Chapter 1 Selection methods and detection techniques applied to tomato fruits based on their physical characteristics

Capítulo 1 Métodos de selección y técnicas de detección aplicados a frutos de tomate en función de sus características físicas

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Abstract

Tomatoes are a vegetable crop of great economic importance worldwide, in addition to being the subject of research to be able to have a higher quality of fruits for consumers. As with many of the crops in the world, the harvest of the tomato fruit is a task that requires a large amount of labor, causing an increase in the costs to be paid by the producer. In recent years, there has been a great and growing interest in automating agricultural processes such as harvesting. This has prompted the development of computer vision and image analysis methods and techniques for the detection of fruits and vegetables. For this reason, given that obtaining images is a very fast and non-invasive way to detect the fruits, these can be classified as both mature and immature or detect some other physical traits that may be useful for the grower of the crop. Some of the systems developed allow the detection and selection of tomato fruits by creating their personalized classification according to the physical characteristics of the fruit. There are a large number of environmental factors that are of importance for the full development of tomato fruits because they have a great influence on the speed of the biological processes of the tomato fruit. During the post-harvest, the care of the plants is as important as the care of the tomato fruit, good care generates a higher quality of the fruits.

Deep Learning, Neural Networks, Object Detection, Artificial Vision, Artificial Intelligence

Resumen

El tomate es un cultivo hortícola de gran importancia económica a nivel mundial, además de ser objeto de investigación para poder tener una mayor calidad de frutas para los consumidores. Al igual que ocurre con muchos de los cultivos en el mundo, la recolección del fruto del tomate es una tarea que requiere una gran cantidad de mano de obra, lo que provoca un aumento de los costos a pagar por el productor. En los últimos años, ha habido un gran y creciente interés por automatizar procesos agrícolas como la cosecha. Esto ha impulsado el desarrollo de métodos y técnicas de visión artificial y análisis de imágenes para la detección de frutas y verduras. Por este motivo, dado que la obtención de imágenes es una forma muy rápida y no invasiva de detectar los frutos, estos pueden clasificarse como maduros e inmaduros o detectar algunos otros rasgos físicos que pueden ser útiles para el cultivador del cultivo. Algunos de los sistemas desarrollados permiten la detección y selección de frutos de tomate creando su clasificación personalizada según las características físicas del fruto. Hay una gran cantidad de factores ambientales que son de importancia para el pleno desarrollo de los frutos del tomate porque tienen una gran influencia en la velocidad de los procesos biológicos del fruto del tomate. Durante la postcosecha, el cuidado de las plantas es tan importante como el cuidado del fruto del tomate, un buen cuidado genera una mayor calidad de los frutos.

Deep Learning, Redes Neuronales, Detección de Objetos, Visión Artificial, Inteligencia Artificial

1. Introduction

The tomato fruit is one of the most demanded around the world and one of the ones with the greatest economic value in Mexico, in addition to this, there is a great variety in terms of types of tomatoes, which also makes the demand even greater and with it, in the same way, its cultivation, production and marketing. That is why in this research a type of tomato called "Saladette" or also known as "Roma" is studied, since it is one of the most consumed tomatoes in Mexico, this because there is a great demand for the product and its great relevance and importance in the daily diet of society. both fresh consumption and preserves. Currently, automatic tomato recognition systems are little used by small farmers, however, they have limitations when selecting tomatoes since they use manual methods and with this they damage or damage the product; which may cause customers to be lost given the condition of the tomatoes offered.

According to Megha.P.Arakeri, Lakshmana, the task of sorting fruits is extremely vital for agriculture given that there is a huge demand for the best quality fruits in the market, however, as previously mentioned the sorting done by humans is not completely effective, so an automated sorting system not only speeds up the processing time, but also it also minimizes errors. The demand for tomato fruits is considerably large both nationally and internationally (Arakeri, M. P., 2016).

Taking into account the points previously stated, it is possible to understand more deeply the need and importance of creating and/or developing an automated system that provides a much more effective and efficient selection of fruits than by performing this process manually, the fruits will be directly less manipulated so the bruises on them will be considerably reduced and the consumer will receive higher quality products.

