LOW-COST SENSOR TECHNOLOGY

A DHL perspective on implications and use cases for the logistics industry

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PREFACE

One day, we may dispatch a fleet of transport vehicles with a simple wave of our hand. We may gather all the information required about the contents of a cargo container with just one brief electronic glance. And before long, we may be wearing our computers on our sleeves.

This may sound like the stuff of science fiction, but it is fast-approaching reality, and it is likely to have significant impact on the logistics industry.

In this trend report, we take a deep dive into the enabler of this impact: Low-cost sensor technologies that were first developed in the consumer world and are now moving into the business world. The potential for low-cost sensors in the logistics industry has already been highlighted in the acclaimed 'DHL Logistics Trend Radar', an overarching study and a dynamic, living document designed to help organizations derive new strategies and develop more powerful projects and innovations.

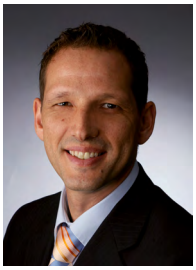
The logistics industry is often criticized for lack of innovation. The usual roadblock to innovation is expense, as it is very costly to trial new technologies across what is such a highly networked industry. Here then is an exciting opportunity – the chance to innovate using low-cost sensors that have already proved their worth in the consumer environment.

This trend report starts by recognizing the phenomenon and powerful benefits of consumerization, including the blurring of consumer/corporate boundaries as we use smartphones, tablet computers, and other mobile devices both at home and at work.

With logistics, we aim to get the right object, at the right time, in the right place, in the right quantity, in the right condition, and at the right (low) cost. We can do this with low-cost sensors, and achieve the new levels of transparency that today's customer demands.

As you will read in this trend report, the DHL Solutions & Innovation team is busy creating and piloting systems based on low-cost sensor technology. Our next step is to bring these systems to market. We hope you enjoy this deep dive into the future of logistics.

Yours sincerely,



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INTRODUCTION AND EXECUTIVE SUMMARY

One of the major current trends in the IT sector is the increasing integration of consumer IT devices in the business world. The buzzword for this is consumerization – the growing phenomenon of leading IT solutions appearing first on the consumer market and subsequently spreading to business and industry. Technology leadership has shifted from serving companies to now serving individual consumers. And the emergence of mobile computing technologies – in particular, smartphones and tablet computers – has resulted in employees being technically better equipped in their personal lives than in their professional world (Bitkom 2012).

Approaches such as BYOD (bring your own device) constitute a first step toward the integration of consumer IT into business and industrial applications. Geared toward the professional use of personal devices (such as smartphones and tablets), BYOD integration has mainly focused on office-related applications such as email, word processing, and telecommunications. Moving beyond this, the consumer sector is now experiencing exciting new developments with innovative sensor technologies, particularly low-cost sensors. This consumer-led phenomenon has great potential for business and industry, and for the development of new mobile devices. The challenge for IT departments will be to integrate these new technologies as they spread from the consumer environment into the business environment.

Low-cost sensor technology is defined in this trend report as sensor technology originally developed for consumer applications. Competitive and low cost because of economies of scale, these sensor technologies enable new applications or allow more cost-effective utilization of sensing in production and logistics processes and environments.

This trend report provides an overview of the low-cost sensor technologies and consumer electronics technology trends that have relevance for the logistics industry. It systematically identifies the sensor and IT solutions capable of impacting logistics applications, and discusses their potential utilization in the logistics industry, as well as the challenges that they are likely to bring.

The findings of this report indicate seven key ideas about the future utilization of consumer electronics in the logistics sector:

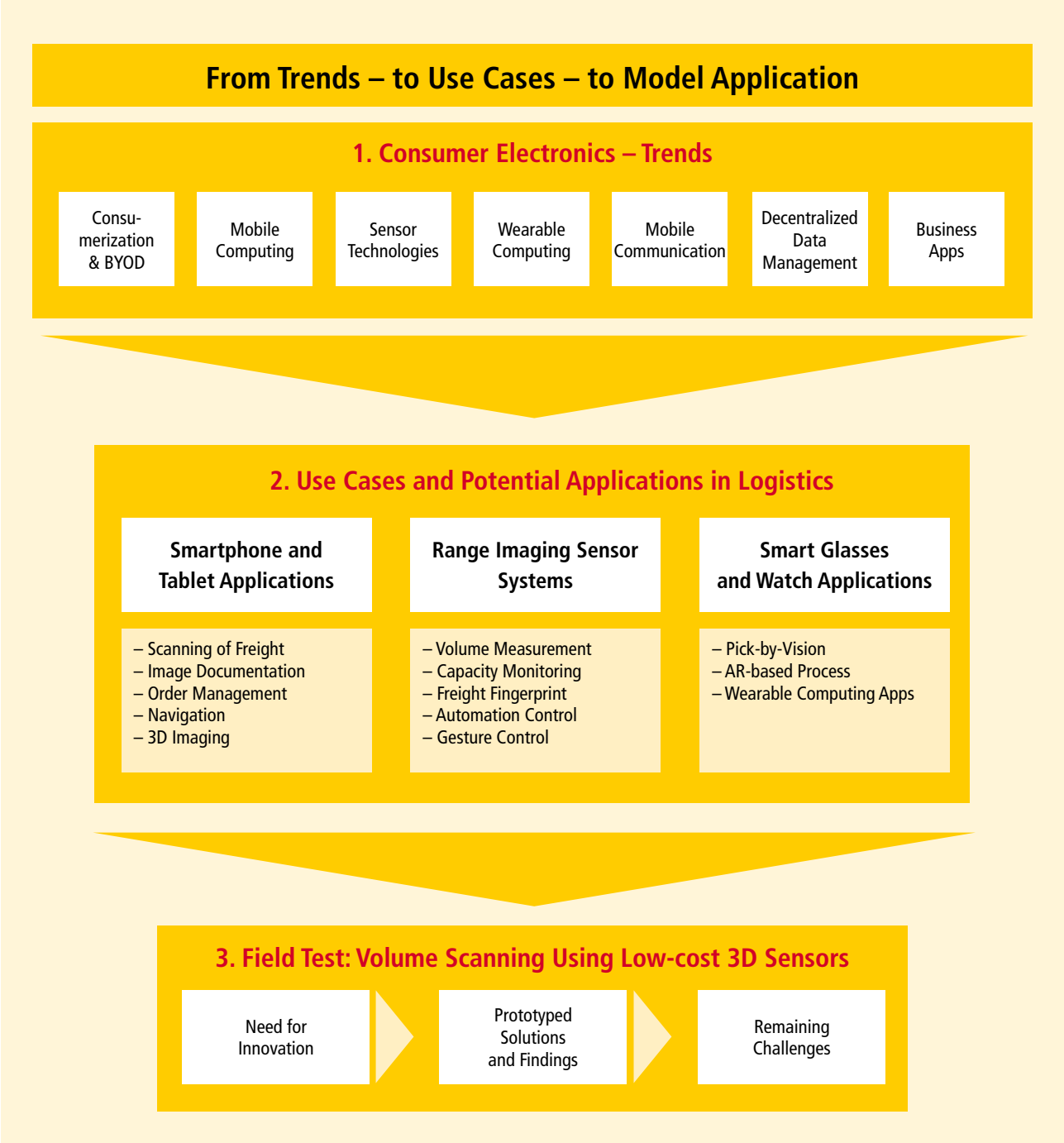
1. Consumer electronics are changing user behavior – in personal and professional environments
2. Consumer electronics integrate customers as active partners in the processing of logistics orders
3. Consumer electronics will advance the utilization of auto-ID technologies in logistics applications – both for logistics companies and for customers
4. Consumer electronics in the form of wearable computers will be essential to personnel working in logistics companies
5. Consumer electronics provide the human-machine interface for the Internet of Things and consecutive stages such as the Tactile Internet
6. Consumer electronics enable and support seamless, real-time monitoring of logistics processes
7. Consumer electronics enable and support seamless, real-time control of logistics processes

