Feature

Warehouse management technologies

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Abstract
Purpose – Aims to discover the different technologies used in warehouse stock control.
Design/methodology/approach – The paper begins with a review of optical and radio-frequency product-labelling technologies, and then examines various devices and systems for reading these labels and integrating stock control into back-office databases. It then looks at techniques for finding the goods within the warehouse, from simple address labels to radar positioning and inertial navigation, considering both operator-based and guided vehicle handling systems.
Findings – Labelling technologies facilitate automatic product identification. Rugged handheld computers with wireless communications give real-time capability and integrate stock control into wider software systems for efficient resource management. Speech synthesis provides one man-machine interface enabling workers to order-pick under database control. Automated readers record products entering and leaving the warehouse, theoretically removing the need for stock taking. Automatic guided vehicles are now available to stack and retrieve goods in the warehouse.
Originality/value – Provides engineers with an overview of the diversity of solutions employed in warehouse stock handling.

Keywords Warehousing, Stock control, Mark scanning equipment, Order picking

Paper type Technical paper

Introduction

To manage a warehouse efficiently, one needs to know what is in it, and where exactly each item is stored. The former is called inventory, and is established by stocktaking. In the old days, this involved reading the labels on the different items and counting them, and recording the information on a clipboard for later analysis. Now, different types of labels such as bar codes, 2D data codes and radio frequency identification (RFID) facilitate automatic reading, and operatives can carry hand-held scanners around the warehouse to speed up the task. Even more useful are rugged handheld computers with sophisticated interfacing capabilities that can identify the products and communicate in real time to back-office database systems. Furthermore, the bar code readers and RFID scanners can be placed at the entrance and exit of the warehouse to keep the database up to date with all goods arriving and departing, giving a continual real-time inventory and theoretically removing the need for regular stocktaking.

Knowing where items are stored is essential to efficient order picking. Simple physical labels give a unique address to every shelf and rack in the warehouse, and databases record the address against every item. There are various ways of communicating picking instructions to human operators, including pick-by-light and pick-by-voice. Fully automated systems are now coming into use in which cranes or fork-lift trucks are controlled direct from the database, and radar or inertial sensing systems accurately monitor the position of the machine.

Labelling technologies

Smart cameras and off-the-shelf image-processing tools offer optical character recognition and text-reading capabilities, and these are often used to check the accuracy of pharmaceutical labelling. However, digital optical barcodes are preferable for simple product identification since they allow faster and more reliable reading by cheaper laser-based scanners. To read text, a 2D image must be captured and thresholded to distinguish the print from the background, analysed by shape-recognition algorithms to determine which letters are present, and then checked against a template to interpret the text. A barcode is read by simply measuring the relative widths of the bright and dark regions of the reflected light. It can be scanned from right to left or left to right and at an angle, and it may contain check digits to detect and correct reading errors.

There are various formats of barcode, including the universal product code (UPC) and the European article numbering code (EAN), Pharmacode and Code 49, used in different market sectors. However, a barcode accommodates only a small amount of data, typically a dozen digits, so two-dimensional digital optical is sometimes chosen. Data matrix is a widely-used type of 2D code which stores thousands of digits in a compact space. Imaging sensors are needed to capture the 2D code, but the predictable layout and black/white appearance makes for easy processing.

RFID tags can store several thousand digits, and can be read without line-of-sight access. The tag has a microchip to store the data and a tiny antenna to communicate it. Detailed data labels can be attached to or embedded in goods and read

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automatically, without the manual process involved in scanning barcodes. An RFID reader can read all nearby tags at the same time, and it can read through the packaging material, which gives advantages over optical coding when handling pallets and crates of goods. Low-frequency RFID at 30 to 500 kHz is the least expensive and has a short reading range, making it suitable for hand-scanning applications. High-frequency systems at 13.56 MHz and ultra-high frequency (UHF) at 860 to 960 MHz give greater read ranges.

Optical and RFID labels are used in picking goods to fulfil customers' orders, for checking goods in and out of the warehouse and keeping an up-to-date inventory. By combining any of these label-reading technologies with appropriate software systems, a fully integrated and sophisticated management system can be achieved, incorporating inventory, remote customer order entry, purchasing, and all other aspects of enterprise resource planning. For example, Sanderson supplies Swords warehouse management software in which RFID or barcode order-picking communicates with a central software system giving continuous monitoring of stock levels, and automatic generation of invoices and despatch notes. A spokesperson from Business Computer Projects Ltd (BCP) comments that RFID systems have not yet become fully mature and standardised, and BCP is waiting to implement RFID when it is stable: "There is still a 'Betamax – VHS' element to the situation."