Now, in order to develop a system of this type, the physical variables of the tomato that are necessary during the development of the system are studied and analyzed, as well as the temperature of the environment, since according to the article by Wosene, *et al* (Tadesse, T. N., Ibrahim, A. M., & Abtew, W. G., 2015) It is mentioned that the most important environmental factor is temperature since it has a great influence on the speed of biological processes, which includes both the color and the softening of the tomato, however, during the post-harvest the most common type of damage that the fruits receive are bruises, so it is also sought to cover that need; A possible solution according to some authors such as Xiaochn is to use technology based on hyperspectral images which consist of collecting and processing information regarding the duration of the electromagnetic spectrum, is then, that these images divide the spectrum into several bands, which allows us to know if there is a malformation or something in bad condition with the tomato fruit. All objects leave unique fingerprints along the magnetic spectrum, allowing the identification of materials and components of the object in question.

For the classification and selection of the tomato, the visual characteristics of the tomato must be considered, one of them is the color that the fruit of the tomato acquires throughout its life. In tomatoes, the ripening process of the fruit involves dramatic changes in small organelles within the fruit cells called plastids, and it is these plastids that are responsible for giving the fruit its color. Phytochromes detect changes in the composition of light that filters through the flesh of the fruit. When the fruit is green due to the accumulation of chlorophyll, it retains the radiation corresponding to the red, but when the fruit and its seeds are developed, the fruit begins to lose chlorophyll, the amount of red in the light that is filtered and perceived by the phytochromes present in the tomato flesh increases, that is, the center of the fruit.

So, knowing the necessary physical characteristics it is key to create a classification with them, that is why it is recommended to make a classification based on the stages of ripening of the tomato, so there are 3 categories: unripe (when the tomato has a green color), light red (intermediate stage in the maturity of the fruit) and finally ripe (when the tomato acquires a red color), This is based on the article published in (Bello, T. B., Costa, A. G., Silva, T. R. D., Paes, J. L., & de Oliveira, M. V., 2020). However, the inclusion of techniques, algorithms and strategies based on artificial intelligence is essential for the development of this system, one of the techniques contemplated is artificial vision, artificial vision systems are based on digital sensors protected inside industrial cameras with optics specialized in acquiring images, so that the hardware and software can process, Analyze and measure different characteristics to make decisions.

Another technique or, rather, devices of great importance in this aspect are colorimetric sensors, which are of complete necessity when making a classification based on maturity levels, which, as is notorious, include or intervene changes in the color of the fruit. However, RGB images are also used for this, which refer to three colors: red, green and blue (Red, Green, Blue). Thus, by merging the studied physical characteristics of the fruit and even the tomato plant with the methods and strategies of artificial intelligence, it is possible to successfully culminate in the development of an automated tomato selection system, which will bring benefits to farmers by being able to offer a higher quality product.

2. Theoretical background

There is now a large amount of recent research examining factors that affect the physical structure of tomatoes throughout their life. Wosene *et al*. (Tadesse, T. N., Ibrahim, A. M., & Abtew, W. G., 2015), mention the most important environmental factor in the postharvest life of tomatoes, they propose that temperature has an enormous influence on the speed of biological processes, which includes tomato color and softening. The objective of the study they propose was to investigate the effect that tomatoes suffer from temperature variations during storage, the effects analyzed refer to the degradation and synthesis of the color of the tomato.

During the post-harvest, bruises are the most common type of damage that tomatoes receive, the study carried out by Xiaochn *et al*., indicates that it is very difficult to detect the damage by each one through human inspection because the changes presented in the fruit are less in the appearance of the fruit. They made use of hyperspectral imaging-based technology to detect those tomatoes bruised by fruit drop. The results they obtained showed that the bruised spectra were lower than those of healthy tomatoes, they eventually developed partial least squares discriminant analysis models to classify tomatoes with an overall accuracy of 90.03% and the data they simulated confirmed that hyperspectral technology can classify bruising damage in tomatoes (Sun, Y., Pessane, I., Pan, L., & Wang, X., 2021).

