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ORIGINAL ARTICLE

Augmented reality system to guide operators in the setup of die cutters

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Abstract
This paper describes an Augmented Reality system for the improvement of the manufacturing process in the packaging sector. It presents a successful use case of how to integrate the Augmented Reality technology in a factory shop floor by providing a tool that helps operators in their daily work. Given a product reference, the proposed system digitizes the setting of the die cutter automatically from an image and stores it in a database to subsequently consult and analyze. Furthermore, the content display is not carried out as a conventional Augmented Reality system (wearable devices such as glasses or mobile), but projecting directly on the workspace to facilitate its interpretation. Compared to the current workflow, where the data is recorded on sheets of paper and stored physically in warehouses, the proposed system offers several advantages such as preventing data loss, reducing costs, or the possibility of increasing knowledge from the post-processing of digitized data.

Keywords Augmented reality · Projection mapping · Manufacturing · Packaging

1 Introduction

Augmented Reality (AR) is a technology that generates a composite view for the user by adding virtual elements (computer-generated) to the real world. AR enhances the perception of the user, and therefore, it also improves its performance, safety, and reliability [1]. Attracted by these benefits, several AR works have emerged in recent years, specially focused on industrial environments [2–4]. These works cover many tasks such as design, assembly guidance, training, inspection, or maintenance. In fact, the term Industrial Augmented Reality (IAR) has been created to refer to those AR solutions that support an industrial process (see [5] for a broad review).

The basic components in AR applications are a display, a camera, and a computer with application software. Nonetheless, beyond traditional handheld displays [6] or HMDs [7, 8], new perspective possibility of displaying the environment of AR is using a projector that displays all the virtual content directly on the real scene, without requiring a screen [9]. This new trend is known as projection mapping (also referred to as Spatial Agumented Reality in a more general sense [10]) and it is well suited for industrial environments [11–15]. Among other advantages, it frees the hands of the worker (there is no screen to hold) and reduces the mental workload (you do not have to translate the data from the screen into the workspace).

In this study, similar to [16], we present an IAR system in combination with projection mapping to provide assistance to operators in the manufacturing process of a packaging company. The proposed system helps operators manage a die cutter, going from the actual manual management to more automated and digitized management, which is more efficient, less prone to errors, and with new possibilities of functionality (data analytics for decision making). Through the proposed system, the operator can digitize the status

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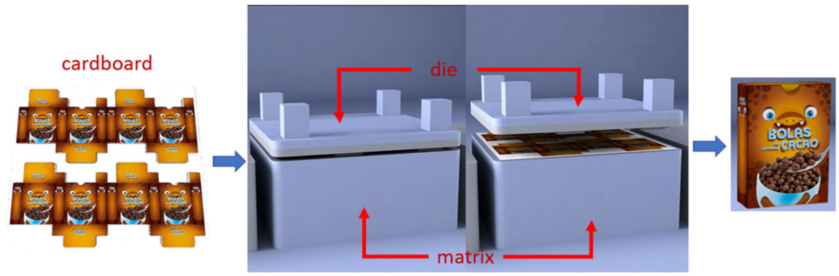


Fig. 1 Overview of the die-cutting process

of a product reference with minimal effort, since the system is in charge of capturing images and processing them automatically (using computer vision technology) to extract the relevant information and store it in a database. Consequently, it avoids the use of physical paper to record the status of a product, i.e., the need for a physical warehouse is eliminated. In addition, using the proposed system the operator can also quickly check the status of an old product reference without moving to any place, as it can be recovered from the database and projected over the work area (using projection mapping technology). Given that, the proposed system is aligned with the trend of Industry 4.0 [17] as well, in the sense that it digitizes the manufacturing process by integrating new technologies such as AR and projection mapping.

Besides facing the technological challenges such as digitizing correction templates of a die cutter from single images in uncontrolled light conditions (Section 3.4), projecting accurately the status of a product reference in the die cutter (Section 3.5), or creating a simple and intuitive interface (including an automatic camera-projector calibration)(Section 3.3), one of the main contributions of this work has been to bring the new technologies to an industrial and traditional ecosystem, knowing how to make the necessary modifications and simplifications in these technologies to achieve a good integration.

The system that has been developed as a result of this work is already working in a real factory. Indeed, to our knowledge, it is one of the few industrial works that are being used in a real factory and that integrate AR with projection mapping.