This trend report follows three steps:

Section 1: A brief review of the most important trends in consumer electronics, analyzing hardware and software trends

Section 2: Identifying key challenges to the integration of these innovative sensor technologies and IT solutions in business applications

Section 3: Identifying implications for the logistics industry, and considering next steps



1 CONSUMER ELECTRONICS: TRENDS

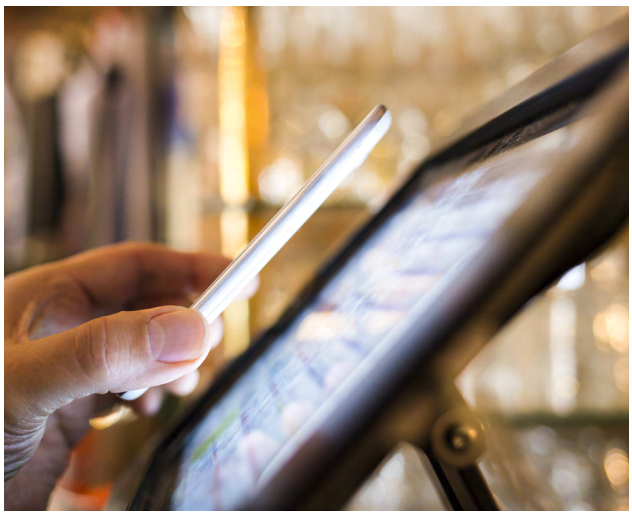
Developments in the consumer electronics market are characterized by short innovation cycles and low prices generated by economies of scale. Of course, these qualities are highly attractive to companies too, particularly organizations under competitive pressure to be agile and cut costs.

Consumer-originated solutions first become familiar to people in their personal lives and then become relevant for professional use. This is why the latest leading information and communication technologies (ICTs) – traditionally anchored in the business world – are now being applied to the consumer market. Application domains previously restricted to the business world are increasingly being driven by consumer developments – examples include augmented reality, gesture control, and 3D printing, to name but a few.

Consumer electronics technology trends are, of course, a subset of overall technology development, which is generally expected to narrow the divide between humans and machines. According to Gartner's latest Hype Cycle, the relationship between humans and machines is at the heart of the increased hype surrounding smart machines, cognitive computing, and the Internet of Things (Gartner 2013a).

Along with mobile computing devices such as smartphones and tablets, emerging sensor technologies that were originally developed for consumer electronics such as gaming consoles are becoming relevant for business and industrial application. And predictably, these consumer sensor technologies cost significantly less than industrial sensor technologies.

This section briefly reviews the consumer electronics trends with potential relevance for the logistics industry.



1.1 Consumerization and BYOD: Changing User Expectations

"I think there is a world market for maybe five computers" are the words allegedly said by Thomas J. Watson, former CEO of IBM, back in 1943 (Roland Berger 2011). He has since been proved wrong. Nevertheless for a very long time computer technologies were reserved for applications in the corporate world; businesses have always had the best IT available on the market. Today, things are changing.

Today, technical leadership – evidenced by innovative hardware such as smartphones and tablet computers, as well as distributed software solutions such as cloud applications – is likely to be located in the consumer world. The growing IT trend of consumerization – in which new IT emerges in the consumer market first, and subsequently spreads into business – marks the shift of technical leadership from corporate and industrial environments to individual consumers.

We are also witnessing other important phenomena. Smartphones, tablets, and cloud-based online storage have changed user behavior, making people more mobile than ever before. Users now expect to access these leading technologies not only in their personal lives but also in their professional lives – they expect their work IT to be as technologically advanced as their home IT.

