonesia is now a bigger source of cyber attacks than China, and the vast majority of South-East Asians have concerns about sharing personal data online.[225] Among its suggestions for enhancing trust and security in digitisation, American consulting firm A.T. Kearney proposes creating national e-ID systems tied to a mobile number, harmonising privacy laws across the region and founding a regional agency to fight cybercrime, similar to Europe's Joint Cybercrime Action Taskforce (J-CAT).[226]

On a macro level, governments and policymakers can sometimes be sceptical of the benefits of technology. This can be a result of previous projects failing to deliver, and applications being more solution- rather than problem-driven, meaning that they fail to address specific, local challenges. Some may find the initial capital investments required to develop and deploy the technology prohibitive, especially in the context of overstretched budgets. Furthermore, efficiencies delivered by these technologies can be seen as potentially leading to job losses, further decreasing a government's tax take. While a manual approach to data gathering and analysis requires a team on the ground – employees responsible for data entry, supervisors, and so on – automation can erase the need for many of these tasks. In the context of automation and related trends such as the gig economy, it is up to the government (and private companies) to provide retraining programmes and ensure that technologies are boosting employment in the long term.[227]

Skills and education

The global shortage of highly skilled workers who are adept at developing and using digital technologies is all the more acute in developing regions. Equipping workers with relevant skills is crucial, especially with the promise of automation and the potential for many low-skilled jobs to be lost.

One way to counter the deficit of know-how is by building region- or continent-wide networks to pool resources and bring experts together from different countries. Data Science Africa aims to connect a network of data science researchers across the continent; the Machine Intelligence Institute of Africa is looking to accelerate research and applications of machine learning and data science. The African Institute for Mathematical Sciences (AIMS) recently launched the African Masters of Machine Intelligence programme, in partnership with international institutions and with sponsorship from Facebook and Google.[228]

In addition to such formal networks and education programmes, tech hubs provide spaces for local talent to develop applications relevant to local socio-economic objectives, and a base from where developers can communicate with governments and regulators. Where these hubs focus on addressing local challenges, they could help overcome issues around unequal distribution of investment.

[225] Sophos (2013) "Security Threat Report 2013", available at www.sophos.com/en-us/medialibrary/pdfs/other/sophossecuritythreatreport2013.pdf

[226] AT Kearney (2015) "The ASEAN Digital Revolution", available at www.southeast-asia.atkearney.com/documents/10192/7567195/ASEAN+Digital+Revolution.pdf/86c51659-c7fb-4bc5-b6e1-22be3d801ad2

[227] Interview with Ernest Mwebaze, 10 July 2018

[228] Cisse, M. (2018) "Introducing the African Master's of Machine Intelligence at AIMS", available at https://medium.com/@moustaphacisse/introducing-the-african-masters-of-machine-intelligence-at-aims-9441b4346a55

Getnet Aseffa, CEO of iCog Labs in Addis Ababa, Ethiopia, listed a number of exciting initiatives looking to grow the talent pool in Ethiopia, and equip young people with problem-solving skills. The 'Anyone Can Code' project is funded by the Lab, and has taught 20,000 high school children (aged 10-20) how to code and control robots, over the last year. The 'Design in Ethiopia' movement is sponsored by the Ministry of Science and Technology, and aims to create a design bridge with China by helping innovators prototype their ideas. The 'Solve it' Innovation competitions, currently sponsored by the US Embassy, encourage participants to develop technology-based solutions for community problems. The programme also provides access to business mentors and venture capitalists. [229]

Electricity

The World Bank's 2017 *State of Electricity Access Report* estimated that, due to population growth, half a billion people still won't have access to electricity by 2040.[230] New models of electrical generation will be required to power the sheer volume of devices, and countries are introducing low-cost alternatives and off-grid solutions. Thanks to cheapening costs of renewable energy sources, solar panels and hydropower may allow countries to leapfrog over coal as a major energy source. For example, Africa's largest dam is currently under construction in Ethiopia, despite regional tensions over potential disruptions to agriculture and industry, and over control of the Nile.[231] In any case, providing reliable universal electricity, at an acceptable cost and without harming the environment, requires input from public and private partners and investment in a variety of solutions – not reliance on a single energy source.

