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The Use of Deep Learning in Verifying the Functioning of LEDs

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Abstract

This article aims to bring an alternative to carrying out manual tests of devices mounted on a production line. One of the tests done by the operator is to find out if the LEDs are present on the device being turned on and working correctly. Image processing techniques were applied in the elaboration of the dataset and the use of Convolutional Neural Networks for the classification of the colors presented by the LEDs and the recognition of their operation. An accuracy of 99.25% was obtained with a low percentage of false positives and true negatives. There were no difficulties in porting the model built to a small computer.

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1. Introduction

The current market has forced companies to work more quickly, evolving their production systems. Thus, they have sought to maintain their share of the market and, at the same time, do their utmost to constantly increase this share. For this, they have used the available methodologies to optimize their productive capacity and improve their competitiveness in relation to competitors (Cardoso and Lopes 2018, Brighenti 2006).

Thus, it is clear that today people live on the threshold of a fourth industrial revolution, called Industry 4.0, which is characterized by the intensive use of digital technologies, in order to manufacture new products quickly, with an agile response to demand and real-time optimization of production and supply chain. Among these technologies, the Internet of Things (IoT), Internet of Services (IoS), 3D Printing, Advanced Robotics, Artificial Intelligence, Big Data, Cloud Computing and Nanotechnology (Lima and Pinto 2019) stand out.

Coelho, mentioned by Lima and Pinto (2019), mentions that the impact of Industry 4.0 goes beyond simple digitization, passing through a complex form of innovation, which will force companies to rethink the way they manage their business and processes, such as position themselves in the value chain, how they think about developing new products and how they place them on the market, adjusting marketing and distribution (Lima and Pinto 2019). The impacts that this revolution has on productivity, cost reduction, control over the production process, customization of production, among others, point to a profound transformation in manufacturing plants (ABDI 2020).

Therefore, there is a growing demand for the elaboration and implementation of solutions responsible for optimizing manufacturing processes, such as the use of algorithms for the replacement of human labor, in repetitive jobs or that require precision, thus avoiding possible human failures and enabling that such workers are relocated to more complex tasks. In this way, the present work aims to bring an automatic way to check and test the functioning of LEDs of an electronic device, in order to optimize the process through the use of Industry 4.0 techniques, especially Artificial Intelligence. Automatic verification seeks to reduce the time needed to perform the manual test performed by the human operator, since it needs supervision throughout its entire process, which added to the number of tests carried out in parallel, results in slowness and stops the production line.

2. Theoretical Foundation

2.1 Computer Vision

The Computer Vision area aims at the automatic extraction of information given an image, which aims to resemble computers to human vision (Solem 2012, Khan et al. 2018). To achieve this result, Computer Vision techniques use statistical, geometric approaches and ways that mimic human vision, to obtain three-dimensional information from two-dimensional images (Khan et al. 2018).

With the growth in the volume of data, especially images and videos, the Computer Vision area has gained increasing notoriety and importance, given its variety of applications, such as closed-circuit camera images, or even the navigation of autonomous vehicles (Solem 2012). The Computer Vision area has as main applications tasks of classification, location, detection and segmentation of objects in images. The classification tasks aim to indicate a group to which an image belongs (Khan et al. 2018).

The location tasks aim to find a specific characteristic within an image. Object detection, on the other hand, identifies all groups that exist in an image. Finally, the segmentation of objects indicates the exact location where the groups of objects are in the image, even if partially covered (Khan et al. 2018).

2.2 Artificial Intelligence

Artificial Intelligence is one of the most recent fields in science and engineering (Russell and Norvig 2013). According to Winston (1992), it can be defined as the study of computing that makes perception, reasoning and action possible (Simões 2000). Artificial Intelligence aims not only to understand, but also to build intelligent entities (Russell and Norvig 2013).

Currently, Artificial Intelligence covers a large number of subfields, from learning and perception to more specific tasks such as chess games, demonstrations of mathematical theorems, creating poetry, driving a car on a busy road and diagnosing diseases (Russell and Norvig 2013). Faceli et al. (2011) shows us that Artificial Intelligence comes to assist in the resolution of tasks that could be solved by human beings, but due to its volume of data and its complexity, they become difficult to be performed correctly. Artificial Intelligence techniques, in particular Machine Learning, have been used successfully in a large number of real problems, including those previously mentioned (Faceli et al. 2011).