In support of this, many businesses now allow employees to BYOD (bring your own device), enabling consumer electronics to be used in the professional environment. They may also or alternatively operate a COPE (corporately owned, personally enabled) policy, equipping employees with the devices they want to use both at work and at home (EMT 2013). The aim of corporate BYOD and COPE policies is to boost employee productivity, but this deliberate blurring of personal/private IT boundaries brings its own challenges (reviewed in Section 2).

Concurrently and inevitably, consumerization is marked by a general decline in development of mobile devices (smartphones and tablets) solely for professional use. The majority of smartphones and tablets today are developed first for the consumer market, and these mobile devices represent merely the first wave of consumer electronics entering the business world.

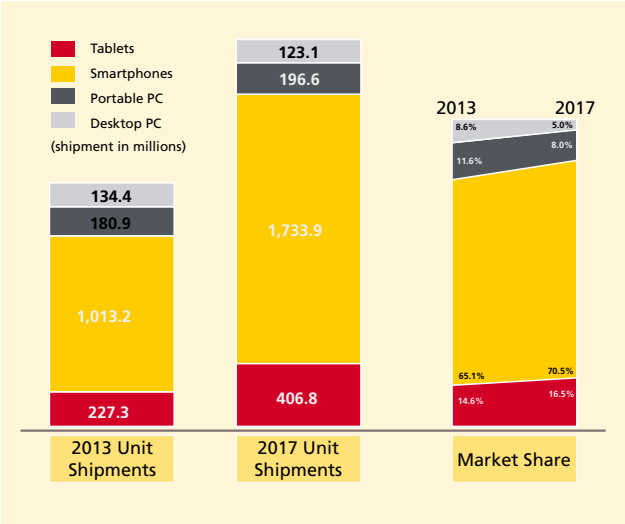


Figure 1: Shipments forecast; **Source:** IDC 2013

1.2 Mobile Computing: Toward the Internet of Things

Sales figures show that mobile computing devices are now the biggest category of IT devices. The global smartphone market alone is already larger than the conventional PC market, and the number of shipped smartphones is steadily growing (by 87% per annum, compared with just 3% growth for shipped PCs). Right now, the market for tablet computers is ramping up to become considerably larger than the PC market (Steria 2012).

What are the implications of all of these trends and developments? As mobile IT devices have outnumbered classic desktop IT systems, some are already calling this the post-PC era. Because of these developments, every user – consumers and employees, at home and at work – expects mobile applications and uninterrupted Internet access on their mobile devices. This expectation is a challenge to the capacities and capabilities of mobile communication infrastructures, and to the availability of any and every kind of online service.

For businesses, this means it is increasingly important to make processes and assets information available in real time. And it is essential for organizations to meet customer expectations of service.

Already this is giving rise to IT-driven paradigms such as the Internet of Things in which objects become smart (uniquely identifiable) and their virtual representations start sharing information. Transferring this paradigm to industrial applications is the aim of various government-driven research and development (R&D) programs, such as Germany's Industrie 4.0 (BMBF 2013).

Witnessing papal history changes within the digital age;
Source: Photoblog 2013

1.3 Sensor Technologies: Everything Gets Measured

Another important trend that's emerging along with the increased use of smartphones, tablets, and other mobile IT and communication devices is adoption of sensor technologies into these devices. With sensors, everything can get measured. As universal tools capable of online data access and exchange, and designed to be physically robust, smartphones and tablets are clearly suited to many business and industrial applications. Once equipped with one or more sensors, mobile devices are ideal for monitoring and controlling the supply chain.

Many more sensors are likely to be integrated in mobile devices. Already there are first designs of modular models that allow free configuration of sensors in smartphones. In future, this will also open the possibility of configuring mobile sensor nodes that use smartphone technologies but dispense with the original telephony function. Given the high levels of hardware integration and the large quantities of low-priced devices, these modular sensor nodes are likely to become significantly more relevant for business and industrial applications such as tracking and tracing goods.

Several wireless technologies that exchange data are already common in smartphones and tablets. The first step towards also enabling wireless communication with passive counterparts is integration of near-field communication (NFC) modules for payment applications. As NFC employs high-frequency radio frequency identification (HF-RFID) technology, it is likely that future mobile device development will support additional RFID standards, and so significantly increase the number of potential applications (BVL 2012).

Gaming consoles use a wide range of sensors for motion analysis and localization and, given their excellent performance levels and low prices, these sensor technologies are of growing interest for business and industrial applications. For example, low-cost sensor technologies such as Microsoft Kinect© can even outperform established industrial sensor technologies in some ways. The development of 3D imaging sensors and other low-cost, high-performance sensors is opening new fields of commercial application.

In the foreseeable future, innovative 3D imaging sensors that augment established methods of identification (such as QR codes) and plain photo documentation are likely to be integrated in mobile devices (Structure.io 2013). And the creation of new applications for commercially available low-cost sensor technologies is fuelled by short hardware innovation cycles and active open source developer communities.

	Sensor Types	Purpose
iPhone 5S	▪ Three-axis gyro ▪ Accelerometer ▪ Proximity sensor ▪ Ambient light sensor	▪ Motion / gesture / facial / voice recognition ▪ Location analysis ▪ Brightness control
Galaxy S4	▪ Three-axis gyro ▪ Accelerometer ▪ Proximity sensor ▪ Ambient light sensor ▪ Temperature, humidity, and barometer sensor ▪ NFC	▪ Motion / gesture / facial / voice recognition ▪ Location analysis ▪ Environmental analysis (temperature, brightness, humidity) ▪ Passive tag identification
Upcoming Devices	▪ Depth-imaging sensor ▪ RFID ▪ Air quality sensor	▪ Gesture recognition and documentation ▪ Passive tag identification ▪ Environmental analysis

Figure 2: Sensor technologies in smartphones, **Source:** DPDHL

1.4 Wearable Computers: Innovative Human-Machine Interfaces

Gartner's Hype Cycle identifies wearable user interfaces as one of the currently most hyped technology topics. Emerging consumer devices such as smart glasses (e.g., Google Glass© and Microsoft's Fortaleza) and smart watches (e.g., Sony's SmartWatch and Samsung's Galaxy Gear) are adding to the consumer electronics range, either as additional interfaces to smartphones and tablets or even as standalone devices, integrating various communication functions.