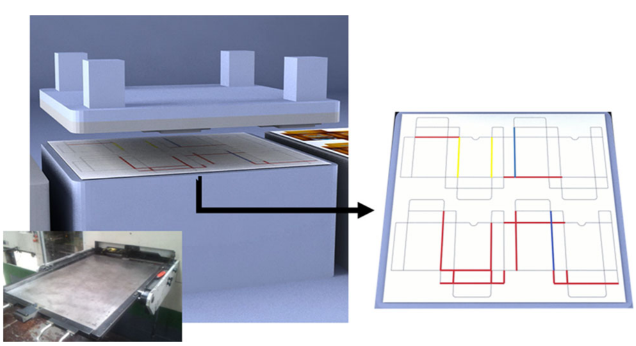


Fig. 2 Correction template that is used to balance the press differences

The rest of the paper is organized as follows. Section 2 presents the context of the problem and the motivation. In Section 3, the details of the proposed system are described, both hardware setup and the operating mode. Section 4 provides an evaluation of the system with real operators in the factory itself. In Section 5, limitations and challenges are discussed, and in Section 6, conclusions and future work are presented.

2 Problem statement

Following is a description of the manufacturing process of the Igamo[1] company, whose main activity is related to packaging. Nonetheless, it can be said that the description provided is valid for all companies in the packaging sector, since all of them work in a similar way.

A die cutter is a machine used in the packaging sector for shearing, bending, stamping, and/or perforating mainly cardboard (Fig. 1). The cardboard is placed on a workspace of the die cutter (a plate-shaped metallic part that is between the die and the matrix), and then, the die is pressed against the matrix to stamp, shear, bend, and/or perforate the cardboard according to the die shape. Once the cardboard (the raw material) has been given the desired shape, it is ready to be folded into the final product (generally a box).

However, due to the use and wear suffered by the die cutters, the press made by the die may not be uniform, getting an incorrectly processed cardboard that may become useless for its purpose or its quality may not meet the minimum quality requirements defined by the customer. To solve this problem, i.e., to balance the press differences, a correction template is used (Fig. 2), which is a sheet of paper with several tapes throughout its surface placed on the metal plate that is on the die. These tapes are of 3 types (associated with 3 colors, yellow, red, and blue), and

[1] http://www.igamo.es/

each type is correlated with a different thickness (0.08 mm, 0.05 mm, and 0.03 mm respectively). Thus, these tapes are located strategically in those areas where the contact (and consequently, the press) between the die and the cardboard want to be increased.

For the creation of a correction template, the operator makes a sample of die-cut with the desired cardboard, and, based on a visual analysis of the processed cardboard and his experience, he places the appropriate color tapes in the required positions. It is noteworthy that each product reference has a different die pattern, so each product reference has its own correction template. Likewise, each machine has its own wear and needs different corrections to compensate the misalignments, so there is a different correction template for each product reference and each die cutter.

2.1 Motivation

A packaging company manufactures several products and has several die cutters in its fleet. Therefore, it needs to manage thousands of correction templates (Fig. 3), one for each product and die cutter.

Nevertheless, the management is not automated. Every time the production of a product is finished and a new one needs to be prepared, the operator has to take the current correction template from the die cutter, go to the warehouse, store it in the corresponding shelf, look for the new correction template, and come back to the die cutter. Aditionally, from time to time, the tape layout of the correction template to be used has to be updated in order to account for the new accumulated wear of the die cutter. This procedure is slow (the operator has to move to the warehouse) and risky, since correction templates can be lost or broken, which causes waste of time (the correction template has to be recreated) and money (production hours are lost).

Given this problem, this article presents a solution to automate the management of correction templates, providing a system that allows to digitize the correction templates and, hence, avoiding the need to store them in a warehouse.

Fig. 3 Warehouse with thousands of correction templates

3 Proposed system

Figure 4 provides a conceptual scheme of the implemented AR system to automate the management of correction templates for die cutters. A camera captures an image of the correction template that is on the die cutter, and it is analyzed using a process unit to extract automatically the position and color of the tapes (digitization). Moreover, this data is stored on a server, and thus, in the future, the status of a correction template can be consulted and projected directly on the die cutter (projection). It is noteworthy that the operator only has to specify to the system the product and the die cutter with minimal interaction to manage the system.