Tackling these challenges can help to ensure that the specific technological applications mentioned in this report can deliver maximum impact. It is important to also remember that many technological advancements that have led to a positive impact on wellbeing in the developing world and elsewhere have not come about thanks to some master plan. Solutions often emerge more organically and iteratively. Mobile money is perhaps the best example of a high-impact application in LMICs clearly developed in this way, from the bottom up. By removing the obstacles discussed above, policymakers can create an enabling environment where similar innovations are more likely to flourish, and perhaps even allow LMICs to leapfrog ahead of developed countries in innovation.

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[229] Interview with Getnet Aseffa, 10 July 2018

[230] World Bank (2017) "State of Electricity Access Report 2017", available at http://documents.worldbank.org/curated/en/364571494517675149/pdf/114841-REVISED-JUNE12-FINAL-SEAR-web-REV-optimized.pdf

[231] Dahir, A. (2018) "A major geopolitical crisis is set to erupt over who controls the world's longest river", available at https://qz.com/1181318/ethiopia-egypt-sudan-and-eritrea-tensions-over-grand-ethiopian-renaissance-dam-on-nile-river

Appendices

Appendix 1: Scenarios

We have included four scenarios to help bring the discussion to life. While they are based on real-world contexts, and rooted in the actual and potential technologies explored in this report, the content is fictional and loosely based in 2030.

Scenario 1: Honduras law enforcement leveraging emerging technologies to combat crime and corruption

Distrito Central describes the area of Tegucigalpa and Comayagüela, two major twin cities in Honduras with a combined population of 1 million. The area has a serious and growing problem with organised crime – the homicide rate is 85.09 per 100,000 inhabitants. Like other countries in Central America, Honduras is in the direct transport route for narcotics moving northwards, which stirs up violence and corruption. Trust in the police force is very low.

Despite the high poverty levels, local law enforcement has prioritised investing in emerging technologies to combat crime, and to raise trust in its police men and women. Initially, there was a lot of resistance to Distrito Central investing heavily in technology over urgent gaps, such as building schools and hospitals. However, tackling corruption within the force and elsewhere remains a top priority. The first step was to install CCTV cameras around the Distrito, which gather information that can later be analysed and used by the police.

Distrito Central police have turned to the IoT and audio sensing systems for detecting gunshots, to help them pinpoint the location in seconds. The systems alert CCTV cameras, slewing them to the scene and helping guide medical response teams towards the victims. Officers are also able to notify public and private sites, such as shops and housing estates, that a criminal has entered the premises, thanks to AI-driven facial recognition software that analyses the Distrito's CCTV footage, matching it to police records.

Poor performance and corruption in the police ranks have led to the creation of numerous entirely new units. By adding two officers for every corrupt one that is removed, Honduras is aiming to double its police force. Therefore, the ability to train large numbers of new recruits is paramount. Distrito Central is achieving this with the help of AV and VR, together with equipment such as visors. This enables them to practice highly dangerous situations, such as rescuing kidnapping victims and storming suspected drug cartel locations, in highly realistic settings, but without any of the risk. Teams of police officers have also been visiting local schools, and are showing their work to pupils through VR headsets, as a way of building trust in the community.

In terms of 'back-end' applications of new technologies, the local government is trialling blockchain technology applications to tackle corruption. With blockchain-based budget tracking, it would no longer be possible to fake expenditures as the transaction data (account numbers, transaction time, transaction amount, receiver) is all saved. The local government will then be able to analyse budget data to identify areas lacking in funding. However, there is still some scepticism as to whether local politicians are genuinely in favour of bringing full transparency to their expenditures.

Scenario 2: Ugandan plantain farmers optimise crop monitoring and resource consumption

Small-scale farmers represent 85% of Uganda's farming community. The majority of what they produce is for their own consumption, although any surplus can be sold at the market. However, poor infrastructure or lack of access to reliable means of transport results in farmers often being forced to sell below value. Women and children are often the main farm labourers, which can cut their education short. Smallholder farmers find themselves unable to respond effectively to weather variability. Traditionally, they use rudimentary farming tools and have limited access to credit and market information. In recent years, Uganda has been trialling various technologies to address these issues, and to boost productivity as well as quality of life.