Other wearable computing solutions have been discussed in recent years. One is to integrate sensor fabrics in clothing. But the most obvious approaches to a wearable user interface seem to be smart glasses and smart watches, as these are enduring and everyday accessories.

Among several developments of wearable computers for industrial environments are augmented reality projection glasses for mixed reality environments in planning processes, and RFID wristbands or hands-free barcode readers that automatically identify objects in handling processes.

As these systems are developed for single applications, it is likely that consumer electronics will be able to execute the same functions in future. Given the high level of hardware integration in consumer electronics and the steady integration of other sensors in smartphone and tablet developments, it is almost inevitable that wearable consumer electronics will be capable of barcode reading and RFID reading one day.

1.5 Mobile Communication: Toward 5G

Uninterrupted availability of wireless communication is a fundamental prerequisite for linking distributed mobile computing devices and sensor nodes and for enabling the Internet of Things. Though no specifications exist yet, discussion and research are underway for the next major development of mobile telecommunications standards to supplant the current 4G standard. The first international consortia have been formed to research the future standards, and in Europe, the Metis 2020 consortium aims to lay the foundation for 5G (METIS 2013).

A brief look at the availability of frequency bands reveals that there is little room for larger bandwidths. This is one reason why discussions about future 5G standards focus less on increasing maximum throughput and far more on targeting lower energy consumption, lower outage probability (better coverage), high bit rates in larger segments of the coverage area, lower latencies, and higher reliability of communication.

As the standards evolve towards 5G, development objectives extend beyond goals such as lower latency and higher communication reliability to also address ability to meet industrial communication requirements. In industrial environments, wireless communication will be increasingly used. R&D into topics such as mobile robots focuses on the speed and security of wireless communication, with the aim of boosting flexibility in production facilities.

Some of the first projects striving to employ future 5G technologies are for automation control, and require a latency of just 1 ms in a closed loop communication process (FAST 2013). Also being discussed, under the concept of the Tactile Internet, are first approaches to enabling reliable real-time communication with (rapidly) moving objects on the basis of mobile telephony. These discussions also include aspects of the mobile Internet and the Internet of Things (TU Dresden 2013b).

Figure 3: Evolution from 2G to 5G, **Source:** TU Dresden 2013a

1.6 Distributed Data Management: Clouds and Big Data

There are some startling descriptions of the amount of data created in today's IT-driven world and the anticipated growth of the Internet. For example, it is estimated that there will be five billion Internet users worldwide by 2020 (up from approximately 2.1 billion users in 2012) (Steria 2012). In addition to this growth, which will mainly occur in emerging and developing countries with young populations, Internet use will increasingly turn toward mobile communication. People are not only consuming information from the Internet but are also creating data. According to Google's executive chairman Eric Schmidt, the world creates five exabytes of data every two days, just as much as was created between the dawn of civilization and 2003 (Economist 2012).

Given that over seventy percent of email traffic is caused by spam, it will be a key challenge to handle all of the data created (i.e., separating the useful from the useless and aggregating, condensing, and automatically analyzing it) (Steria 2012). Furthermore and essentially an outcome of the Internet of Things, the amount of data from distributed sensor systems and smart objects will continue increasing in corporate and industrial applications. Meeting the challenge of capturing, storing, searching, transferring, and analyzing this so-called Big Data is one of the recent major issues of IT-related R&D. Gartner defines Big Data as "high-volume, high-velocity, and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making" (Gartner 2013b). Distributed data management in the cloud is just one approach to meeting this challenge – and the cloud is already very familiar territory to consumers.

Effective use of Big Data is imperative for business. Top-performing companies are advanced in rapidly processing data that is collected inside and outside their organization. This includes processing data from Internet tracking technologies and social network analytics (Economist 2012).

1.7 Business Apps: Speeding Up Innovation Cycles

The extensive use of mobile devices such as smartphones and tablets, in conjunction with mobile Internet access, has laid the groundwork for individuals to access information and to interact anywhere and anytime. This is why enterprise mobility (a generic term for several concepts and solutions) is growing in importance. As smartphones and tablets have become the main communication devices between enterprises and their customers, one of the keys to successful enterprise mobility is providing the company's own business apps (Bitkom 2012).

But maintaining customer relations is only one reason for business apps. Internal business apps (e.g., for maintenance and overhauls) can make internal business processes more efficient (e.g., they can facilitate user flexibility and shorten innovation cycles). They can additionally boost utilization of smartphones, tablets, and other mobile devices in internal business processes.

In recent years, the trend has been for business apps to shift from native apps to web-based apps, which allow centralized updating procedures and facilitate customization. However, expectations of an HTML5 web apps standard were disappointed in part and – as a result – hybrid apps have appeared which combine the advantages of both native apps and web apps. These hybrid apps are expected to become dominant in the coming years (Computerwoche 2013).

2 POTENTIAL APPLICATION OF LOW-COST SENSORS IN LOGISTICS

"The logistics industry isn't always well-known for embracing innovations in technology – often for good reasons, after all moving goods around the globe reliably can be hard enough as it is ... Yet think how simple collaboration could be if simple user interfaces for key logistics software started to be made available as smartphone/tablet apps? As well as potentially much cheaper to implement, it's a much smaller 'ask' of frontline staff to check a couple of boxes on their iPhone screen and confirm a time of receipt."

(Kewill 2012)

This application scenario demonstrates the potential of mobile consumer devices for communication and documentation in logistics. A closer look at the sensor technologies already available in smartphones and tablets reveals that these can be used to execute nearly every control operation necessary in logistics. Assuming other sensor technologies (e.g., depth imaging sensors) will be integrated in future, smartphones are likely to gain even more condition monitoring capabilities.