3.1 Hardware setup

The camera and projector must point to the workspace of the die cutter, covering the entire area of the correction template. Therefore, they must be installed in the die cutter using some fixing brackets (Fig. 5). Since the camera and projector are placed very close to the projection surface to capture as much detail as possible in the image, wide-angle lens and projector models have been used.

The work station (the unit process and screen) has been connected to the network in order to send the data to the server. No special configuration has been required for the unit process, just a off-the-shelf computer is recommended. Likewise, although it is not a necessary condition to use a touch screen, it is much more pleasant and intuitive for the operator, so it is the one that has been established.

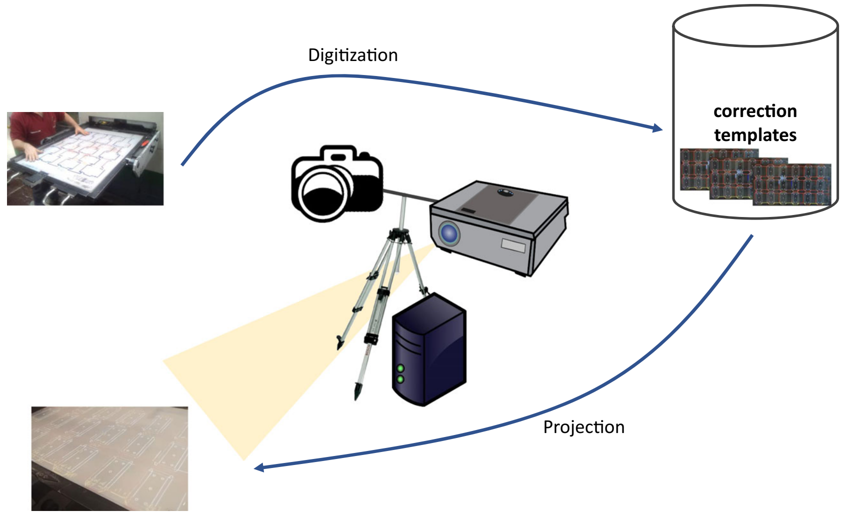
In the server, a data duplication mechanism has also been incorporated to increase security against data loss.

3.2 Correction template simplification

As stated in Section 2, a correction template is a sheet of paper that contains a graphic pattern representing the indentations and cuts of a particular product. Additionally, different tapes are superimposed on the pattern to balance the press differences of each die cutter (Fig. 2). Thus, each product-die cutter combination requires a unique correction template, which means handling many correction templates.

However, the proposed system eliminates this problem by using the same sheet model for all products and die cutters. Mor e precisely, the proposed system works with a white sheet of paper that has some markers (black squares) at its corners

Fig. 4 Overview of the proposed system



(Fig. 6 left), which are only used to center the position of the sheet in the camera image (see Section 3.3). Following this methodology, there is no need to store physically different correction templates as they are virtually registered and projected directly on the white sheet of paper. To prepare a new product, the new procedure is as follows (Fig. 6): (i) the operator puts a new white sheet in the die cutter; (ii) the system projects the pattern and the corresponding color tapes; and (iii) the operator puts the required color tapes on the white sheet of paper to replicate the projected status.

3.3 Calibration

To achieve the proper functioning of the proposed system, the following points must be calibrated before performing any digitization or projection:

- *Correction template position:* the position of the correction template in the image has to be known to identify in which area we have to detect or project the pattern of the product and the tapes. To do this, the system takes an image of the scene and looks for the 4 markers of the correction template (Fig. 6). These markers are easily identifiable in an image, since they are black squares with known dimensions [18, 19]. In addition, since the correction template has the same dimensions as the die and fits precisely on it, once the position of the markers are known it is possible to align the projected pattern with the underlying die.
- *Camera-projector transformation:* the proposed system allows to project content directly on the real scene (more specifically on the correction template), so it is necessary to calculate the transformation that takes points from the camera's coordinate system to the projector's coordinate system, i.e., it relates one point of the camera's image with the appropriate point of the projector's area that is subsequently projected. This transformation could be fixed manually, but in that case, if there is a minimal change/movement in the camera, projector, or the scene (the projection is also dependent on the shape of the surface where it is projected), it must be calibrated again and again. To avoid that effort, the proposed system calculates the camera-projector calibration automatically by projecting several calibration