Some studies were based on specific study and testing. In Thaísa et. al., its objective was to evaluate the colorimetric and physicochemical variables of tomatoes, grouping them in tomato ripening stages. During their experiment they used 150 fruits and classified 3 stages of ripening (unripe, light red and ripe). The variables were evaluated using a method that makes use of images in RGB color model taken with a digital camera, in the case of the correlation between the colorimetric variables it was analyzed using Pearson's coefficient. In the end, they obtained that the colorimetric variables present a greater explanatory capacity of the maturation variation than the physicochemical variables, the colorimetric indices presented a higher performance in the maturation clustering with an accuracy of 0.98% (Bello, T. B., Costa, A. G., Silva, T. R. D., Paes, J. L., & de Oliveira, M. V., 2020).

Halil *et al*., make use of deep learning in order to obtain the anomalies that occur in the tomato plant. They intended to use an algorithm based on deep learning to detect plant diseases by means of a robot, this robot allows the monitoring of tomato leaves by taking photographs and making an exhaustive analysis of the photographs taken (Durmuş, H., Güneş, E. O., & Kırcı, M., 2017).

Dayana *et al*. also developed a robot (LEGO-Mindstorms NTX 2.0) whose purpose was to recreate a scenario where pests that affect the growth and structure of tomato fruits can be detected. The solution was to implement a color sensor and an infrared sensor for color detection on the pests, the software they used allows to determine the color of the pest in real time from the images of leaves, obtaining very encouraging results, although statistical data of the results are not specified (Ariza, D. V., Palacio, A. M., Aragón, I. P., Logreira, E. A., Pulido, C. M., & Mckinley, J. R., 2017).

On the other hand, Xiukang Wang and Yingying Xing, conducted an evaluation on the management of water and nutrients applied to fertilizers, which are the factors that most affect crop growth and productivity. In recent years, tomatoes have quickly become one of the most popular products in the world, and tomatoes are marketed to consumers as a health food that can help reduce the risk of contracting certain human diseases and developing many forms of cancer. However, when there is a shortage of water, it is very likely that fertilizers will be used, which affects the alterations of the product in question, causing physical and chemical changes in the fruit (Wang, X., & Xing, Y., 2017).

Murtaza *et al*. also investigated the effects on tomato fruits by applying the effect of plasma-activated liquid, i.e. plasma-activated water (PAW) in order to reduce pesticide residues applied to tomato fruits. The results revealed that by applying this effect, fungicide residues were reduced by between 79.43% and 85.3%, avoiding alterations in tomato structure (Ali, M., Cheng, J. H., & Sun, D. W., 2021).

Hilje and Stansly mention the evolution of a methodology for the evaluation of trap crops for the management of Bemisia tabaco. The whitefly Bemisia tabaci is a pest of tropical and subtropical regions that affects the status of tomatoes and other crops such as tobacco, beans and eggplant. This method demonstrates prevention in pest situations, especially for the tomato plant (Hilje, L., & Stansly, P., 2017).

2.2. Fruit sorting systems

Currently, many of the systems are based on factors such as color, which is a physical and sensory phenomenon, captured by the human perception of the light reflected by an object and is affected by the observer, the illuminant, the optical geometry, the area, background, surface, brightness and temperature. These properties function as indicators of degradation in tomato fruits to determine those that are in poor condition or in the process of ripening.

The quality of the tomato can be judged by its visual characteristics, this being one of the main starting points for its classification because from its brightness and color it can be determined in which stage of ripeness the tomato is, this characteristic has been studied by the researcher Saber e*t al*., by using artificial vision and soft computing approaches for automation and improvement of processing time (Iraji, M. S., 2019) while Dussan *et al*., make an observation about the differences that exist when using digital cameras as color instruments vs. the use of sensors and the ease of data acquisition (Dussán-Sarria, S., Garzón-García, A. M., & Melo-Sevilla, R. E., 2020).

