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Reducing ergonomic strain in warehouse logistics operations by using wearable computers

Anca Mocan[a]*, Anca Draghici[a]

[a]Politehnica University of Timisoara, Faculty of Management in Production and Transportation14 Remus str., Timişoara 300191, Romania

Abstract

Ergonomics is the study that deals with the design of products and processes that improve both human well-being and overall system performance. In order to reduce the ergonomic strain that the workers in the warehouse sector experience, while also increasing competitiveness and tact time, businesses have to understand the importance of emerging technologies and how these can be applied successfully in their working area.
This paper offers a grading of existent wearable computer technology that can be used within a warehouse environment, based on their capacity to reduce ergonomic strain both by means of reducing or eliminating repetitive motions as well as by increasing scanning usability through their software integration with existing ERP systems. Besides the ergonomic efficiency, the analysis also looks at the necessary financial investment and the training effort needed to implement such a solution in order to offer a holistic view of the topic to decision makers. The detailed explanation of the results also offers a purchase decision framework, based on the current market trends in warehouse technologies and on the future development capabilities of the technologies analyzed.

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Keywords: Warehouse; logistics; ergonomics; competitiveness

1. Introduction

According to International Ergonomics Association (IEA), ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the

* Corresponding author. Tel.: +40724340951;
E-mail address: ancamocan2003@yahoo.com

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profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. It is considered that the role of ergonomists is to contribute to the design and evaluation of tasks, jobs, products, environments and systems so that they are made compatible with the ways in which people access them, by using both theoretical research as well as practical tool implementations. Such a practical tool implementation that has wide-ranging applicability is that of the wearable computer.

With the decreasing size and increasing power of most of the components of a modern computer, it was only a matter of time until computers that could be worn on the body began appearing (Bass, 1996). The social implications of a given technology are not always clear during the technology's introduction and it takes even more time for scientists to start analyzing the effects said technology has on the world around (Pool, 1977). While still in its infancy, wearable computing is graining steady ground both in the private as well as corporate life. Although its advances are still slow, wearable computing has the potential to have one of the biggest efficiency improving impacts to date in society. Research is currently focused on using wearable computers to get this kind of technology in places where it previously wasn't available before, due to space or activity restrictions, such as for medical monitoring (Martin, Jovanov & Raskovic, 2000), or mechanical inspection (Sunkpho, Garrett, Smailagic & Siewiorek, 1998; Ockerman & Pritchett, 1998).

This paper proposes to analyze the benefits of wearable computers in warehouse scanning activities in which computers are already being used, but are one of the main sources of inefficiencies and ergonomic strain.

1.1. General aspects on wearable computers

A wearable computer implies a computer that can be worn or transported and on top of this, a wearable computer is a computer that is controlled by the user and has operational and interactional consistency (Mann, 1998). They should be designed in such a way that the user sees them as part of themselves. As such, in differentiating wearable technology from portable technology, three criteria can be proposed (Knight, 2002; Knight et al., 2006):

1. The device is attached to the body and does not require muscular effort to remain in contact with the body (i.e. you do not have to hold it);
2. The device remains attached to the body regardless of the body's orientation or activity (i.e. you do not have to take it off to perform a task specific action);
3. The device does not have to be detached to be interacted with (i.e. the first two criteria are not violated when the device is in use).

Given these criteria, one can separate between three different types of wearable computers that can assist with warehouse scanning operations, as following:

- Head mounted scanners (eyeglass-like);
- Arm mounted scanners (watch-like);
- Hand molded scanners (glove-like).

1.2. Warehouse scanning operations

1.2.1. Current environment (the use context)

Due to the ubiquitous use of barcoding for product identification, the current process of warehouse item scanning involves some type of handheld barcode scanner, which, as ca be seen in Figure 1 is composed of a scanner window, a trigger switch and a cable interface port. This can be held in a gun like manner, i.e. the scanner is held with the dominant hand, gripped between the index finger and thumb, with the index finger on the trigger switch and the middle ring and pinky finger around the base of the grip, between the trigger switch and the cable interface port. Given the fact that the human arm has a tremor even in a static position that influences accuracy in a negative, depending on the width and breadth of the scanner window the time it takes to find the accurate position for proper scanning is not optimal. The rapid and repetitive pressing of the trigger switch can also lead to loss of pressure sensitivity in the index finger.