Fig. 5 Hardware setup that has been performed at the Igamo factory

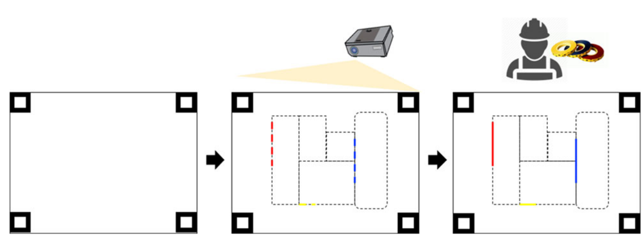


Fig. 6 Steps (right) to use a white sheet of paper (left) as a correction template. Dashed lines represent a projection, while solid lines represent those that physically exist

Fig. 7 Color calibration process. Sample of colors that the operatos puts in front of the camera (left) and how these colors are specified to the system (right)

patterns (chessboards) that are detected in the camera image. The dimensions of the projected calibration patterns are known, so when they are detected in the image of the camera, they produce several point matches between the projector's coordinate system and the camera's coordinate system, which are used to solve the transformation (see [20] for more details).

– *Color:* some factories (including Igamo) have large windows in the ceiling that allow the entry of light from outside, and therefore, they are uncontrolled scenarios. To achieve robustness against light changes, the proposed system requires a color calibration in which the operator places a sample of colors in front of the camera and indicates in the system (by means of marks made with the mouse) each sample to which color corresponds (red, blue or yellow) (Fig. 7). This is a very simple process that takes a few seconds and allows to adapt the sensitivity of the automatic detection of the color of the tapes during the digitization (Section 3.4).

Assuming that the system is installed in a fixed way and it is guaranteed that the devices do not move, it would only be necessary to execute these calibration steps only once. Nevertheless, due to the vibrations generated by the operation of the die cutter (which can produce certain small movements in the camera or projector, and consequently, turn into small precision mismatches) and the uncontrolled light conditions that there may exist in a factory, it is advisable to do these calibration steps periodically.

3.4 Digitization

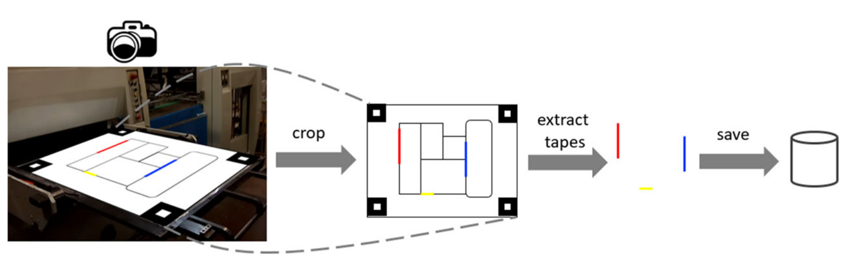
After preparing the die cutter for a product, the operator can save the status of the correction template with minimal interaction. It is then when the system captures an image of the scene, crops the area of the image where the correction template is (by means of the detection and delimitation of the markers, see Section 3.3), processes the cropped image and sends the calculated state of the correction template, i.e., the location and color of the tapes, to the server so that it is stored in the database (Fig. 8). Note that the operator also has the option to manually edit the digitization before being sent to the server, adding or eliminating the presence of any additional tape.

To detect the presence of the tapes in the image, the known pattern of the product is applied as a mask to segment the cutting and creasing areas, which is where the tapes should be placed. Moreover, the color samples of the calibration step are used to generate a color distribution and update the segmented image. Each pixel is labeled as red, blue, yellow, or background according to the probability with respect to their respective distributions (the color that offers the greatest similarity with the values of the input pixel is chosen). This new labeled image is then used to search for color segments (group of contiguous pixels that has the same color label), which correspond to color tapes (Fig. 9).