2.3 Machine Learning

In the last decades, with the increasing complexity of the problems to be treated computationally and the volume of data generated by different sectors, it became clear the need for more sophisticated computational tools, which were more autonomous, reducing the need for human intervention and dependence on specialists (Faceli et al. 2011). Machine Learning is an area of Artificial Intelligence whose purpose is the development of computational techniques on learning, as well as the construction of systems capable of acquiring knowledge automatically (Monard and Baranauskas 2003).

This learning system uses successful experiences from previous problems to make new decisions (Monard and Baranauskas 2003). According to Flach (2000), previously cited by Monard and Baranauskas (2003), research carried out in the Machine Learning area can provide improvements to current techniques and a basis for the development of alternative approaches to knowledge acquisition (Monard and Baranauskas 2003).

Machine Learning algorithms are used in several tasks, which use different criteria to be organized, such as the learning paradigm. These learning tasks can be divided into descriptive, where the objective is to explore or describe a set of data, and predictive, whose objective is to find a function from the training data to predict a label or value that characterizes a new example, with based on input attributes (Faceli et al. 2011).

Machine Learning methods induce predictive models and follow the supervised learning paradigm, which indicates the presence of a supervisor who knows the desired output for each example. We can say that there is a hierarchy where, at the top, inductive learning appears, which indicates that generalizations are made from the data. Below, we have the types of predictive or supervised and descriptive or unsupervised learning. After that, we have that the supervised types can be distinguished by the type of the label being discrete in the case of classification, and continuous in the case of regression (Faceli et al. 2011).

The unsupervised types can be divided into: grouping, according to the similarity of the data, summarization, whose objective is to find a simple and compact description for a dataset and association, which seeks frequent patterns of association between the attributes of a set of data (Faceli et al. 2011). In addition to these, we have other well-known paradigms, like reinforcement learning, which is a particular case of supervised learning, and competition learning, which is a particular case of unsupervised learning (de Pádua Braga et al. 2007).

2.4 Artificial Neural Networks

Artificial Neural Networks are Artificial Intelligence techniques inspired by the functioning of neurons in the human brain (Mergulhão et al. 2019). As neural computation is not based on rules or programs, it is an alternative to conventional algorithmic computation (de Pádua Braga et al. 2007).

Such networks are adaptive systems composed of interconnected processing units, called neurons, distributed in different layers working together to solve a problem (Mergulhão et al. 2019). These units calculate certain mathematical functions, generally non-linear and are arranged in one or more layers and are interconnected by a large number of connections, which are normally unidirectional (de Pádua Braga et al. 2007).

The architecture of Artificial Neural Networks is usually defined through parameters such as the number of network layers, number of nodes in each layer, type of connection between the nodes and network topology. They can be classified according to their connectivity, being a partially connected network or a fully connected network (de Pádua Braga et al. 2007).

The great advantage in the use of artificial neural networks to solve complex problems comes mainly from its learning capacity through generalization of the response acquired during the training of the network, through the use of examples that have already occurred in the past (Mergulhão et al. 2019).

We also have Convolutional Neural Networks, which can be defined as Artificial Neural Networks that employ convolution operations in at least one of their levels. These models stand out for their success in practical applications, being widely used in data processing with a well-defined grid topology, such as images and time series (Goodfellow et al. 2016).

2.5 Deep Learning

Deep Learning, from the English Deep Learning is a subfield of Machine Learning responsible for the construction of conventional Artificial Neural Networks, however with multiple intermediate layers, capable of building even more sophisticated models, since with the greatest number of layers, they are capable of better abstract the problems addressed, with applications in image classification tasks, speech recognition and hand made transcriptions, having reached almost human levels in these tasks (Chollet 2018, Gulli and Pal 2017).

Therefore, Deep Learning is a subarea within Machine Learning, which in turn is an Artificial Intelligence subarea, as we can see in Figure 1.