	BYOD	QR Code NFC RFID	Clock	GPS WLAN GSM Cell	Temperature Humidity	Depth Imaging
The right object …		✖				
at the right time …			✖			
in the right place …				✖		
in the right quantity …		✖				✖
in the right condition …					✖	✖
at the right (low) cost	✖					
Smartphones Tablets	✖	✖	✖	✖	✖	**to come**

Figure 4: Sensor technologies in mobile devices that execute control operations in logistics; **Source:** Fraunhofer IFF

Analyzing sensor technology usage and consumerization in relation to the classic six overall objectives in logistics – the right object, at the right time, in the right place, in the right quantity, in the right condition, and at the right (low) cost – shows that smartphones, tablets, and other mobile devices are already multi-sensor tools capable of performing most requisite control operations. As consumerization enables low-cost sensor technologies to be employed in logistics, the social trend of BYOD ties in with the corporate goal of "at the right (low) cost".

The focus in this section is on use cases employing consumer electronics, distinguishing between established use cases and potential future applications under development.

2.1 Smartphone and Tablet Applications

The use of mobile devices such as smartphones and tablets in warehouse and delivery processes is a current trend in the logistics sector. The first successful use cases not only take advantage of the diverse technical capabilities of these mobile devices but also utilize cloud-based software-as-a-service. Inventory management systems are a good example. The initial focus for applications are scanning of barcodes and other markers, image documentation of freight, integrating scanned information in the company network, and even signature capture on delivery of freight.

Over two hundred users and vendors of logistics software were surveyed in BVL's latest study "IT in der Logistik". This study determined that thirty-eight percent of vendors sell logistics software programs for mobile devices. Companies are typically using the mobile devices' image functions (e.g., barcode scanning), software interfaces, and – to identify HF-RFID tags – near-field communication (NFC) interfaces (BVL 2012).

NFC technology and HF-RFID technology operate in the same frequency (13.56 MHz), and HF-RFID is already widely used for product identification and maintenance. Being able to communicate at a frequency of 13.56 MHz between an NFC-compatible smartphone and HF transponders in compliance with ISO 15693 (NFC-V) opens up many new possibilities for logistics. And because anyone with an NFC-compatible smartphone can use RFID transponders to identify items wirelessly, it is certain that consumer mobile devices will appear in every domain of logistics in the future, not least because of their capabilities for image and wireless identification of freight.

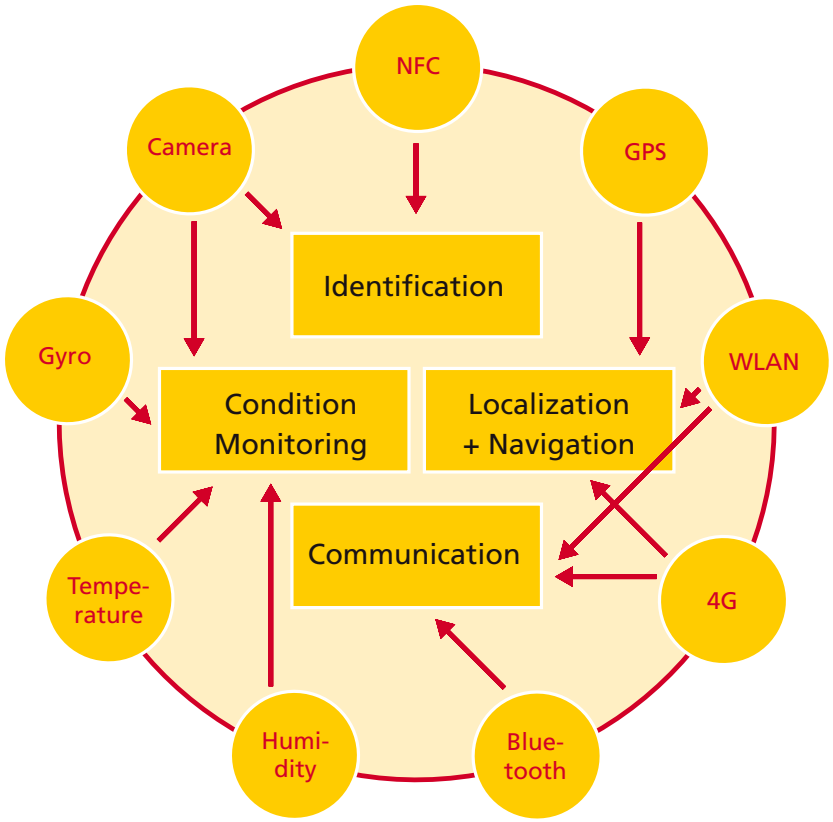


Figure 5: Sensor technologies in current mobile devices and how they can be applied in logistics; **Source:** Fraunhofer IFF

An obvious use case is to track freight with smartphones and a cloud-based app. This app would synchronize data on the cargo scan in the warehouse and on the vehicle scan during delivery with the existing logistics control IT systems. A significant argument for the use of smartphones is the substantial cost savings for this hardware compared with the conventional scanner systems used in the logistics sector.

Tracking freight this way, it is possible to scan process steps electronically (something that wasn't affordable with high-cost scanners). Also, with cloud-based freight tracking, scan data is directly available, boosting the efficiency of internal process control. Furthermore, shipment tracking becomes far more transparent for customers thanks to more extensive process coverage, and this – in turn – reduces customer inquiries so that less labor input is required to expedite delivery (Tecchannel 2013).

However, there are two issues that currently stand in the way of the wider use of smartphones, tablets, and cloud-computing applications in the logistics industry. One is that devices developed for consumers rarely offer the physical robustness (even simply against falls) required in the everyday world of logistics. The other is that business users doubt the security and reliability of cloud-based applications.