Label-reading systems

The Wrexham-based company igroup Ltd supplies hardware and software for warehousing. Handheld barcode scanners and RFID readers communicate with its iWarehouse software for stocktaking and order picking. The software also interfaces with scanners that monitor all incoming and outgoing goods to give real-time inventory information, to track current orders and store historical transactions. The company supplies rugged personal digital assistants (PDAs) for data capture. For example, the Archer Field PC (Figure 1) has a 520 MHz Intel processor and Microsoft Windows Mobile operating system. It has the choice of Bluetooth, Wi-Fi or wireless cellular modem for GPS/GSM communications. It is waterproof and dustproof to IP67 standard, and withstands multiple drops from 1.5 m height onto a concrete floor.

Another useful handheld device available from igroup is the Datalogic Jet family which features automatic data capture from barcodes, 2D data codes and RFID tags. The built-in barcode laser scans over an angle of 42° at a rate of 35 scans/s. It has a resolution of 0.127 mm and reads various barcodes including EAN/UPC, Codabar and Code 128. A visible laser diode assists the operator to aim at 2D codes, and a CMOS array with 640 × 480 elements images the code with a reading field of 21.8 × 16.7°. The integrated RFID reader operates at 13.56 MHz with a range of up to 10 cm. The PDA is small and rugged. It has internal antennas for 2.4-2.5 GHz Wi-Fi local area network, 900/1800/1900 MHz GSM/GPRS wide area network, and Bluetooth personal area network. Rechargeable Li-Ion batteries store up to 13.3 Watt-hours, and a real-time clock provides time and date stamping under software control.

Nordic ID develops and manufactures wireless handheld equipment for retail, logistics and warehousing (Figure 2). Its PL3000 handheld computer weighs 450 g including battery,

Figure 1 The Archer Field PC from igroup Ltd is a rugged handheld computer used for data capture in the warehouse and wireless communications

and measures 230 × 90 × 45 mm. It survives 1.5 m falls onto concrete, and operates between −10 and + 50°C. It has a built-in laser scanner and imager supporting most formats of 1D and 2D data codes, and an optional UHF RFID multi-standard reader. Communication options include wireless local area network (WLAN), GPRS and Bluetooth for interfacing to the back-office software systems. A software development kit facilitates custom programming with Visual C++ and.NET languages. The computer has 64 MB of SDRAM, 32 MB of Flash memory, with 6 MB free for a client application, and a slot for an SD/MMC memory card, giving a total possible capacity of 4 GB. The 29-key keyboard has a backlight with adjustable brightness, and an automatic tilt switch helps the operator to use it for extended periods of time in various lighting conditions. Its ergonomic design enables operation with one hand. It has a configurable speaker, and can be used in voice-directed warehouse picking.

Microlise in Nottingham supplies and integrates RFID systems for organising goods within a trailer (Figure 3). Its RFID Trailer Portal uses EchoPoint "active tag" technology and SmartChain software from Savi Technologies to track goods as they are loaded from the warehouse and as they are transferred from the lorry to the customer. Microlise has designed a custom antenna (Figure 4) to detect all tagged

Figure 2 Nordic ID makes handheld computers with integrated readers for product labelling codes and wireless communications interfacing to back-office software

items as they move on and off the trailer, and a UHF RFID tag reader examines their details. A display module confirms what items have been loaded or unloaded and alerts the driver to any mistakes. The system speeds up the delivery procedure and reduces the associated paperwork.

EchoPoint technology uses two different operating frequencies: a low-frequency transmitter at 123 kHz with a range of up to 3.7 m activates the tags as they pass through the trailer door, and a UHF receiver at 433.92 MHz reads their responses. The receiver has a range of up to 30.5 m, but the activation procedure and its directional antenna ensure that only the tags actually passing through the door are read, and avoids unintentional cross-talk.

Location-finding

Account view is one of the companies that supplies integrated business software, and the warehouse locations module of its stock control package keeps tabs on which warehouse stocks each inventory item, and where that item is within the warehouse. It gives each paper a complete address, involving its row, rack, section and shelf, and the software has the capacity for 60 million different locations within each warehouse. Other companies, such as ASG Services Ltd, manufacture, and install durable labels and signs for the shelves and aisles within the physical storage area.