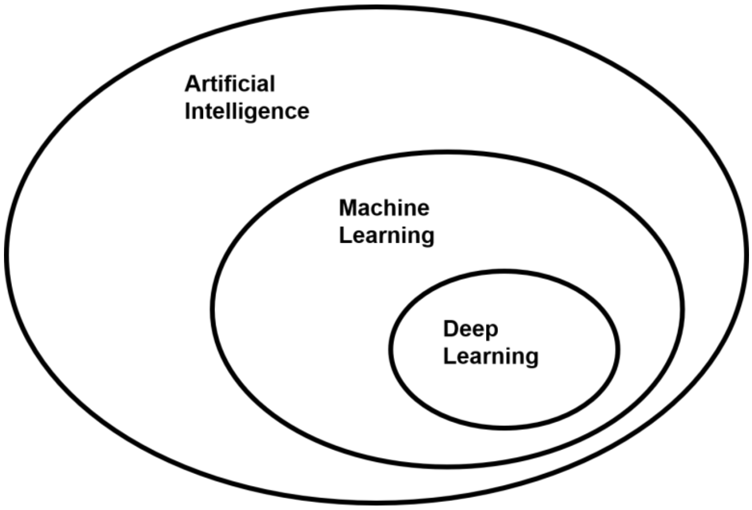

Figure 1. Artificial Intelligence, Machine Learning and Deep Learning (Chollet 2018).

Consequently, the field of Deep Learning has been widely used in Computer Vision tasks, more specifically, in the classification and detection of objects in images. In addition, Deep Learning is also used in recommendation systems, which are used to list consumer items and potential customers, in order to maximize profits through targeted advertising (Goodfellow et al. 2016).

3. Related works

Tsai et al. it brings an automated color inspection, using an optical sensor to assess the color emitted by the LED (Tsai et al. 2011). Before the sensor perform this inspection, color matching functions corrected by the least squares approach method were used. The LED was placed in a dark place to avoid light pollution from the environment, which could interfere with color detection. Two red LEDs, one green and one blue, were analyzed. With the method proposed by the authors, a significant improvement was obtained in the average color difference of each LED after compensation, while the average luminance reduced to less than 3.5%.

Banik's work brings a way of detecting colors from an LED using a smartphone camera (Banik et al. 2017). Multivariate regression analysis was used to detect color in LEDs. As the methodology used, for the LED image, the region of interest was identified, image processing was performed together with the K-means algorithm to generate the possible colors of the LED and the regression model was applied to predict the color emitted by the LED . Red, green and blue LEDs were used, with R-square results of 91.4%, 94.8% and 96.2%, respectively.

Polzer et al. features an integrated sensor without a filter for determining the color of LEDs (Polzer et al. 2011). This sensor was manufactured in the BiCMOS process, which allows the sensor to be integrated with other circuits on a chip without modifying the process. It determines the central wavelength of an LED and uses the silicon penetration depth of the incident light to find the resulting RGB output from the LED. The results obtained show an accuracy of approximately 10 nm, which the authors claim is suitable in environments with an external light source.

The work of Dias et al. it consists in the development of a color detection system for people with low visual acuity (Dias et al. 2016). The authors used the Arduino platform and the App Invertor to have a low-cost solution. During the test phase, the authors found that the change in lighting in the environment affected the reading value in the voltage of the light sensors, influencing the identification of colors, which made it necessary to use algorithms for lighting compensation. After that, 31 different colors were measured in 3 different environments, obtaining a result of 100% accuracy.

Thus, it is observed that most studies use physical methods for the detection of colors, which are conducive to the variation of tension that can influence the results obtained. In addition, it is possible to observe that, in the work that used Computer Vision techniques, the approach used less robust methods for the detection and prediction of the colors of each LED.

4. Methodology

For the implementation of the proposed solution, images were collected for the construction of the dataset. Then, a model more suitable for the image classification activity was chosen and built, considering its size and performance. After that, this model was submitted to the dataset and trained, having its weights saved at the end of the training. The weights along with the model were embedded on the small computer. The following subsections better demonstrate the steps mentioned.

4.1 Proposed Solution

The proposal developed consists, in principle, of a camera that captures images and performs the classification of colors emitted by LEDs of an electronic device assembled and tested by a production line. This camera is associated with a small computer in order to optimize the space used in the production line. The dataset built for training was divided into parts for training and testing.

On the computer, there is the Artificial Intelligence model and an algorithm that assists in the necessary procedures for prediction such as redefining photos, exchanging information with other test equipment, among other activities. A multilayer Artificial Neural Network was used, responsible for the task of supervised learning, performing the classification of the LEDs in three classes, representing the LED turned on in red, green, or the LED off. This model and the algorithm were implemented in the Python programming language, using the Keras Neural Networks library and the OpenCV library for image manipulation.