In Sun *et al*., he performs the evaluation of the brightness of the surface of apples where he performs the extraction of color parameters from areas of high light and detection or classification of the SVM model. This sorting method had 96.7% accuracy results, showing good operational results in terms of sorting accuracy rates and calculation speed for tomato quality processing (Sun, K., Li, Y., Peng, J., Tu, K., & Pan, L., 2017). The proposed method achieved a sensitivity of 83.2%, a specificity of 96.50%, and a mean g of 89.40% with accuracy of 95.5%. On the other hand, Liu *et al*., detail a new way for the automatic detection of fruits using the YOLO-Tomato model based on YOLO v3 that, among its main advantages, facilitates the reuse of functions and helps to learn a more compact and accurate model. It uses a circular bounding box to locate the tomato, matching it to the shape of the tomato. The results obtained under mild occlusion were an identification rate of 94.58%, demonstrating that it can be applied to picking robots for tomato detection (Liu, G., Nouaze, J. C., Touko Mbouembe, P. L., & Kim, J. H., 2020).

In all cases, it can be observed that the model or system developed is made from a certain range of colors or values where the environmental conditions change notoriously according to the area where the system is implemented, one of the conflicts being the level of illumination and that the sensors have a limited range of colors. In turn, K. Schmitt, *et al*., mentions that colorimetric sensors based on color-changing dyes offer a convenient approach to quantitative gas measurement. An integrated mobile colorimetric sensor can be particularly useful for occasional gas measurements, such as informal air quality checks for odors. In these situations, the main requirement is high availability, ease of use and high specificity towards a single chemical compound, combined with cost-effective production (Schmitt, K., Tarantik, K., Pannek, C., Benito-Altamirano, I., Casals, O., Fabrega, C., ... & Prades, J. D., 2017).

On the other hand, Bif Leonardo, *et al*., investigates the potential use of low-cost, short-range terrestrial RGB imaging sensors for fruits. Traditional digital image processing in approaches such as RGB color space conversion were applied in several terrestrial RGB images to highlight the information presented in the original dataset (Biffi, L. J., Mitishita, E. A., Liesenberg, V., Centeno, J. A. S., Schimalski, M. B., & Rufato, L., 2021). Afterwards, binarization and segmentation of optimal images were carried out, once these processes were carried out, parameters were chosen to detect the fruits efficiently. Megha.P.Arakeri and Lakshmana, mention that the task of sorting fruits is vital in agriculture because there is a high demand for high-quality fruits in the market. There is a high demand for tomatoes both locally and abroad (Arakeri, M. P., 2016).

The fruit of the tomato is very delicate and, therefore, needs a lot of care. The proposed quality assessment method consists of two phases: hardware and software development. The hardware is developed to capture the image of the tomato and move the fruit to the appropriate containers without manual intervention. The software is developed using image processing techniques to analyze the fruit for defects and ripeness. According to Manya Alfonso, *et al*., Deep Learning-based methods emerged as the cutting-edge techniques in many image segmentation and classification problems, and are very promising in challenging domains such as agriculture, where they can deal with the great variability in data better than classical computer vision (Afonso, M., Fonteijn, H., Fiorentin, F. S., Lensink, D., Mooij, M., Faber, N., ... & Wehrens, R., 2020).

