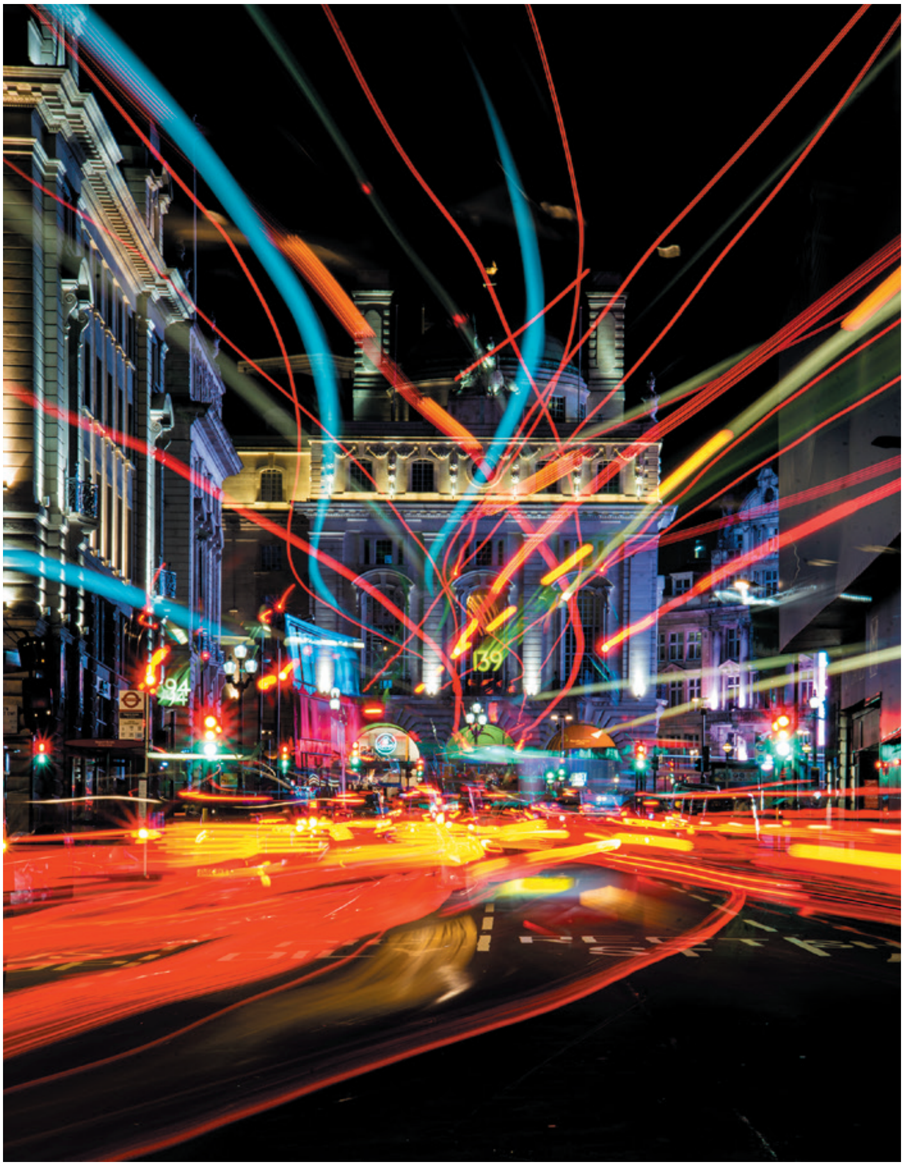

PAUL GROGAN/PHOTOPLUS MAGAZINE VIA GETTY IMAGES

**The paths of vehicles along Regent Street in London, revealed by long-exposure photography.**

# Use or lose our navigation skills

Automatic wayfinding is eroding natural abilities, warns **Roger McKinlay**.

In 1984, I was part of a team that was developing a receiver for a satellite-navigation system. After weeks of debugging, the blur of random digits settled on a location. We grabbed a map and plotted the point. The pencilled cross landed exactly on the building that we were in. More than 30 years later, the amazement that I felt still remains. The technology we use is the same — just smaller. But our dependence on knowing exactly where we are has changed.