3.5 Projection

When an operator wants to check the status of the correction template of a product it is enough to specify the product id in the system and it will project the pattern and the last configuration of tapes that was used to balance the press differences. This is a complementary functionality to digitization (see Section 3.4). To perform the projection the system creates a synthetic image by drawing the pattern of the product and the configuration of tapes that has obtained after getting access to the database. Then, using the correction template position and the camera-

Fig. 8 Steps during the digitization of a correction template



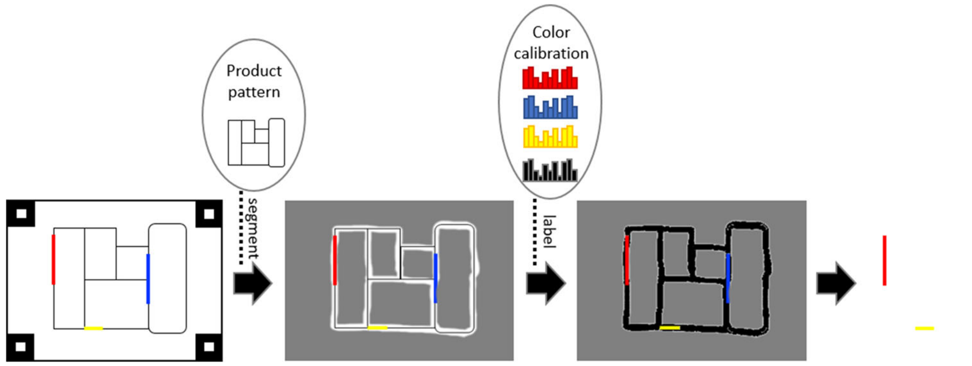


Fig. 9 Image processing during the digitization of a correction template. After segmentation, gray color means area of image that has been discarded. After labeling, black color corresponds to background

projector transformation that has been calculated during the calibration (see Section 3.3), it deforms the synthetic image to align its corners with the 4 markers that have been detected in the camera image, i.e, to align with the die that exist in the real scene (Fig. 10).

4 Evaluation

Some experiments that have been carried out at the Igamo factory (i.e., in a real environment) are presented.

4.1 Execution time

We have measured and compared the time that an operator takes to set the correction template on the die cutter using the standard procedure (Table 1) and with the help of the proposed AR system (Table 2).

Traditionally, the operator has to go to the warehouse, find the corresponding correction template, and come back to the die cutter to set the template. Then, after updating the status of the template (by adding or removing tapes), the operator has to come back to the warehouse to store the template. The total time of the whole procedure depends on the time to find the correct template in the warehouse (Table 1).

With the proposed AR system (Table 2), the operator does not need to move from the workstation. The operator sets the simplified correction template (Section 3.2) on the die cutter, finds the reference in the system (by typing the corresponding numerical code), and then the AR system projects the corresponding pattern on the template so that the projected tapes can be replicated. In case the operator wants to modify and save the status of the current reference, the AR system has the possibility of taking an image and automatically detect the presence of tapes (Section 3.4). The calibration processes (camera-projector pair and color) have not been considered here, since it is not necessary to do them constantly, only from time to time to readjust.

Comparing these execution times of both procedures, it is noteworthy that the AR system is faster (48 vs 97-122 s). However, in the execution time of the AR system, besides the calibration time, the time to replicate the tapes has not been considered either, as it is dependent on the number of tapes and is difficult to offer a general measure. Considering the task of replication, the difference would be reduced. Moreover, these execution times of the complete procedure can be optimized by overlapping some tasks, such as bringing/carrying the correction template from/to the warehouse while the die cutter is doing the previous/next job in the case of the traditional mode, or doing the calibration and preload the search of the reference while the previous job is being processed in the case of the AR system. Considering overlapping, traditional mode would take 30 seconds (just the *Set the correction template on the die cutter* task), while the AR system would take 40 s (*Set the correction template on the die cutter*, *Projection* and *Digitization* tasks). Thus, there is not a time gain properly in the preparation task using the AR system, the advantages are given by other concepts, such as not being forced to leave the workstation or not having to transport objects (correction templates), being free to face other tasks or reduce the mental workload.

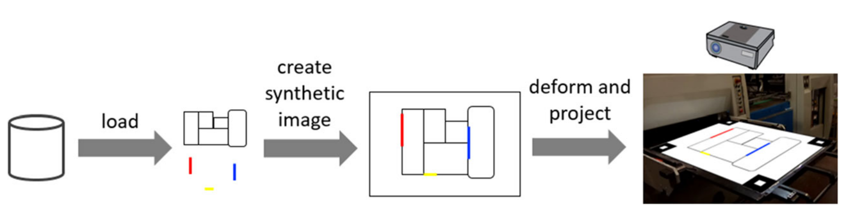


Fig. 10 Steps during the projection of a correction template

Table 1 Task execution time (seconds) using the traditional mode

Task	Seconds
Go to the warehouse	14
Find the correction template	25–50
Back to the die cutter	14
Set the correction template on the die cutter	30
Back to the warehouse	14
Total	97–122