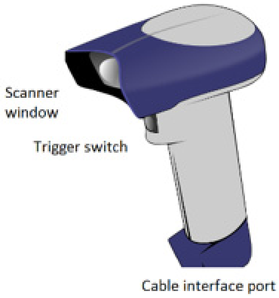

Fig. 1 Standard components of a handheld scanner

With the introduction of tablet like scanners or tablet integrated scanners the holding position has changed towards a cellphone like manner, with the palm turned upwards, the wrist flexed laterally to allow the scanner window proper access. Depending on the weight of the scanner and the positioning of the keyboard/buttons on its surface prolonged use of this position can induce muscle fatigue (Shim, 2012) or even enlarges the median nerve, causing pain in the thumb and decreasing hand functions (İnal, Demİrcİ, Çetİntürk, Akgönül, & Savaş 2015).

1.2.2. Future environment

Ever since the 1960s barcodes have been used to scan products. They are standardized, readable from almost any angle and at a wide range of distances, cheap to produce and easy to print (Seideman, 1993; Global Market Insights Inc., 2016). In warehouse management, barcodes have been used for everything from goods storage to reparcellation to movements inside as well as outside the storage facility. While easiness of reading and processing barcodes has been an issue that has been solved in the retail business, the standard countertop laser scanner being equipped with mirrors that can obtain signals from multiple angles, it is a fact that handheld laser scanners are less powerful and less accurate than the countertop ones. They are not capable of gathering multiple signals and the necessity of operating smaller optical devices leads to worse readings or longer reading times (Wittman, 2004). Due to this, there is a clear need to analyze different scanning solutions that might limit the amount of time spent per scanning either via integrating the scanning within the already necessary manipulation movements, improving the scanning technology or both. Wearing technology instead of holding it has the advantage of freeing up the hands for other functions.

Head mounted scanners provide the operator freedom to move their arms unimpeded in order to perform the task the way they usually do, thus causing the slightest amount of inconvenience. When designing a head mounted scanning system, one needs to take into consideration the location of the scanner and how this will be activated during regular operations. Because of this point of attention, scanners attached to eyeglasses can directly take advantage of the line of sight and of the natural tendency to look at what we are manipulating. Therefore this limits the need to create a special "to scan" movement as the scanning takes place as soon as your line of sight aims towards the package, if continuous scanning is applied.

When designing such scanners as presented in Figure 2, the mass, the bulk, the heat dissipation and optical performance (Spitzer, Rensing, McClelland & Aquilino, 1997) of the equipment have to be taken into consideration. Loading of the ear and nose should be tolerable for several hours. Scanning should be easy to stop when encountering another person, in order not to cause visual inconveniences.

Fig. 2 Eyeglass mounted scanner

Fig. 3 Arm mounted scanners

Arm mounted scanners take advantage of the hand placement during manipulation movements. It eliminates the need for a grip of the scanner, as it is attached to the wrist, and in some cases can extend to the finger, like in the case of Figure 3. For visual scanning the device places the scanner on the front facing side of the intermediary phalange of the index finger and the trigger button on the side of the index, for easy push access from the thumb. This offers more movement control, as the scanning happens both at a closer distance and that the

The biggest downside to the optical scanning is the need to press a trigger button and the instability of the finger scanner on the finger during the course of strenuous manipulation. This can be fixed by the usage of radio-frequency identification (RFID) technologies (Nambiar, 2009). These were first used in the 1940s as a method to identify allied airplanes, but have current frequent applications in transportation, services, supply chain and manufacturing. During recent years, an interest in RFID technology has arisen with the goal of increasing readers' mobility as something transparent for users, and their combined integration into wireless communications systems (Muguira et al. 2009). Passive RFID tags are small electronic components with an integrated circuit and a small antenna usually sealed in one small package. The tags do not need a battery; the reader via electromagnetic induction energizes them during access (Merz, Gellersen & Schmidt, 2000). Each tag contains a numeric code that uniquely identifies the object and can be queried by a wireless reader (Want, 2006). While the price of this technology is slightly higher than barcodes, the ability to scan an item without having as specific target the tag itself, can lead to easier storage solutions and less manipulation of a package in order for it to be processed.