Workers can assemble orders by moving about the warehouse collecting goods from positions listed on a clipboard or displayed on a hand-held computer. A more sophisticated approach is "pick by voice" (Figure 5). The BCP web site describes this technique. Each worker wears a headset and microphone, and a belt-mounted wireless computer, and moves through the warehouse to locations directed by the headset. This does away with the clipboard and leaves the worker's hands and eyes free to move. The BCP version uses wireless Talkman computers, which communicate with the warehouse management system software by means of an 802.11 b radio frequency local area network. The Talkman unit carries out the speech synthesis and speech recognition, whilst raw data are transmitted over the radio frequency network. The picker reads back the last 2 or 3 digits of the barcode after picking an item so that the system can check that the correct item has been picked. This system claims dramatic improvements in the accuracy of order picking compared with a paper-based system. It operates at temperatures down to $-29^{\circ}C$, so it can be used by glove-wearing operatives inside freezers (not an enviable task!)

The "pick by light" approach requires indicators permanently mounted on the shelf units. The indicator lights up to attract the worker's attention, and it displays a number to show how many items are to be picked from that location. Each operative has a particular work zone, and for each order all the relevant indicators light up simultaneously. Lightning pick technologies claims that this leads to faster picking than any competing operator-based technology.

Symeo GmbH has patented a Local Positioning Radar (LPR) system for the precise location of goods within a warehouse. The 5.725-5.875 GHz radar works in conditions that would obscure optical signals, and is not affected by dust and grease, or by the steamy conditions of a steel plant or the

Figure 3 The Trailer Portal system from Microlise reads RFID tags on the goods transported, and automatically updates the manifest and proof-of-delivery documentation in real time

