Assessment of Sensor Technologies for Gate-Based Object Counting

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***Abstract*— On the area of automating object counting, we concentrate on uniform, disposable products stored on a pile, queue or a stack (e.g., a shelf) and examine a number of different technologies for sensing input and output through a gate to the storage area. We define a set of comparison criteria with practical flavor in order to examine and evaluate twelve different types of sensors. The intention for our study is to form a baseline for anyone needing to implement gate-based input/output control.**

Keywords: sensor evaluation; gate control; evaluation of sensor technologies

I. INTRODUCTION

Product counting is an important aspect of stock control and may take many forms depending on the material being stocked and counted [4]. Automating this process of object counting can bring many benefits by simplifying the renewal process, eliminating errors etc. [2].

In this paper, we concentrate on the context of a gate-based, disposable material placed in a casing, stored in a pile or queue in and examine the case-study of detecting the addition or removal of a product and consequently calculating reliably the number of items in stock. The question this paper deals with is assessing the different types of sensors available for automating this process. Towards this objective a set of criteria with a practical orientation is defined [5].

Under this perspective, the paper is organized as follows. Section II describes current techniques in Supply-Chain Management (SCM) and Section III records the factors for sensor assessment. Section IV discusses the different types of sensors giving a brief definition and listing their advantages and disadvantages with reference to the assessment factors. This critique is subsequently summarized and we finish with outlining a case study and listing conclusions and pointers to future work.

II. RELATED WORK

Most of the today's stock control systems use extensive use of Radio-frequency identification (RFID) technology [1] [2] due to the effective way of recording movement of objects within a networked system [3]. In these systems the stock control is achieved automatically by the information system that supports the Supply-Chain Management (SCM) and unauthorized removal of an object is detected by electronic gates that monitor continuously the physical entry points of the area that the system is installed. To add system intelligence, traditional RFID based SCM are integrated with Wireless Sensor Networks (WSN) [4] [5]. These systems incorporate advanced sensing technologies while for the monitoring of the position of an object, we could use localization techniques.

The above practices though, are applied in large scale deployments and are not cost effective for ad hoc or small scale deployments. They require changes in the existing physical infrastructure and the deployment of sophisticated Information Systems for which the support cost is not insignificant.

SCM systems are expensive because of the nature of the sensors (RFID) that are deployed and the extensive features that are available nowadays. The cost of the SCM is high and the problem we set in this paper is the monitoring of stock in a pile or queue. The basic requirements are

1. low cost solution,
2. easily deployable, and
3. no modifications in the existing physical infrastructure.

III. SENSOR EVALUATION FRAMEWORK

As mentioned above our assessment has a practical orientation and envisages the scenario when products such as cans or bottles are stores on shelves, stacks or piles. The main, driving requirement of our assessment is to be able to count adding or removing products in a reliable way defined as

1. Reject false positives, for example the hand of the carrier is not measured as a product.
2. Spot attempts of cheating, for instance trying to extract a product from an input-only entrance.
3. Work under environments that can be cold/warm and/or wet (e.g., freezer)

Under this context, we define the assessment factors of Table 1 under which the different types of sensors are evaluated and consider two main areas namely, usability and technology. The rationale behind this partition is that in an industrial setting the decision makers are usually business people who are interested in the costs of the sensors and the installation process and technical personnel who focus on suitability of the sensor from a technical perspective. We decided not to assign weights to these criteria in order to leave the decision making open to each case-study.

TABLE I. CONSIDERATIONS DRIVING EVALUATION

Usability Considerations	
Cost	
Installation procedure	Purchase pricing per unit of coverage, e.g., per shelf
Proven in Industry	Technical expertise and time required contributes to ease of use
Technical Considerations	
Power consumption	Influences simplicity of installation and ease of use
Form Factor	Could turn particular choices inappropriate for certain applications
Robustness	Working in diverse (e.g., wet, warm) environments
Reliability	Detecting false positive/negatives, e.g., human hand
Integration	

IV. MATERIALS AND METHODS

This section lists twelve different types of sensors we identified as suitable for gate-based object counting. Due to space constraints, it outlines the way each sensor operates, where our survey has revealed that it is mainly used and what are the main advantages and disadvantages.

A. *Capacitive Sensors*

Capacity sensors detect changes in their electric field to estimate proximity. Industrial Style Sensors detect objects passing under/past them. They are widely used in large Form Factors and appear in a number of different packages, suitable mostly for manufacturing lines. They are relatively cheap and can operate under harsh environments. They rely on power supply and while they can be in due course accurate, their calibration can be very tricky and lengthy process requiring software intelligence.