If the RFID reader can be placed within the wristband while also being screened from accidentally scanning nearby items it would lead to reducing the amount of movement necessary and thus creating an uninhibited work experience for the operator.

The arm-molded scanner takes the wristband scanner concept and integrates the industry mandated hand protection that workers have to wear at all times during their operation. As can be seen from Figure 4, it leads to less slippage of the finger-mounted grip as this feature is fully incorporated into the glove itself, minimizing unwanted movements.

Fig. 4 Arm molded scanner

2. Description of the research method

Continuing previous research into the ergonomic efficiency of warehouse equipment (Mocan, Draghici & Mocan, 2017) the following paragraphs will present an analysis of the existing wearable computers that has been made based on three perspectives or criteria namely the total investment amount, ergonomic efficiency and ease of use (Chu, Egbelu & Wu 1995; Tompkins, White, Bozer & Tanchoco, 2010). The considered criteria have been graded on a scale of 1 to 5 (1 being least desirable and 5 being most desirable) based on which would best maximize the efficiency equation (1):

$$E = \frac{I*p1+Ee*p2+Te*p3}{p1+p2+p3} \quad (1)$$

where E is the overall efficiency;

I - Investment volume;

Ee - Ergonomic efficiency;

Te - Training effort;

p1, p2, p3 - weights given to each considered factor.

The investment costs refer to the purchasing value of the wearable computers and not to subsequent training and re-equipping the warehouse with the correct type of scanners for the particular technology used. For this purpose, the type of scanning used is also mentioned, for an easier recognition by potential users as to the type of technology change needed to reach the ergonomic efficientization specified. This refers to the capacity of the equipment to reduce strain of the employees' human body that would otherwise be caused by the manual manipulation, which the equipment is replacing. The grading explanations presented in Table 1, show that the best possible grade that an equipment can get is 15 if all the weights in the formula are equal to 1 (p1 = p2 = p3 = 1), which is the case that will be further examined. Training effort refers to the average amount of time that workers will need to spend for trainings in order to be able to correct use the equipment. The overall cost has been calculated based on a warehouse with 100 workers involved at least partially in package scanning operations (i.e. their job implies scanning at least one package per day for various purposes).

Table 1. Grading structure.

Grade	Investment	Ergonomic efficiency	Training effort
1	€100000-€500000	Minimal manipulation strain reduction	> 1 week training
2	€50000-€100000		1 week training
3	€20000-€49999	Average manipulation strain reduction	1-3 days training
4	€1000-€19999		1/2 day training
5	<€1000	Complete manipulation strain reduction	< 1/2 day training

Three types of scanning equipment have been analysed, and graded based on the presented structure in Table 1.

3. Research results

In order to get a finer granularity between different solutions with regard to their overall efficiency grading and to help understand the practical differences between them, for each type of handling equipment, both proprietary as well as generic options have been analyzed. The grading took into account the factors of the ergonomic efficiency formula (1) posited above and the grading structure presented in Table 1. Thus, Table 2 shows the grading of all handling equipment analyzed. These research results will be further discussed.

Table 2. Grading of material handling equipment.

Equipment type	Equipment name	Type of scanning	Investment	Ergonomic efficiency	Training effort	Overall grade
Head mounted	Eyeglass mounted scanner - generic	Barcode, QR	3	3	5	11
	Eyeglass mounted scanner - proprietary	Barcode, QR	1	4	4	9
Arm mounted	Wristband mounted scanner – generic	Barcode, RFID	3	1	5	9
	Wristband mounted scanner - proprietary	Barcode	2	1	4	7
Hand molded	Glove mounted scanner – generic	RFID	4	3	5	12
	Glove mounted scanner –proprietary	Barcode, QR, RFID	2	4	4	10

4. Discussion

4.1. Proprietary versus generic

While the base purpose of the equipment (i.e. scanning the item) can be achieved by using the generic version, or self-developing similar equipment, the proprietary version has added benefits that try to justify the price difference. Proprietary versions provide a wide range of software connection plug-ins that reduce the manual input work forced by hand held scanners during the receiving of incoming goods. In these situations, the scanned barcode does not provide the full range of information related to a product normally required by an ERP system, thus extra manual input of data is required to fill in required fields. This procedure usually takes time, is done in a seated position in front of a computer screen and requires repeated head movements back and forth between the printed out delivery note that comes with the package and the ERP screen into which the data needs to be added.