4.2 Accuracy

To measure the accuracy of the AR system, a printed correction template has been set on the die cutter and then the same correction template has been projected using the AR system (Fig. 11). In most areas, the projection fits to the printed version with high accuracy (left of Fig. 11). Only in some areas, due to the inaccuracy of the any of the calibrations (camera, projector, or the pair camera-projector), a deviation is observed (right of Fig. 11). Nonetheless, this deviation (about 2–3 mm) is smaller than the width of the tape (about 5 mm), so the fit is good enough for the purpose described here.

4.3 Digitization

Figure 12 shows the response of the digitization process (Section 3.4) for a given correction template. When the light conditions are good, the digitization is perfect (middle of Fig. 12), while when the light conditions are bad (we have simulated it by illuminating an area with a light bulb) the digitization result is not perfect (right of Fig. 12, where undetecting tapes have been highlighted in green), but remain quite stable, correctly detecting large number of tapes and not giving false positives.

Additionally, for those cases in which the digitalization has not been perfect, the system has a functionality in which the operator can manually edit the position and color of the digitized tapes (Fig. 13).

Table 2 Task execution time (seconds) using the proposed AR system

Task	Seconds
Set the correction template on the die cutter	30
Find the correction template	7
Correction template positioning	1
Projection	1
Digitization	9
Total	48

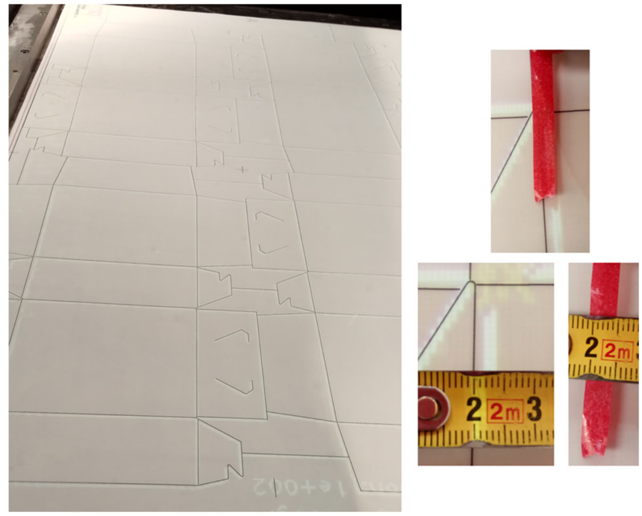


Fig. 11 Projection accuracy of the AR system

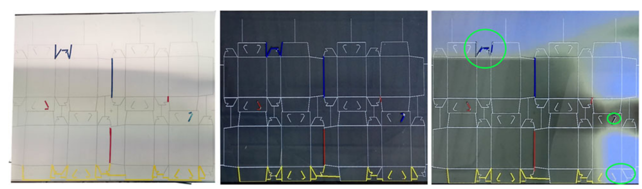


Fig. 12 Digitization of a correction template (left) with good (middle) and bad (right) light conditions. Errors in the right image have been highlighted in green

Fig. 13 Manual edition of a digitization of a correction template

4.4 Usability

To evaluate the usability of the AR system, 4 operators who used the new system for 2–3 months, and have great experience with die cutters (between 15 and 23 years of exprience), have answered the questionnaire presented in Fig. 14 (left), which follows a simple usability scale (SUS, The System Usability Scale [21]).

Analyzing the answers, all very positive, it can be stated that the usability of the system has been clearly approved by experienced operators. Among other aspects, the operators have found it easy to use and it is a system that they would like to use frequently. The distribution of the answers is shown in Fig. 14 (right). The mean SUS score is 82.5 (stdev 8.42), which is a single number that represents the overall usability of the system being studied. Considering that this value is ranged from 0 to 100, being 100 a very usable system, it can be stated that the propose AR system is very usable.