Navigation has invaded our dreams of the future. Fleets of driverless cars will transport us around cities. As you are driven past the shop that you viewed online, the mannequin wearing the dress that you clicked on will wave and call your name. Or you could stay at home and let a drone deliver your goods. This is the vision with which innovative companies such as Google and Amazon tempt us.

The days of being lost should be over. Access to satellite navigation is ubiquitous, and 80% of the adult population worldwide is likely to own a smartphone by 2020. But it is still not easy for people or machines to find their way around. Satellite navigation is unreliable because it does not work well indoors or in built-up areas. When your phone tells you where you are in a shopping centre, for example, it will actually be a guess based on ground-based WiFi networks. That is because signals from satellites are weak (similar to viewing a 20-watt light bulb from almost 20,000 kilometres away), prone to error and easily disrupted.

More satellites are being launched to improve coverage. By 2020, 30 orbiters from Galileo, the European satellite-navigation system, will complement the US Global Positioning System (GPS) and the Russian GLONASS network. China has just launched the twenty-first satellite in its BeiDou system.

Successful navigation indoors will need other solutions, such as a combination of wall-mounted antennas and WiFi. Quantum physics could come to the rescue. Although the technology is still in its infancy and will take more than a decade to develop, small and super-sensitive quantum sensors might pinpoint our location to within centimetres by picking up tiny changes in Earth's gravitational or magnetic fields.

But navigation is about more than knowing your position. When I followed my satellite-navigation system to a country house, ▶

I found my way blocked by a gate with a notice attached: 'No access, GPS wrong!' I was not lost — my satellite-navigation system knew my position accurately. But it did not understand roads. Newspapers regularly pick up 'satnav' disaster stories — such as a lorry bound for the Mediterranean that arrived at Gibraltar Point near Skegness in the United Kingdom. A sense of direction, a sense of scale and a map are essential. And knowledge of where you want to go also helps. The disappearance in 2014 of Malaysia Airlines flight MH370 is a reminder of the vastness of our world.

Mobility will not become intelligent unless we break two bad habits. First, we must recognize that digital navigation tools do not come for free. They rely on expensive infrastructure — satellites or ground stations — that governments have to pay for. The United States invested more than US$10 billion to put the GPS satellites in place and spends around $1 billion each year to maintain the service.

Second, we should make better use of our innate capabilities. Machines know where they are, not the best way to get to a destination; it might be more reliable to employ a human driver than to program an autonomous car to avert crashes. If we do not cherish them, our natural navigation abilities will deteriorate as we rely ever more on smart devices.

## USE OR LOSE

Human spatial memory is outstanding. In Ancient Greece, orators visualized their speeches as a mansion, placing topics in each room, then retrieving them while taking an imagined route through the building. Memory champions still do the same.

But navigation is a 'use-it-or-lose-it' skill. Drivers in a simulator who follow satellite-navigation instructions find it more difficult to work out where they have been than those who use maps. Instructed drivers also fail to notice that they have been led past the same point twice. Mountain-rescue teams are tired of searching for people with drained smartphone batteries, no sense of direction and no paper map.

As we age, our spatial knowledge and our capabilities for route learning and recall also decline. Loss of spatial orientation is an early indicator of dementia. Those who are affected are often moved to unfamiliar places such as care homes, which can exacerbate disorientation. The minimalist interiors of hospitals lack signposts: in a 2015 study[1], nearly half of junior doctors reported that they had got lost in hospitals on the way to a call in which a patient's life was in danger.

The solution might lie in designing buildings that are easy to navigate[2] — rather than in gadgets. Repeated and mirrored layouts cause confusion; cluttered corridors overload the mind. Placement of simple, memorable and unique landmarks such as pictures can help with orientation.

The human brain has everything that a hill walker might put in a rucksack. Behavioural neuroscientist Kate Jeffery at University College London describes how mental activity moves from the brain's striatum to the hippocampus when we leave familiar routes[3]. Studies in rats have revealed three types of cell that enable navigation: place cells, which fire at certain locations; head-direction cells, which track the orientation of the head; and grid cells, which set up a coordinate system for assessing scale and distance.

***"When it comes to choosing routes, humans outwit machines."***

Learning the layout of the streets of London — known as the Knowledge — has been shown to increase the size of part of a taxi driver's hippocampus, and a similar effect has been observed in musicians[4]. While improvising music, a friend who is a free-jazz saxophonist 'sees' a landscape of notes to navigate.