B. *Capacitive array sensors*

Capacitive Arrays are placed on the “floor” side and sense an object placed on it. A modern analogy on how they operate is how a Smart Phone screen detects touch. They are a fairly novel technique and being innovative they are not yet industry proven and therefore risky. Occupying a whole side, they could be an accurate solution and filter false positives.

However, they may not work well in potentially wet environment and would require employing a clever grounding mechanism.

C. *Inductive Sensors*

In a method similar to capacitive sensors, inductive sensors employ changes in their magnetic field to pinpoint proximity to detect proximity and hence measure distance of metal objects. Industrial variants have the same type of form factors as capacitive sensors and for all intents and purposes, operate the same as Industrial Capacitive Sensors but only detect metal objects.

They are also proven in industry, are accurate, come in robust packaging and large form factors, suitable mostly for manufacturing lines. Most important could only work with products of a metal element like metal caps.

D. *Ultrasonic Sensors*

Ultrasonic sensors transmit a sound wave (“Ping”) of ultrasonic frequency and measure the time it takes for the wave to return in order to measure distance. They are widely used in both industrial and hobby circles and come in different form factors. A simple everyday day example of the technology is reversing sensors on modern cars.

They are accurate and cheap but potentially inaccurate since they would for example count employee hands.

E. *Camera-based Sensors*

A camera can be paired with a smart controller to detect patterns, shapes or colours to detect objects entering a storage area. The camera could be trained to watch for a distinctive feature of the object, for instance a branding logo, a characteristic shape or a specific colour.

With the appropriate software processing, cameras could be extremely accurate. Nevertheless they are a complex solution. Cameras are an expensive and sensitive component and they would need a more powerful MCU to process images while also being susceptible to environmental changes, such as lighting.

F. *Switch Technologies*

The usage of simple mechanical switches positioned in a way that they switch and count objects as they enter or exit the storage area. They are scalable; one can use just 1 on each point of entry/exit or an array of switches to reduce the chance of false switching and infer direction.

An interesting aspect is a rotary encoder to detect direction as well as actuation. Switches are reliable and simple, proven in industry and a very cheap solution. Since they require power only when activated, they consume minimum power. Although they cannot differentiate between object and detect false positives if placed in clever way they can minimize such occurrences. They are easy to install and replace.

G. *Magnetic switches*

These can be described as small, mechanical switches encapsulated in a small glass or plastic enclosure, activated by changes in the magnetic field. They are more reliable and space efficient to the simple mechanical switches and are used in industrial applications. They are cheap, however could be fragile especially the ones with the glass enclosure.

H. *Hall-effect switches*

They come in the form of integrated circuits, also activated by changes in a magnetic field. They are smaller and more sensitive than the magnetic switches and therefore can achieve better performance. They are available in analog and digital form providing higher resolution and can detect not only presence but also distance and speed (through change). Also proven in industry, they add a degree of complexity compared to other solution since they are an electronic component with power and enclosure requirements.

I. *Optical Sensors*

There are various types of optical sensors, two of which are applicable in our domain of interest. The first are Interrupt Beam type sensors, where the transmitting beam and receiving sensor are placed opposite each other. When the object passes the beam the interrupted beam would cause a switch.

The other choice are reflected Beam type Sensors, where the transmitter and receiver are next to each other and the changed angle of the reflected beam is detected when an object passes through it.

Optical sensors have no mechanical parts, so virtually there is no wear. They have many industrial variants that are well proven and can be easily simplified to a light source and photodiode. They may have very small form factors. Their performance though, may be erratic not be able to detect different opacities or false positives.

J. *Strain gauge*

Load cells are a practical application of Strain Gauges. Ultimately, they measure weight; they consist of an array of piezoelectric materials that generate a voltage proportional to the stress applied. There exist three types worth considering:

a. Bending Beam
b. Shear Beam
c. Pancake Cell

This solution would be the most accurate representation of how many objects are in a storage area if these objects have uniform weight. Since it counts objects individually, it would have the least number of false positives. They are in cheap price if bending or shear beam but they need to be customized for different products.

K. *Barcode*

A barcode is an optical machine-readable representation of data relating to the object to which it is attached. Originally barcodes systematically represented data by varying the widths and spacing of parallel lines, and may be referred to as linear or one-dimensional (1D) [6]. In order to use barcode sensors extensive rework must happen to the mechanical part of the system in order the items to leave from a particular exit and with a certain orientation so that the sensor would be able to identify them correctly. The implementation of the sensors is cost effective since low-end microcontrollers have the necessary processing power to cope with the algorithm of the barcode decoding [7].