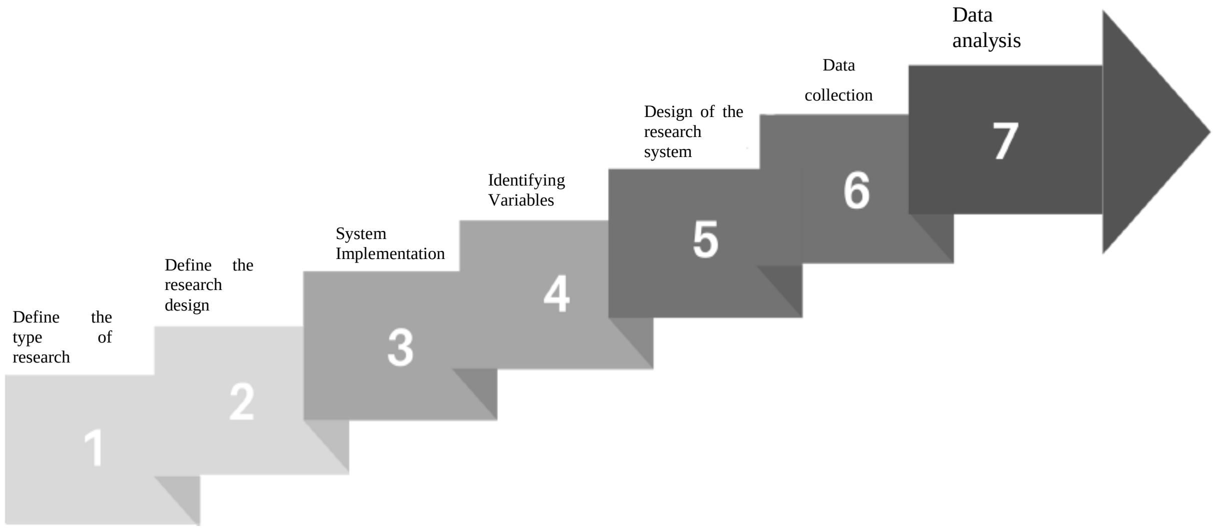
The study carried out by Juan Víctor Eduardo Ramos Diaz had the objective of determining the effectiveness of the algorithm integrated with artificial intelligence supported by a robotic hand in the recognition of tomato ripeness and four phases of development were applied (understanding of the business, development of the robotic hand solution, obtaining data and development of the neural network solution) in order to recognize the maturity of the fruit.

For the results of the maturity recognition network, the prediction of probabilistic category and 4 independent numerical variables (humidity, temperature, luminosity and color) and a dependent category variable (maturity recognition) were used, we worked with a data that contained 161 records divided into two groups, one of 80 for training and testing. the other 81 records for prediction (Ramos Díaz, J. V. E., 2020).

3. Methodology

The proposed methodology for the research is Search Learning, which describes the research process that has as its main objective to develop a system of classification and detection of tomatoes, discarding physical anomalies. The research describes techniques and processes applied to the classification of tomatoes, as well as the use of tools that allow the study of physical anomalies that this fruit may present (See Figure 1).

Figure 1 Search Learning Methodology



Source: Authors' Own Creation

3.1. Define the type of research

The type of research is practical, since based on the processes applied in the research, a solution will be given to a specific problem, in this case, a system will be developed that allows classifying and detecting physical anomalies in the tomato fruit making use of current technologies such as Machine Learning and the implementation of some devices such as colour.

3.2. Define the research design

The research is based on the comparison of the physical or color properties of the tomato, which allows us to identify its state of maturity in unripe, ripe and rotten. The influencing factors that make it difficult to identify the state of the fruit are the quality of the environment, within this are the level of luminosity, humidity, temperature and the state of the soil.

3.3. System implementation

The classification system will be implemented in a fixed place, this place will be the place of study for the plant and the fruit, which will allow the corresponding field tests to be carried out.

3.4. Identification of Variables

The variables involved in the study are:

- Environment variable: Humidity, temperature, luminosity and color.
- Intervening variable: Tomato classification algorithm.
- Dependent variable: Identification of tomato status (ripeness).

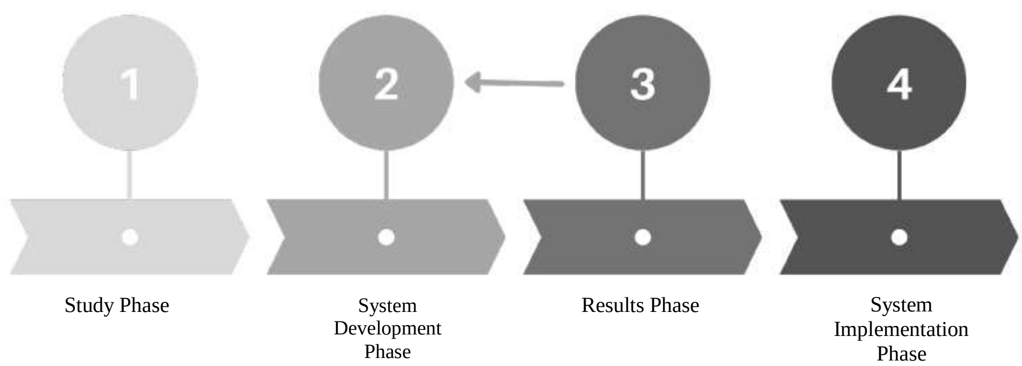
3.5. Data collection

Population and sample: The tomato population to be studied will be taken from the greenhouse dedicated to the cultivation of tomatoes. For the samples, groups of tomatoes in various conditions and states will be selected to obtain detailed information that will help generate an evaluation and classification according to their condition.