Fresh locational cues can conflict with the maps in our brains. So it is unsurprising that it takes time to reorient when we emerge from an underground station or that the voice of the in-car satellite-navigation system grates on us. Our brains must decide whether to accept the new information and rejig our internal maps or to reject it as being wrong. A simple, reliable cue — such as a north-facing arrow at the top of an escalator — can help to speed up reorientation.

## SIX NINES

Accurate position fixing using satellites is fallible. Out in the open, GPS has good horizontal accuracy — to within about 3 metres. Positions are determined by calculating the time that the signal takes to reach the receiver, and not from any information that is being carried in the signal. Indoors or in built-up areas such as cities, signals can bounce around and give false information.

Intentional disruptions are on the rise. In 2009, engineers who were testing a GPS-based system at Newark airport in New Jersey experienced a daily interruption that was traced to a passing truck. The driver had fitted a GPS jammer to his vehicle to stop his employer from tracking him. Thieves use such jammers to defeat the trackers in luxury cars.

For wayfaring purposes, positions must be aligned to a worldwide reference map. GPS uses the World Geodetic System 1984, for example. In the 1980s, few locally used charts followed this standard, causing mariners to collide with unexpected rocks. The maps of today are vast digital databases, such as the Ordnance Survey MasterMap, which contains 450 million geographic features and is updated continually.

When it comes to choosing routes, humans outwit machines. Yet it is the instinct of designers to make smarter machines — such as satellite-navigation systems that are aware of traffic. A better option would be to make it easier for the user to plan their route. Although a computer program can find the shortest or fastest path through a database of roads, in reality, time of day, level of traffic and personal preference also play a part. The driver of a high-sided vehicle needs to know whether a route is passable.

If there is no driver, the consequences of errors in position, mapping or routing could be serious. The information given to the vehicle has to be accurate, always available and reliable and of high integrity.

Often, these requirements can be met only using simple navigation systems. Aircraft rely on radio-based aids that date back to the 1940s. These measure distances from or bearings to known locations on the ground. Since the mid-1960s, aircraft have been able to land automatically in fog by flying down a radio beam that is generated at the end of the runway.

Such systems aim to meet what engineers call the 'six nines' — they work correctly for 99.9999% of the time. It must also be clear who is responsible for maintaining them and the processes that must be followed.

Satellite-navigation systems will meet this standard only if helped by reliable terrestrial-based systems. Plans to develop the Wide Area Augmentation System and the European Geostationary Navigation Overlay Service were put in place more than 20 years ago. But they are yet to make satellite navigation good enough to replace the conventional terrestrial systems used by aviation. For ships, a new terrestrial navigation system called eLORAN is being considered, with signals that are one million times more powerful than those used in GPS.

## NAVIGATION AIDS

Why do we need tools for navigation? Like most animals, our dominant sense is vision. The combination of eyes and our internal map can do an outstanding job. But we need to see at night and in fog, and be aware of out-of-sight landmarks. Pigeons use magnetoreceptors to sense Earth's magnetic field[5]. If humans could 'see' Earth's gravitational or magnetic fields, we might have no need for expensive satellites, radio beacons or even vision.

Aircraft, ships and submarines have for decades used inertial sensors on gyro-stabilized platforms to determine their positions. These systems accurately measure motion with respect to a known starting point but accumulate errors as they cover distance. By the end of the 1960s, aircraft inertial systems could remain accurate to within 25 nautical miles (about 46 kilometres) after a 10-hour

SWNS


A lorry wedged between houses in Bruton, UK, after its driver followed satellite-navigation instructions.

flight, allowing aircraft to stay within prescribed air lanes during oceanic crossings. But such equipment is bulky and expensive.

Quantum gravitational systems are being developed that might detect changes in force as small as those caused by the gravitational pull of someone standing about one metre away. These systems rely on quantum superposition, in which particles exist in many states simultaneously and are very sensitive to time and electric and magnetic fields.

But all sensors have their own equivalent of fog. Compasses can be confused by magnetic rocks. The Moon landings were affected by the density of rocks in the lunar seas. A robust solution could involve a combination of many sensors. As with satellite navigation, we will need new standards and new maps.