Arguments in favor of smartphones, tablets, and cloud-computing apps in the logistics industry include the potential cost savings (the cost of cloud-computing apps is estimated at 25% of warehouse applications, for example) and the design refinements of mobile devices (Handelsblatt 2012). There is a growing trend towards development of more physically robust outdoor devices for both personal and recreational use. Also, design engineers are creating advanced smartphones with integrated energy storage systems and no keyboard – design features enabling high international protection ratings and even certification for use in explosive environments (ATEX).

It seems that the boundary between consumer and professional devices is increasingly blurred.

Given the multi-functionality of smartphones and tablets, designers are sure to integrate other functions into them – functions that are presently distributed on different subsystems. For example, as well as cargo scanning and documentation, smartphones can also support navigation. Rather than relying on several different devices inside a vehicle, delivery drivers could have a single, mobile device that scans to confirm receipt of deliveries, makes telephone calls to expediters, and provides navigation support.

Another future use case will be using positioning and web-based communication to deliver freight shipments more accurately and at times synchronized with each customer. DHL is currently working on solutions to synchronize delivery routing and customer availability.

In the future, mobile devices will also be able to supply 3D scan information to document cargo during delivery operations. These devices can include range imaging sensors, such as those already familiar on game consoles. Likely logistics applications are 3D documentation of freight condition during delivery to customers/partners within a supply chain, and free-hand scanning of shipments by couriers to bill shipments based on volume.

2.2 Range Imaging Sensor Systems

Introduced at the end of 2010, Microsoft Kinect was the first sensor system available in the consumer sector that scans three-dimensional structures. Freelance developers envisaged and quickly added numerous applications to the original games console application of a gesture controller, operating on the basis of pattern projection. And inevitably new fields of application were also rapidly identified – including production and logistics applications. Refinements to these sensor technologies are facilitating integration in mobile devices. And alternative methods of measurement (e.g., time-of-flight) penetrating the consumer sector are also bringing the advantages of higher precision and insensitivity to various surface materials and light interference.

Hand movement tracking with sensors such as the Leap Motion© 3D Controller; **Source:** Fraunhofer IFF

The sensor technologies capable of ascertaining surface contours can be used diversely in logistics to scan and determine the volume of cargo (Borstell et al. 2013). Volume determination can be used to scan individual freight items or to calculate the fill level of storage space. The single-shot method enables sensors to scan even moving objects very rapidly. This also makes it possible to scan volume and classify objects on conveying and handling equipment.

Different approaches and functionalities to scanning freight structures and volumes in logistics processes are explained in more detail in Section 3. But there are problems with the basic suitability of low-cost sensor technology for measuring tasks – the challenges of process integration and the lack of physical robustness for mass application. Nevertheless, the first products are now commercially available, launched by companies that have developed their industrial system solutions from consumer sensors.

Mobile device volume scans are useful not only in warehouses but also for automatic inspection of cargo compartments. Whether based on free load meters, available cargo space, or utilized volume, scanning freight contours in the cargo compartment of a transport vehicle is an easy way to determine the truck's capacity. This also opens up new possibilities. For example, during the dynamic routing process, relevant data could include not just current traffic information but also the availability of free freight capacity in each transport vehicle.

In addition to scanning freight volumes for process control or billing, automatic scans of the dimensions, contours, and colors of individual shipments could be used to generate digital images as shipment fingerprints. Already, the first R&D projects are underway – they use not only shipping labels but also appearance to classify and identify individual parcels (Borstell et al. 2012).

Fingerprinting is of particular importance to supply chain security. In the above example, the digital fingerprint combines item labeling and appearance, and can also incorporate identification features such as RFID and condition data. Any change in cargo contour would indicate tampering or damage in transit, and this would be automatically identified in logistics processes at an early stage.

The application of 3D sensors is relevant for the automation of logistics processes, too. Automatic scanning of freight structures by means of 3D sensors is the basis for controlling robotic unloading systems that will unload containers in the future, for instance. To this end, the applicability of low cost 3D sensors has already been studied in research (Thamer et al. 2013).

2.3 Smart Glasses and Smart Watch Applications

Augmented reality (AR) applications are playing an important role in increasing the blending of the digital world and the real world. By displaying additional contextual information in the field of view, a larger quantity of information can be conveyed in a real-world scene. For logistics applications, it would be very useful to provide additional information on transport units or process control. And for example, it would boost logistics efficiency and security to display a packing list when examining a container, or provide the next process step (e.g., picking information for unloading or order picking).

Most smartphone and tablet AR applications are available in the domain of consumer electronics. For industrial use, however, head-mounted display (HMD) solutions were developed early on, as workers needed to receive contextual assembly instructions over displays while using both hands and being unable to look at a stationary monitor. A typical example of a logistics application that exploits AR information to assist and guide users is order picking (e.g., Pick-by-Vision solutions) (Logistics Viewpoints 2013).

With the introduction of consumer-oriented HMDs such as Google Glass, these types of AR system are likely to become established in everyday working life as part of consumerization. Data glasses, which not only provide AR information but are simultaneously controlled by language or gestures, provide a “hands-free” advantage, especially in the professional world. These benefits will lead to a greater proliferation of AR applications.

Augmented reality providing worker instructions;
Source: Fraunhofer IFF

Smart glasses and even smart watches, the first models of which are available in the consumer sector, will additionally emerge from their role as expanded smartphone and tablet interfaces in the future. Increasing technical integration will make it possible for smart glasses and smart watches to replace mobile devices in certain application domains, especially those which require high mobility of workers. Consequently, the above use cases, already conceivable now with smartphones and tablets, will also be relevant for wearable computing devices.

3 FIELD TEST: VOLUME SCANNING USING LOW-COST 3D SENSORS

The use of mobile devices such as smartphones and tablets for office applications and customer communication is an initial step toward the integration of consumer electronics in the business world. How can individual sensor technologies be transferred to commercial applications? How can sensors designed for personal applications be modified for use in the harsh process environments of logistics? This section examines DHL's studies on the integration of low-cost range imaging sensors in logistics applications.