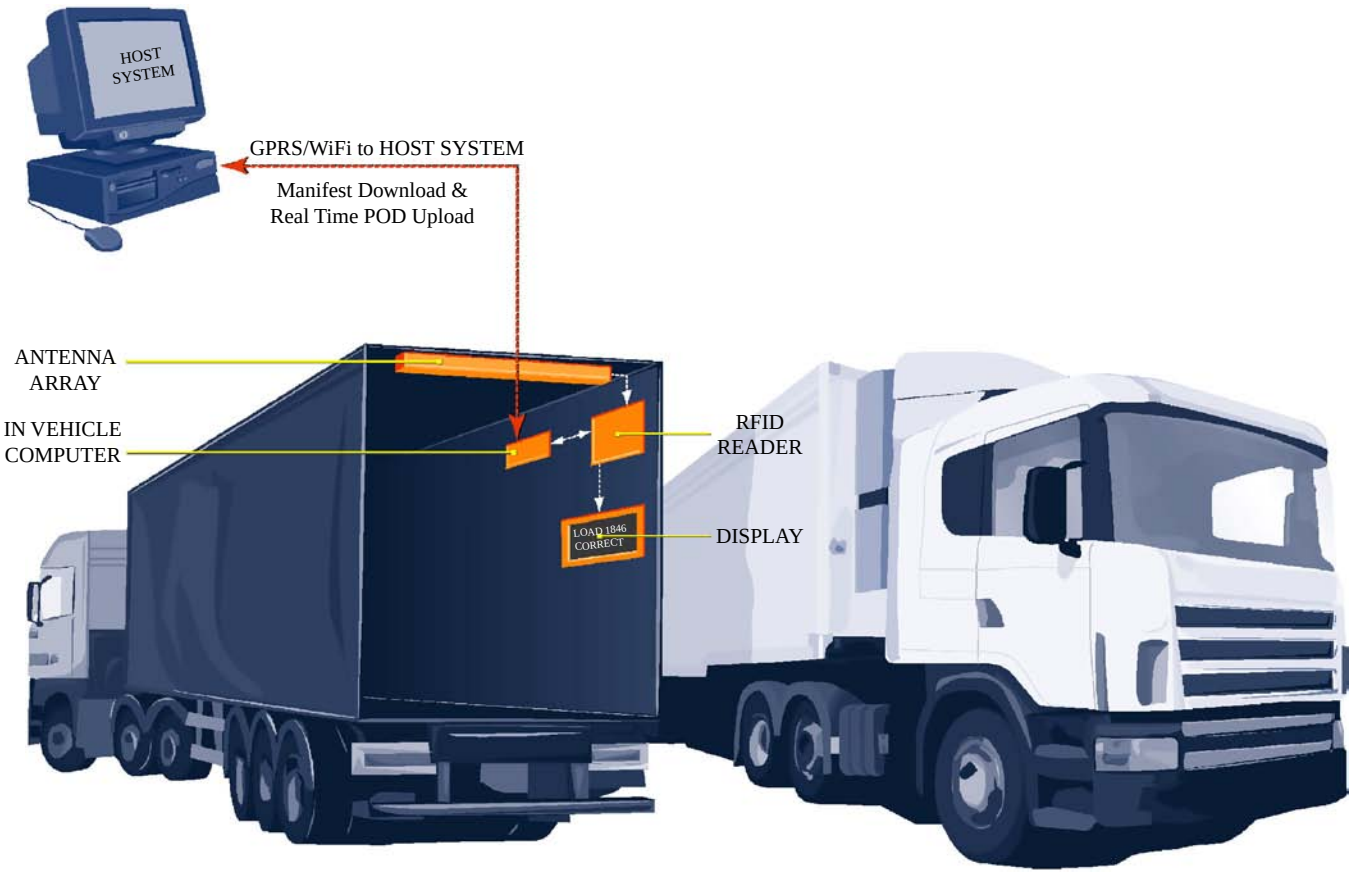

Figure 4 Microlise's custom antenna detects all RFID-tagged items and whether they are moving on and off the trailer

mist of a seaport terminal, where it can be used to track containers. In warehouses where pallets of goods are stacked, a base station on the fork-lift truck measures the truck's position and angle as it stacks the pallet, and this information is recorded on a database alongside a description of the contents of the pallet. Figure 6 shows this LPR-A system in operation in the steel sheet warehouse of voestalpine Grobblech GmbH. A radar signal from the moving crane is picked up by multiple transponders fixed within the warehouse structure, and these send back the signal labelled with unique transponder-identification codes. The base station then combines these time-of-flight measurements using trigonometry, and thus finds its own current position. This system detects the storage position of each sheet with centimetre accuracy, and communicates with the warehouse management and logistics system so that individual items can be tracked throughout the plant.

The position calculation is carried out 20 times per second, and relies on there being at least three fixed transponders within range. The radar signal has a transmission power of up to 0.025 W, and a range of 250 m. The system works in a temperature range of -20 to $+75$°C. To achieve a position measurement accuracy of the order of 10 cm, the time of flight measurement needs picosecond precision. In June 2007, a PhD student working in Symeo's R&D department won an IEEE award for his contribution to the LPR-B internal clock synchronisation algorithm.

Automated handling

Watson Industries is one of the companies supplying inertial navigation systems for robotic material-handling equipment in warehouses. Inertial navigation usually relies on occasional checking "fixes" by GPS or magnetic compass, but neither of these is available inside a warehouse. Therefore, extremely stable gyroscopes are employed to provide heading information, and the position is calculated by dead reckoning. The VSG-E Series gyroscope is a solid state rate sensor with a resolution of 0.025°/s, high reliability and low-output noise of 0.02°/s root-mean-square (rms). The gyro is part of Watson's dynamic measurement system, originally developed for automotive testing but now also applied in warehouse navigation and robotic control. It outputs angular rate and acceleration, and linear acceleration along real-world x, y and z axes. It is a solid-state strapdown system withstanding 500 G of shock and 10 G rms of vibration.

Inertial guidance is used by the SmartLoader from Jervis B. Webb (Figure 7). This is an automatic fork-lift truck that stacks and retrieves palettes of goods in the warehouse, and automatically loads trailers. It is currently in use in the warehouse of a large brewery company in the USA. Each truck has an on-board computer to maintain the desired path using the inertial sensors, augmented by "fixes" from transponders embedded along guide-paths in the warehouse floor. A central "vehicle system manager" module interfaces with the warehouse management software and controls up to 100 SmartLoaders. The small transponders use radio signals to check that each vehicle is on the correct track. In some of its applications, the company uses laser guidance for the SmartLoader, in which a laser scanner measures angles and distances to reflectors mounted on walls and fixtures.

SmartCart (Figure 8) is another automated guided vehicle from Webb, and this is steered by magnetic tape guide-paths. The Cart is less expensive than the Loader and is designed to be flexible and easy to use. The magnetic tape track is easy to lay and move, and the accompanying software

Figure 5 Voice WMS from BCP integrates Talkman headset, microphone and belt-mounted computer with its Accord Warehouse Management System software for pick-by-voice order picking in the warehouse

Figure 6 Cargo cranes use Symeo's radar-based LPR system to locate steel sheets in the warehouse

Figure 7 SmartLoader from Jervis B. Webb is an automatic forklift truck guided by inertial sensors and radio transponders

Figure 8 Webb's SmartCart magnetic-tape guided vehicle transports goods in the warehouse of an automotive supplier

is windows-based and has a simple user interface. The vehicle has a 24 V dc drive motor powered from a battery with capacity of up to 180 amp-hours and has a maximum speed of 120 ft/min. A fail-safe optical sensor covers the full width of the front bumper and the spring-set electrically-released brake stops the vehicle within the bumper-collapse distance.

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