L. *QR code*

A QR code [8] consists of black modules (square dots) arranged in a square grid on a white background, which can be read by an imaging device (such as a camera) and processed using Reed–Solomon error correction until the image can be appropriately interpreted; data is then extracted from patterns present in both horizontal and vertical components of the image [7]. The need for a camera in order to capture the image makes the technique expensive, while the algorithms in order to decode the QR code are quite sophisticated [9].

V. CASE-STUDY AND DISCUSSION

Our survey outlines twelve different types of sensors. Table 2 presents in an organised format our findings which generated the following outcomes:

1. Although some are relative to each other (e.g., QR and Barcode), the number of different available approaches makes evident that even in quite specialised situations, an optimum solution could be achieved exactly because of the sheer quantity of solutions.
2. Cost does not appear to be a forbidding factor for any of the technologies, switch-based approaches seem to be the most suitable when cost and simplicity are the main requirements.
3. Sensors are available in three forms, namely, mechanical, magnetic mechanical and half-effect providing different levels of sensitivity.
4. As Internet of Things (IoT) grows in importance, choosing the right technology of sensor to link to the communication module of an IoT device will also be pivotal.
5. Requirements, such as power consumption and durability will player a major role as well as compatibility among modules and the existence of a communication protocol or a feasibility to create one.

This research is currently investigating the applicability of these solutions using as a case-study shelves in which objects embedded in a cylinder shaped boxes are stored. The setup is located in the lab setting and is used to organize and store any material used by the Nimbus centre researchers, ranging from chips to small mechanical and wooden tools. Placing them inside a cylinder box ensures uniformity and eases stock control. Moreover it is a shape that is compatible with switches, capacitive arrays, QR code and optical sensors.

Different shelves with the twelve sensors are used to measure their reliability, endurance, easiness of installation and sensitivity. The results up to now indicate that the mechanical switches suit better. They perform better in the sense of minimum cases of false positives and false negatives especially when they are used in numbers to verify each other's triggering. The capacitive arrays also provide accurate measurements however their installation process is longer and need to be refitted for every new shelf. The optical sensors require the usage or development of extra software to filter out hand movements of the hand placing objects in our out of the shelf. Finally, the QR and barcode choices need special care from the user to scan the code and from the system to give feedback (e.g., sound).

This case-study, while installed in a lab environment can be classified as pre-production because of the volume of use and the number of users. However, we acknowledge that additional levels of testing are needed to extract more results and also test different setups.

VI. CONCLUSIONS AND FUTURE WORK

This paper examined the applicability of twelve different types of sensors in facilitating gate input/output control of simple, every day products. As requirements and their gravity vary on each application, there is no single preferred solution. It is remarkable however how technologies of diverse orientation could be applied to solve a single problem.

Current and future research work involves not only the further specification of the assessment factors but the application of techniques, such as fuzzy logic with sets associating factors and sensors and different fuzzy rules to apply in order to get a qualitative or quantitative marking. This will enable to objectify the suitability of every sensor technology for specific application needs. We also intend to extend this study and perform quantitative analysis with specific application domains.

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Table II. SYNOPSIS OF SENSORS AND THEIR FEATURES

Sensor	Costing	Installation	Industry	Power	Form	Robustness	Reliability
Capacitive Sensor	Cheap	medium complexity	Bottling and Manufacturing plants	High	Small to Medium	High	High if no unpredicted obstacles
Capacitive Array	Cheap	complex / difficult	None	High	Small to Large	Medium	Unproven
Inductive Sensor	Cheap	medium complexity	Manufacturing Bottling	High	Small to Medium	High	High
Ultrasonic Sensor	cheap to medium	medium	Diverse	Medium to High	Small to Large	Low to High	High if no unpredicted obstacles
Optical Interrupt Beam	medium to expensive	medium	People Counting Bottling and Manufacturing plants	Medium to High	Medium	High	High if no unpredicted obstacles
Optical Reflected Bean	medium to expensive	medium	Bottling and Manufacturing plants	Medium to High	Medium	High	High if no unpredicted obstacles
QR	Expensive	Medium	Diverse	High	Medium	Low to High	High
Optical Camera	expensive	difficult	None	High	Big	Low to High	High
Mechanical Switch	Cheap	easy	Diverse, Variety of equipment and applications	No	Small	Low to High	High if no unpredicted obstacles
Magnetic Switch	Cheap	easy	Diverse, Variety of equipment and applications	No	Small	Low to Medium	High
Hall-effect Switch	Cheap	easy	Diverse, Variety of equipment and applications	No	Small	Medium to High	High
Weight Load Cell	cheap to expensive	difficult	Weighing scales, Mini Bar fridges,	Low	Small to Large	Low to High	High
Barcode	cheap to expensive	medium	Diverse	High	Small to Medium	Low to High	High

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