3.1 Need for Innovation

The key to efficient logistics is an optimal freight flow and related information flows. DHL endeavors to optimize its processes continuously in order to meet customer needs. It researches innovative, industry-independent technologies and transfers them to logistics.

Volume scanning in conjunction with the weight and image of freight items is an integral part of internal logistics processes in many DHL units. Various commercially available system solutions are already partly in use in the DHL network. Typically, these systems entail high capital expenditure and are sometimes difficult to integrate in existing processes.

For instance, the systems currently used to scan pallets in the shipping business have proven to be bottlenecks because of their unduly high process times. In addition to weighing a pallet on a floor scale, there is considerable downtime while pallets are scanned. The scanning systems generate a multitude of partial images of the pallet, which have to be reconsolidated afterwards. A promising alternative is sensor systems such as Microsoft Kinect – as these new systems employ a different, faster scanning method. DHL is studying the feasibility of adopting this type of consumer electronics product for industrial use.

Since low-cost range imaging sensors made their appearance in Microsoft Kinect and similar input devices for gaming console applications, a wide variety of applications have been developed. By acquiring an object's surface contours with a total of 640 x 480 range values per scan and at up to 30 scans per second, 3D models of scanned objects can be generated, even when objects are moving relative to the scanner. The sensor in the pattern projection system transmits an established, matrix-like pattern of points of light, which is altered by the object's surface structures.

The original and the altered pattern are reconciled, and distances (so-called depth values) are determined from this. A depth value matrix is used to calculate an individual object's volume in the effective range. In addition to scanning volume, a low-cost range imaging sensor can use a camera to take pictures in order to document a precise transfer of risk.

The objective of DHL's studies is to develop a complete system, combining low-cost 3D sensors with mobile scale systems, to deliver the volume, the weight, and a picture of each pallet. As this type of system requires lower capital expenditure and is capable of efficient process integration, it would be an extremely attractive alternative to current industrial sensor systems.

3.2 Prototyped Solutions and Findings

As a first use case, and to test technology transfer, a concept solution was developed employing low-cost 3D sensors to scan volume. This initial approach was strongly oriented toward commercially available solutions that are already in use to scan pallet volume. The prototype has two sensors installed on a gate structure. These sensors scan the volume of pallets placed in their defined read range. This single-shot method of measurement cuts the previously required measuring duration by 50%.

This concept additionally incorporates weighing units on forklifts. While their volume is being scanned, pallets can therefore be weighed at the same time. Also, with a color camera installed in the 3D sensor, this prototype solution generates color pictures that can be referenced if there is a subsequent claim for damages. Data acquisition is initiated by simply scanning each item's barcode, and data links transmit the collected scanned information to a higher-level database.

Developing beyond the stationary concept, a mobile prototype has also been developed. For this, the sensors are installed directly on the forklift, which is also equipped with weighing units, thus allowing entirely mobile data acquisition. Items no longer have to be transported to a certain location inside the warehouse for their volume and weight to be scanned, and data can be flexibly acquired inline anywhere in the warehouse.

This application also benefits from the low-cost 3D sensor single-shot system, something that is impossible with current laser scanners. Measurement is again initiated by a barcode scan, and data is transmitted to a higher-level database through a wi-fi link.

The graphic below presents an overview of both systems, test results, and use cases.

In many respects, the results of the pilot phase have met expectations, including high accuracies as well as validation of complete system functional performance. Given shortened process times and relatively low capital outlay, these systems pay for themselves five times faster than current solutions. The results underscore the high potential for low-cost 3D sensors and highlight the trend of transferring this consumer electronics technology to industrial applications.

Building upon the first tests and widespread interest from users, DHL is also studying other potential use cases for this technology, including but not limited to the following:

- In addition to scanning volume data, object contours can also be recognized. Sensors mounted above a conveyor section can identify packages based on their external attributes and thus steer them through the material flow. Three-dimensional images and pictures can be combined to use color as an additional attribute.

- Storage space is a scarce commodity in logistics. With integrated monitoring in a warehouse, it is possible to identify free space in the system. Filling-level status is thus always known automatically, and processes affected by it can be modified. An area of 30 m² can be monitored by just one sensor – a low-cost alternative to current camera systems.

- Cargo space in vehicles is also limited, and is an important criterion for optimized routing. Sensors installed inside truck cargo compartments can transmit utilization data to a planning system in real time. In combination with job order and traffic data, routing can be done dynamically. DHL sees potential in this to boost vehicle fleet efficiency, both economically and ecologically, especially in pickup and delivery traffic. Volume scan modules flexibly integrated in transport vehicles are currently in development.

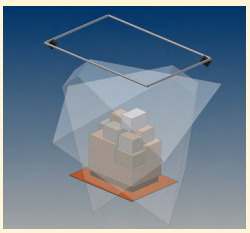
	Arrangement		Results	Use Cases
Gate System		▪ Two depth-imaging sensors in inclined arrangement ▪ 3D measurement of a defined area ▪ Installation above scales ▪ Stationary solution	▪ Measurement and photo documentation of all visible sides of an object ▪ Low shading effects even with complex structures ▪ Complex system calibration	▪ Optimized packing sequence ▪ Status documentation ▪ Contour check prior to loading ▪ Volume-based pricing
Mobile System		▪ Two depth-imaging sensors on forklift mast ▪ 3D measurement of the area on forks ▪ Integrated fork scales ▪ Wireless data transmission to database	▪ In-process measurement for short process times ▪ Classification of pallets and height measurement ▪ Complex system integration	▪ Volume-based sorting ▪ Optimized packing sequence ▪ Status documentation ▪ Contour check prior to loading

Figure 6: Protyped solutions; **Source:** Fraunhofer IFF

3.3 Remaining Challenges

In addition to the high potential of low-cost sensor technology and these promising findings, some important questions about usage have been identified during testing. Answers to these questions are likely to generate other important findings and developments in this domain, and constitute important milestones in the refinement of this technology for industrial solutions.