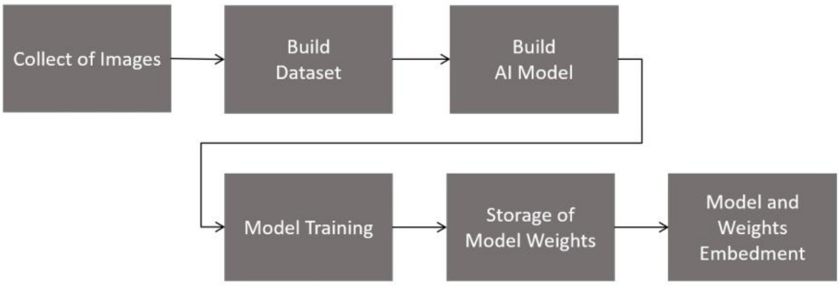

Figure 2. Block diagram that represents the sequence of steps performed in the process.

4.2 Dataset

The data for training and testing of the built model were collected directly from the electronic device, captured by the camera itself connected to the reduced size computer. The camera used had night vision technology, since the place where this prototype would be placed would have a discreet amount of light. A total of 450 images were captured, with 150 images of the green LED on, 150 images of the red LED on and 150 images of the LEDs off. Figure 3 contains some examples found in the dataset.

Figure 3. Example of images found in the dataset representing the LED in off mode and the colors green and red, respectively, used in training the model.

The captured images were organized in folders identified according to the color of the corresponding LED, and renamed in order to be in sequence. The labels of the folders were selected in order to allow the later use by the implemented model. The partition adopted for the dataset was of the hold-out type, in the proportion of 70/30, with 70% of the dataset being designated for the training phase and 30% for testing.

In addition to the separation of data for training and testing, it is also important to note that each class had balanced amounts of images of each possible scenario for the problem, such as different amounts of light or the presence of specific objects, so where the model was trained and evaluated within the broadest possible scenarios. After dividing the dataset, the images were manipulated in order to be redefined from their original size of 640 x 480 pixels, to the size of 150 x 150 pixels, in order to adapt to the data entry expected by the implemented model, with the necessary manipulations also being made at the implementation level.

4.3 Developed Model

As previously seen, Deep Learning has good applicability in Computer Vision problems. Thus, for the addressed problem, techniques from this area were used, through the use of Convolutional Neural Networks, since they provide good results regarding the task of image recognition.

For this, a model was elaborated according to the following architecture: an input layer of 150 x 150 pixels, to contemplate the images of the dataset, followed by three layers stages, the first two being composed of 32 convolutional layers and the last one composed of 64 convolutional layers. As an activation function for these convolutional layers, the rectifier linear unit, or ReLU, with 3 x 3 size filters was used. After each step of convolutional layers, a 2 x 2 Max Pooling layer was added.

After the convolutional layers, a fully connected layer with 64 neurons was added followed by another fully connected layer with 3 neurons, or three outputs, in order to cover the three possible classes for forecasting, as already mentioned. After assembling the final model, we have a total of 1,212,643 parameters, 1,212,643 of which are trainable and 0 non-trainable. Figure 4 shows how the final architecture of the model was assembled.

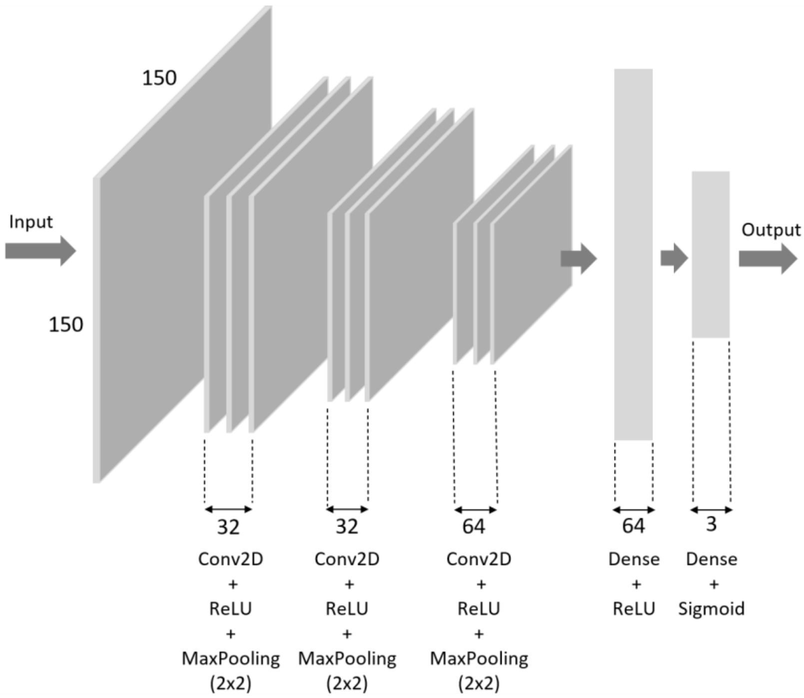

Figure 4. Illustration of the model architecture. It is possible to observe the number of layers used for each stage of the model, represented by the values at the bottom of the image.