Dembe is a young woman who works on the family plantain farm. Her 11-year-old daughter Masiko helps her out, although Dembe would much rather she focused on getting an education, which could enable her to get a skilled job. Five years ago, the family was struggling, as their soil was too tired to grow enough plantain, and the plants were being routinely attacked by soil-borne worms. However, since then, Dembe and her family have been gifted with a smartphone, equipped with an AI-driven app for crop monitoring. By taking and uploading photos of her plantain, Dembe is able to get an immediate diagnosis and advice. She is consequently losing a minimal amount of crop and making great savings.

Dembe wasn't initially able to use the app on her own. But she and Masiko were also given access to a personalised education platform, which guided them through the tool and lots of information on plantain, maintenance and disease. The great thing about the platform was that it used automated translation to provide the information in their own indigenous language, as well as natural language processing, so they could both ask questions as they went along. This helped build Dembe's confidence, and she travelled to the local bank, where she applied for a loan. Owing to the lack of formal proof of Dembe's land ownership and any credit history, the bank employs machine learning to predict creditworthiness; Dembe was a granted a small loan to help cover the cost of sensors.

With the combined help of the crop surveillance app and the sensors, Dembe is able to monitor her plantain crops with far greater precision than ever before. She knows when to water and how much fertiliser to use. Receiving alerts through her app means she and Masiko don't need to be out in the fields all day; instead they are using the education platform to gain new skills and learn about additional financing methods. They are intending to participate in a trial that would see drones pick up their plantain and send it to local markets. This means they would no longer be hindered by adverse weather, which clogs up the roads and restricts the movement of delivery trucks. Hopefully Masiko will soon catch up with the national curriculum, and be able to join a local school.

Scenario 3: Boosting healthcare in resource-poor rural communities

Inequality of access to good healthcare has been a longstanding problem for much of India's rural population. Over three-quarters of the country's doctors in rural areas work in the private sector, resulting in fewer healthcare professionals left to tend to poorer citizens. There is also a risk of patients turning to unqualified informal practitioners. As a result of unsuccessful efforts to train sufficient numbers of healthcare workers, the Ministry of Health and Family Welfare has refocused on leveraging emerging technologies to enhance the capabilities of its existing workforce, in particular in rural areas. It has worked hard on regulation, to ensure the safe delivery of healthcare through apps and other tools.

Dr Rao studied medicine in Visakhapatnam and has since returned to his birth town of Kirandul to work in the local hospital. He remembers the local community mainly accessing the centre for simpler procedures such as eye tests, and having to travel hundreds of kilometres for specialist care. Now, medical staff are using AI-driven tools to enhance their diagnostic and treatment capabilities, and citizens are feeling more empowered through special apps on their smartphones.

Dr Rao has noticed a big change in the approach of patients in the last few years. Most local citizens are now equipped with a whole host of medical apps on their phones. These enable them to book appointments with their doctor, and even detect abnormalities by analysing photos of the user's skin and eyes. It took some time to acquaint people with the apps, especially for those with lower levels of education and who were not familiar with medical processes. Volunteers from the hospital staff organised town hall meetings, where they demonstrated some of the apps and encouraged people to raise questions and concerns. People have become better at managing their own health, but are also more likely to seek medical attention at the hospital when an app flags a potential problem.

Technology is also helping Dr Rao and his colleagues better manage their limited resources. At an administrative level, AI and the IoT are helping to maintain fresh supplies and allocate human and medical resources much more accurately. The predictive software considers additional data sources such as harvest time and weather, as people can be more prone to injury or disease. In the event of an urgent need for medical supplies, they can have these delivered by drone. The staff are also using a variety of AI-driven triage systems, allowing them to submit scans and receive alerts of potential issues such as signs of stroke, cancer and even mental illness. This means patients are being referred to specialists much sooner.

Dr Rao recently managed to raise the funds necessary to purchase surgical robots and VR headsets. The new robotic arm has already assisted him in orthopaedic procedures, such as a hip replacement, that would have previously required the patient to travel to neighbouring cities. He has also gained access to the expertise of doctors from leading medical institutions elsewhere in the world, by visiting their OR as an avatar. As many of the hospital's surgical nurses differed in the levels of their training and experience, Dr Rao and his colleagues have been successful in bridging gaps in their knowledge with the help of VR headsets. This way, the nurses can practice procedures in their own time and as often as they want, without feeling pressured or embarrassed. Dr Rao hopes that all these technologies will soon become routinely available to medical students too.