User friendliness – is out-of-the-box calibration feasible?

The newly developed systems are prototypes that cannot be installed yet without expertise. System software must be developed so that each system can be commissioned automatically.

Durability and service – can these systems offer adequate quality?

It is essential to guarantee the durability of these systems. Business customers are familiar with guarantee standards of the leading commercial sensor system vendors, and will demand the same quality and durability in systems based on low-cost sensors. If these new systems are to provide a real alternative to conventional systems, they must come with comparable guarantees and servicing/repair services.

Modifications for industrial use – will they be tough enough?

The harsh environment of logistical infrastructures imposes different system demands than the living room. These new systems therefore have to be refined to meet industry quality standards. Already, an embedded system has been developed that meets these standards – it comprises a low-cost sensor with an IP54 rating, a controller for data processing, and an industry-standard interface for data transmission.

A range imaging sensor in an ebedded system with an industrial housing; **Source:** Fraunhofer IFF

Clarification of legal requirements – what conformance testing is required?

Compliance with particular directives and legal regulations must be verified, regardless of the use case. This would be essential for applications that make use of data to assure payment. The new systems will have to meet specific quality demands and standards that require certification by an accredited body.

SUMMARY AND OUTLOOK

Consumerization is an important trend for the use of IT. It is already an established phenomenon in the business world, as companies with BYOD programs allow employees to use their own smartphones, tablets, and other mobile devices at work. As this gains momentum, more and more consumer electronics are likely to appear in the workplace.

The market launch of smart glasses and smart watches is providing new IT devices for user interaction, and these show great potential for integration in production and logistics processes. With access to low-cost sensors, the logistics sector is likely to increase its use of sensors in many processes, creating smart logistics infrastructures. The use of low-cost sensor technology will open new fields of application for monitoring, inspecting, and controlling industrial and logistical processes – applications which were previously technically impossible or unaffordable.

The blurring of boundaries between consumer electronics for personal use and business devices for industrial use presents new opportunities. Developers, integrators, and users have the chance to identify corporate applications for consumer electronics at an early stage. Whether sensors are integrated into mobile "all-rounders" such as smartphones and tablets or a specific sensor module (such as a range imaging sensor) is used to create a dedicated system, these devices all benefit from cost reduction and this current period of highly dynamic development.

Innovation cycles for both sensors and software (including app development and cloud-based applications) are significantly faster than for traditional industrial sensors. Combining this highly dynamic development with the necessary quality and durability will be key to the success of low-cost sensors in logistics.

In response to the outstanding potential of low-cost sensor technologies, companies are already modifying their requirement profiles for industrial electronics components. This trend is set to continue.

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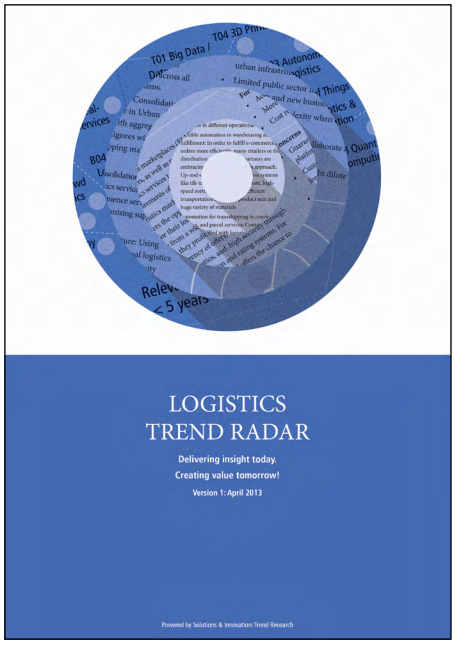

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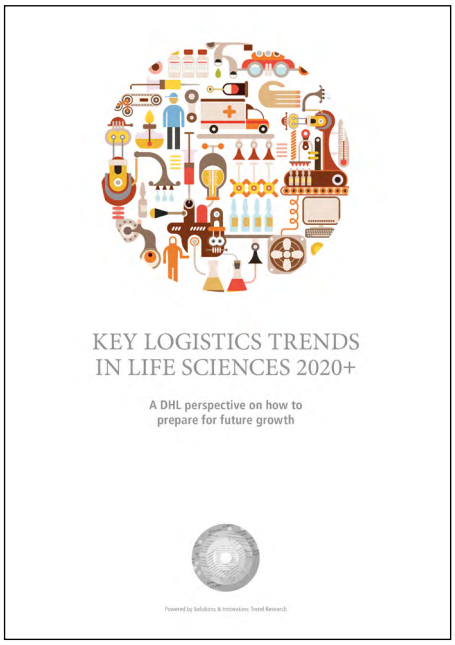

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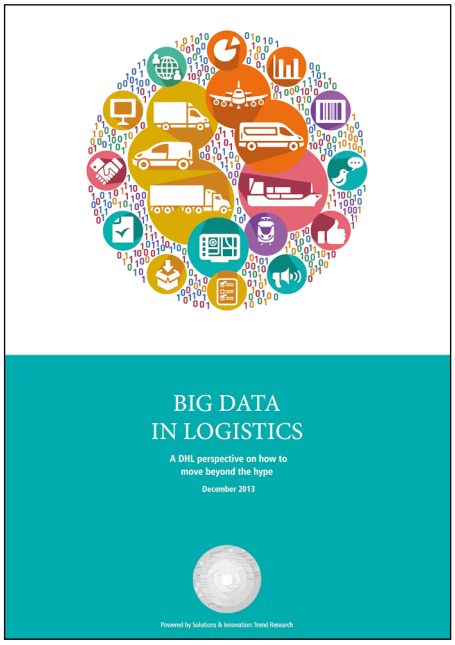

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