	Totally disagree 1	2	3	4	Totally agree 5	Mean	Stdev
I think that I would like to use this system frequently						3.00	0.00
I found the system unnecessarily complex						3.25	1.50
I think the system is easy to use						3.25	0.50
I think that I would need the support of a technical person to be able to use this system						3.75	0.50
I found the various functions in this system were well integrated						2.50	0.58
I thought there was too much inconsistency in this system						3.25	0.50
I would imagine that most people would learn to use this system very quickly						3.75	0.50
I found the system very cumbersome to use						3.50	0.58
I felt very confident using the system						3.00	0.82
I needed to learn a lot of things before I could get going with this system						3.75	0.50
SUS score						82.50	8.42

Fig. 14 Questionnaire answered by operators to evaluate usability of the AR system

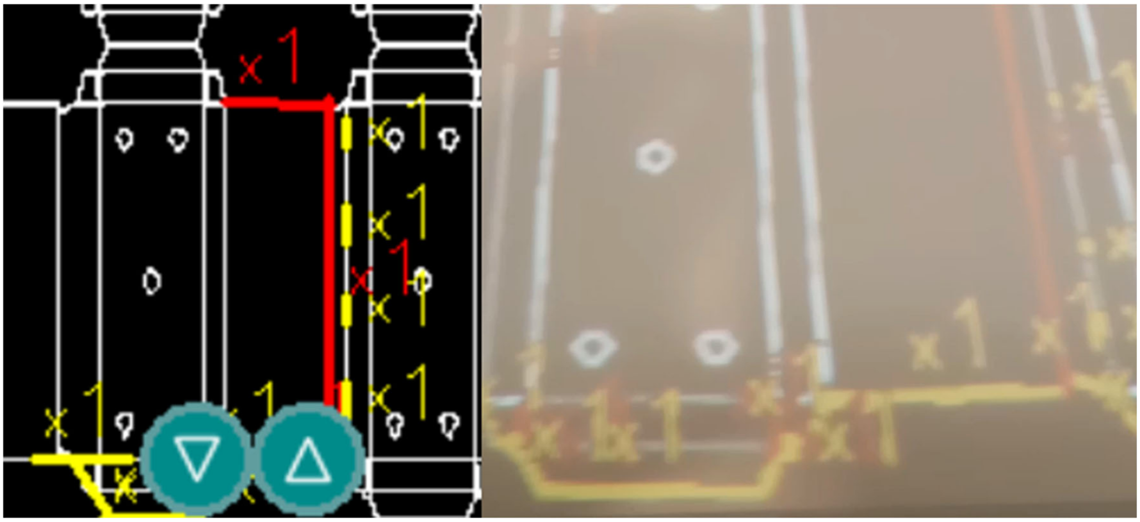


Fig. 15 Manual edition of the number of tapes in a specific point (left) and the corresponding projection that indicates the quantity of each one in each point (right)

5 Discussion

Involving operators to use an AR system is challenging, since there are several factors that hinder its acceptance, especially those related to ergonomics. That is why in the proposed AR system the content is projected directly onto the scene, without the need for the operator to carry any additional device, leaving their hands free. Likewise, a lot of attention has been paid in the installation of the system in the factory, choosing a design in which the camera and the projector are fixed in the die cutter, suspended on the top and without interfering with the movements that the operator must perform (Fig. 5). These decisions have proved to be key to facilitate the integration of the proposed AR system in the daily work of the operators.

The effort to generate the digital content to be used in the system is another factor that tends to hamper the integration of an AR solution. However, the proposed system has been properly integrated in the Igamo factory, since it only needs the pattern of the product as an initial input (the rest of the content is generated by the system itself), and it is a data that is already digitized and available in the Igamo's information system.

For the correction template simplification (Section 3.2), we considered not to use a white sheet and work directly on the metal plate that rests on the die (Fig. 2), but the initial tests carried out showed difficulties in performing the automatic calibration of the camera-projector, the detection of the tapes and the projection visbility due to the reflections on the metal plate.