Because of the reduction of this activity through direct automatic input, the proprietary versions receive a higher ergonomic efficiency grading than their generic counterparts. This extra capability, however, leads to a higher training effort, as operators need to be made aware of the ways in which their workload will shift and which operations are no longer needed. This coupled with the higher investment costs leads to the generic equipment overtaking the proprietary one in each of the 3 equipment types.

4.2. Current capabilities versus future improvements

While the generic or self-made equipment proves to have a higher overall grade for the current research question and optimization equation, the proprietary equipment promises more future improvements while reducing investment costs for businesses.

The proprietary head mounted scanner provides a good starting point for pick to light systems as well as voice tasking technology. While current ergonomic efficiency improvement is modest, the future developments on holograms and augmented reality could provide on the shop floor training for operators that can be taught what to pick and how much of it directly by their lenses.

Wristband mounted optical scanners have the smallest possible ergonomic efficiency improvement capability, as their usage still requires an outstretched hand and pushing of a scanning button. Though in most cases the capability of continuous scanning exists, this is not capable of sustaining a full shift battery life. The advantage of this system is its lower cost and the existence of various options on the market from various producers that allows the company to choose the most cost efficient option. Wristband mounted RFID scanners are more efficient by means of not needing an extra push movement, as the scanning happens automatically, and can prove to provide a higher ergonomic efficiency capability, if there is a way in which screening accidental scanning’s of nearby packages can be efficiently done.

The implementation of a glove-mounted scanner is in RFID glove has been extensively researched (Merz, Gellersen, & Schmidts, 2000; Muguira et al., 2009; Lee, Kim, Park, Oh & EOM, 2010). While the proprietary version is still currently used exclusively for optical barcode and QR scanning (based on Quick Response Code), prototypes are already being developed to include shock resistant and water resistant RFID capabilities. This would lead the operator to not have to rely on any extra movement to scan the item, as it would be automatically scanned upon touching it.

Since cost-wise the three types of equipment are within the same range, further analysis needs to be done on a case by case level within the company to determine which type of wearable computer would best satisfy the needs of the operator and if the scanning operations and their frequency within the workday warrant equipping the operator with this technology.

5. Conclusions

The research method provided in the current paper has been entirely theoretical as a means to get a first rough insight into the possible ergonomic improvements one can have in a company. The next step is to apply the research method in practice and start developing it based on the results, adding factor interaction and its economic influence, if any.

Wearable computers are an easy way to reduce unnecessary movement that can cause strain or injury. While there may currently be a barrier related to the cost of equipping workers with such tools, during the next few years, as technology advances, the costs will decrease, as it has already been shown for other technologies (Bureau of Labor Statistics, 2015). These mean that the incentive to use this equipment has to be clearly stated and disseminated within the business decision-making community in order to ensure the quickest possible adoption of the ideas within the nonacademic environment. Currently the cost of applying smart technologies to existing jobs is most related to cost efficient, improvement means that does not require the restructuring that automated scanning lines and robotization would imply.

Certain warehouses are already starting to use Google Glasses' functionalities to replace handheld scanners as they have been proven to reduce the time needed to pick out an item and pack it for shipping by 25%. The possibility of completely eliminating scanning work by equipping cameras with RFID means making it possible to record images as well as the identities and locations of all RFID-tagged objects contained within each image. This can lead to workplace reorganization where customer value added operations are being applied in the place of essential, but repetitive and non-value adding tasks such as scanning (Whelan, 2015).

Besides the reduction of ergonomic strain alongside reduction of throughput times the application of wearable computers has the advantage of creating an innovation mindset within the organization where the objective of doing more efficient work in a healthier way can be easily understood by the workers as they are directly involved in the usage of the new technology. As of now, the topic offers fertile ground for more investigation.

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