The technical challenges are huge. Cooling sensor atoms to near absolute zero to reduce thermal noise involves bulky lasers and elaborate optics that fill a room. Miniaturization will take time, but within a decade a system that is small enough to fit on a train could map structures, cables and pipelines that lie under the tracks — work that at present is slow and costly.

The impact on robots and autonomous vehicles will be great. Drones will be able to avoid collisions over long distances in the dark. Autonomous operation makes sense where there is plenty of space — in the ocean or the sky.

But on congested roads, efficiency and safety stem from cooperation. Rules and common standards are important. Mallards in tight formation tend to face either north or south when landing. Because vision alone cannot prevent collisions between these high-speed flyers, the ducks use sensors in their eyes, beaks and ears to align themselves to Earth's magnetic field[6]. Aircraft are confined to air corridors. Navigation conflicts need to be resolved and a controller must decide who gets priority.

Fully autonomous cars will not work without an agreed set of rules and communication between vehicles, which requires an infrastructure. Slow 'hop-on, hop-off' cars might be able to cruise safely around a shopping centre, but hundreds of independent, driverless vehicles roaming city streets, or flocks of drones in urban skies would be impractical. The cost of making such systems safe could be prohibitive. Legal and institutional issues — liability and insurance — must also be addressed.

*"The solutions lie around the next bend, just over the hill."*

Even without full automation, sensors and links could make cars easier to drive and safer. Satellite navigation could turn every road into a toll road. Travel history logged in the car could be used to charge drivers for actual road usage, rather than having a flat-rate road tax. When a congestion charge to reduce traffic flow in central London was introduced in 2003, the only available compliance option was number-plate recognition.

## NEXT STEPS

Governments must invest in research, infrastructure, rules and regulations. Improving navigation cannot be left to companies alone. A trustworthy network of ground stations that would improve satellite navigation enough to guide driverless vehicles could present a country of the size of the United Kingdom with an annual maintenance bill of the same order as a global satellite-navigation system. Cars that are capable of doing tasks by themselves — some are already able to park — could appear within a few years, but fundamental changes in the way that our road networks operate will take decades to implement.

In the meantime, three practical steps should be taken.

First, improve the science. We need to understand how systems that include — or lack — people work in practice. Cognition research can tell us where ergonomics and systems engineering will help or hinder human abilities. Increased funding for quantum technology research is welcome, such as the United Kingdom's allocation of £270 million (US$386 billion) in 2013. And billions of pounds more will be needed to build infrastructure.

Second, engineers must acknowledge the complexity of these systems. They must use quantitative models of how people navigate and drive and should incorporate findings from neuroscience. Basic mistakes need to be avoided — such as relying on satellite-navigation systems to open doors in the impenetrable zones of stations and railway cuttings, as one train company in the United Kingdom did in 2014.

Third, invest in education. Schools should teach navigation and map reading as life skills. The introduction of computers and calculators has not removed the need to understand numbers. The US Navy has started to teach celestial navigation again as a backup skill.

Navigation is where complex systems meet capable users. Marrying them to enable truly intelligent transport will position us to get the best out of people and technology across many fields. The solutions lie around the next bend, just over the hill. ■

**Roger McKinlay** *is a satellite communication and navigation consultant based in Leatherhead, UK, a former president of the Royal Institute of Navigation, and a former head of engineering at Thales UK. He sits on the EPSRC Quantum Technology Strategic Advisory Board.*
*e-mail: roger.mckinlay@ntlworld.com*

1. Brown, M., Shaw, D., Sharples, S., Le Jeune, I. & Blakey, J. *BMJ Open* **5,** e006102 (2015).
2. Wiener, J. The effects of typical and atypical ageing on orientation and spatial navigation. *Proc. CogNav 2015* (2015).
3. Jeffery, K. Making a map in the brain using neurons. *Proc. CogNav 2015* (2015).
4. McGuire, E. A., Woollett, K. & Spiers, H. J. *Hippocampus* **16,** 1091–1101 (2006).
5. Wiltschko, W. & Wiltschko, R. *J. Navig.* **46,** 174–191 (1993).
6. Hart, V. *et al. Front. Zool.* **10,** 38 (2013).