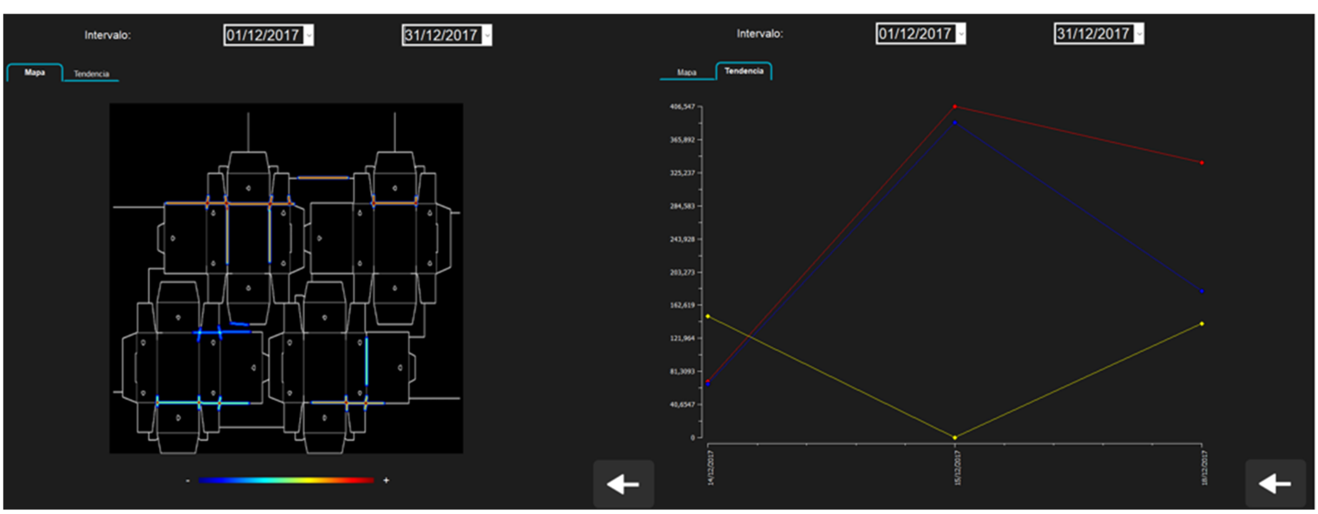


Fig. 16 Advanced visualization modes due to the digitization of correction templates. Heat map that indicates the density of tapes by zones (left) and temporal evolution of the number of tapes to detect sudden changes (right)

There is a problem during the digitization (Section 3.4) when there are several tapes superimposed on the same point. In these cases, a system that is based on computer vision can only detect the upper tape, since the rest are hidden. To overcome this problem, the proposed system allows the operator to edit manually a digitization that has been initialized automatically. It is an easy task with a simple interface, the operator selects a tape with the mouse and then specifies how many tapes there are at that point (increase a counter with the mouse, Fig. 15 left). The number of tapes is subsequently projected by the system so that the operator can replicate a state faithfully (Fig. 15 right). Current implementation only allows to indicate how many tapes of the same color there are, but in the future it is expected to expand this option to edit the number of tapes as weel as the color of each of them.

The proposed system only identifies tapes along the pattern of the product, it does not detect anything outside that area of interest, and therefore, this supposes a plus of security. If the operator places a tape in an inappropriate area, the system does not register it, and consequently, the next time that the status of the project is replicated and projected, this error will not be reproduced.

The digitization of the correction templates allows for a more advanced and efficient management mechanism. In fact, in the proposed system an additional visualization tool has been implemented (Fig. 16), which shows a heat map or the evolution of the tapes for each correction template. This allows the operator to detect easily anomalies in the die or the die cutter, for example, a specific area where the number of tapes has increased notably.

6 Conclusion and future work

A novel AR system oriented to die cutters has been presented. It digitizes the correction templates automatically by processing some images and applying some Computer Vision techniques. Moreover, it is able to project a digitized correction template directly in the die cutter using Projection Mapping techniques. Thus, the proposed AR system replaces the actual manual and paper-based management for automatic and digital management.

The proposed AR system has been tested in a real factory and has been evaluated by some experts in the field, resulting in a positive assessment in aspects such as time consumption, accuracy, functionality, and usability. Several advantages have been identified with respect to the traditional procedure:

- Savings in storage cost: the use of a warehouse is not required.
- Reduce risks: sheets of correction templates are not broken, damaged or lost.
- Increase process knowledge: all data is stored digitally so it can be processed to extract additional information (feeding new functionalities as, for example, doing preventive maintenance).
- Less mental workload: operators do not need to search or transport correction templates, they only need to push few buttons in the computer.

Performing further experiments, with more operators, is a task that will be faced in the future work. Likewise, the integration of data analytics techniques on digitized correction templates to offer additional functionalities (more sophisticated visualization modes or assistance in decision making) will be studied in the near future.

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