Scenario 4: Democratic participation in South African rural communities

The history of South Africa's democracy is complex, at times characterised by conflict and exclusion, and at others by reconciliation, optimism, and participation. It is still considered a fairly new democracy, with the Republic only having been established in 1961, and the tumultuous events leading up to and following the end of apartheid being very fresh in the minds of many. As such, increased participation in democratic processes, and ultimately, having a stake in the development of their country, is a major topic for many South Africans.
Besides its fraught history, the situation is complicated by the fact that South Africa has 11 official languages (among the highest number of languages for any country in the world) and 98% of South Africans speak one of the 11 as their first language, while 2% speak a first language other than an official one. English is most commonly spoken in government and business contexts, but it is a second language for many South Africans.

Nokuthula Nkosi has identified an opportunity to use technology to make more South Africans feel like they can contribute to their democracy. Her think tank – South Africa's Speaking – has partnered with IBM South Africa and the South African government to develop a platform called "Iqhaza" ("participate" in Zulu). Users can download this free app to their smartphone and use it to get their views across to central government. They can type in any of South Africa's 11 official languages – the text is automatically translated into all the other languages and recorded. Speech-to-text technology means that users can also speak in any of these languages – their speech is transcribed and translated on the fly. Thus, users can read all other users' contributions in their preferred language.

The most useful application of Iqhaza so far has been to allow the central South African government to conduct truly public consultations. When a new policy is being discussed in the corridors of power, it can be opened up to consultation via this app. A notification pops up on the app users' phone, and they can read the question posed to them and choose whether to answer or not, via the message or speech interface. The government has received thousands of responses to questions it has set so far, such as "What is the main thing that is contributing to your cost of living?" and "What can we do to improve your access to healthcare?" It is impossible to go through each response individually, so Nokuthula and her partners developed a 'sentiment analysis' tool that can be applied to these thousands of responses to extract an overall sense of what people think about the issue at hand. This has proved technically challenging – besides having to train the tool across multiple languages, even the English-language aspects of this tool could not be obtained off-the-shelf, but were developed with the English vernacular spoken in South Africa in mind.

Another challenge has been the realisation that early versions of the tool required powerful smartphones and fast data connections to be useful. Those with older phones and poor mobile internet connections were frequently frustrated by problems using the app, and ended up not using it. Thus, Nokuthula has made it her aim to make newer versions of the app that can be used on the widest possible range of phones and internet connections.

Appendix 2: Impact-Likelihood Calculations

This can be found in the table shared via the XL spreadsheet here at this Google Docs link.

For a full description of the methodology, please refer to the Conclusions in Section C.

Appendix 3: List of Interviewees

- **Dr Urvashi Aneja,** Associate Fellow at Chatham House and Founding Director of Tandem Research

- **Getnet Aseffa,** CEO of iCog Labs

- **Jennie Bernstein,** Urban Innovation Specialist in UNICEF's Innovation Unit

- **Dr Kamal Bhattacharya,** Chief Innovation Officer at Safaricom

- **Sherif Elsayed-Ali,** Head of Technology and Human Rights at Amnesty International

- **Professor Ian Goldin,** Professor of Globalisation and Development at the University of Oxford

- **Tom Johnson,** Managing Director at Trajectory Ltd

- **Faith Keza,** Chief Executive Officer at RwandaOnline

- **Shu Yang Lin,** Co-founder of Public Digital Innovation Space Taiwan and Founder of Creative Coding Taipei

- **Dina Machuve,** Lecturer at the Nelson Mandela African Institute of Science and Technology

- **Mish Mashkautsan,** Partner at LocalGlobe

- **Tšabi Molapo,** Researcher at IBM Research – Africa

- **Ernest Mwebaze,** Head of the Artificial Intelligence and Data Science Research Lab at Makerere University

- **David Sangokoya,** Knowledge Lead, Society and Innovation at the World Economic Forum

- **Kai Schmidt,** Co-founder of the Crypto Development Fund

- **Lucas Zaehringer,** Founder of Positiveblockchain.io

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