5. Results and Discussion

5.1 Results Obtained

To measure the performance of the built model, two main performance metrics were adopted, namely, accuracy and F-Score. Accuracy can be defined as the metric that returns the number of correct answers taking into account all attempts of the model. This metric reveals the percentage of correct answers that the model has. The F-Score is defined as the harmonic average between precision and recall of the model, where precision indicates the true positives among those that were predicted as positive and shows the number of false positives and the recall indicates the percentage of true examples that were classified as true and the positive examples that the model did not classify (Marques 2017). Figure 5 describes the performance of the model in its confusion matrix.

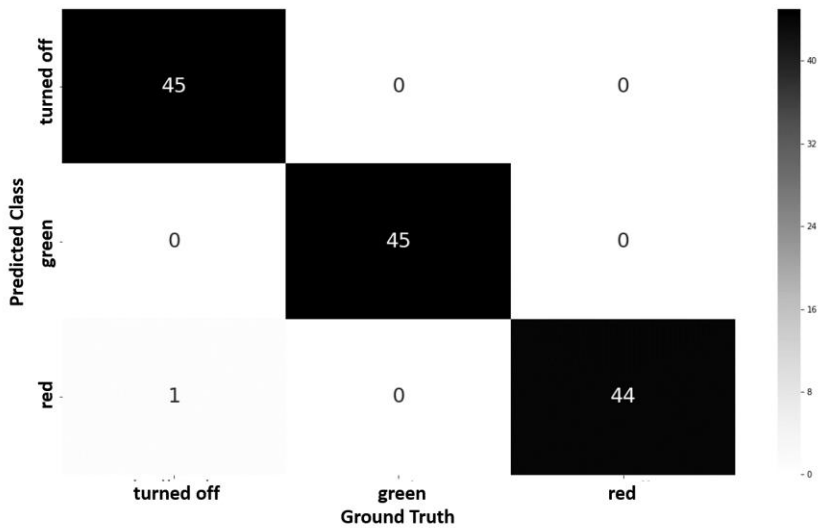

Figure 5. Confusion matrix of the results obtained, where the performance of the model is observed.

In this way, after the training period has passed, the model then had its performance measured according to the test data, obtaining the metrics of 99.25% accuracy, with 0.9925 F-Score, showing the good performance of the built model, given the problem addressed. It is also worth mentioning that the results obtained were achieved without any additional Image Processing technique, fine adjustments to the built model, or grid searches, relying only on the methodology previously described.

4.2 Discussion of Results

With the results obtained, the remarkable performance of the model built for the addressed problem is observed. It is also noticed that in the examples in which the proposed model incoherently inferred, such an error can be attributed to the fact that the camera used is made for night vision, in order to interpret the clarity of the images with a reddish tone, which may have confused the model in its test stage. However, even if such an error has been verified, it is important to emphasize the accuracy achieved in the other classes, where for the green color, for example, the model did not present errors.

With regard to the possibility of portability of the model built to the reduced size computer, no problems were found, since due to the size of the model, there were no major impacts on computer processing. It is also noted that the model developed has about half of the trainable parameters of architectures already popular for the same task, such as MobileNet V3, ideal for embedded environments (Howard et al. 2019).

In comparison with the related works, it is not possible to make a direct comparison with the results of the mentioned works, since they are in different contexts. However, in relation to the detection of LEDs, it is clear that the model built obtained better results for the classification, when compared to the work of Banik, where the K-means algorithm was used, emphasizing that in such work, a camera was used smartphone to obtain images (Banik et al. 2017). Compared to the works in which physical methods were used, such as sensors, it is observed that the same model obtained similar results, after considering the compensations and Image Processing techniques used in the related works.

6. Final Considerations

The work developed showed a good result, both in the construction and training of the model, as well as in the process of embedding the model trained in the reduced size computer. An accuracy of 99.25% was obtained with a low percentage of true negatives and false positives. For the next works we can mention the construction of a dataset of LED images in environments with different incidence of light and the change of the technology of the camera, without night vision, to evaluate the behavior of the model with these changes.

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