3.6. Design of the research system

The methodology used is divided into 4 subphases (See Figure 2).

Figure 2 Phases of research system design



Source: Authors' Own Creation

Study Phase

In this first phase, a one-week field study will be carried out in which data will be obtained on the state of the tomato in various conditions so that later, taking into account these conditions, these data will be obtained conditions, can be implemented in the next phase, which is the development of the classification system.

System Development Phase

In phase 2, the classification system will be developed to detect the physical anomalies of the tomato. To this end, an algorithm will be developed to classify the state of the tomato according to the information it receives from the sensor and thus be able to classify it. To program the sensor, the Arduino board will be used.

Results Obtaining Phase

In phase 3, the results obtained in one week of the operation of the system will be taken into account in order to detect failures, possible improvements or, in case of satisfying the classification needs, to be able to approve it. If this is not the case, you have to go back to the previous phase to verify which procedure was done wrong and to be able to improve it.

System Implementation Phase

In phase 4, the system will be implemented in the greenhouse once it has already met the acceptance level and the error rate is minimal.

3.7. Data analysis

At the end of the collection of results, tables will be generated that show the results of the field study and in this way classify the data to generate graphs that allow representing the percentage of predictions to obtain the failure and error rate of the system.

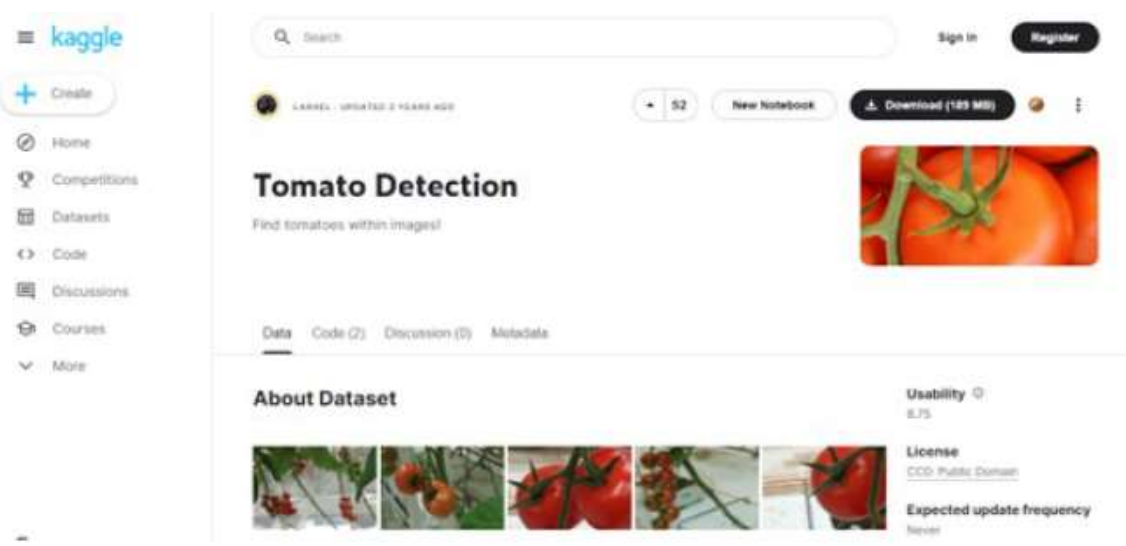
4. Development

4.1. Downloading the Dataset

The development begins from phase 6 of the methodology, this phase is called Data collection and is based on the implementation of the dataset to create the model that addresses the problem raised in the research and is also capable of detecting objects based on the parameters of the tomato fruit such as its color.

To acquire the dataset, the Kaggle web platform was used, since it has a fairly large Data Science community in which users publish their dataset to contribute to the community belonging to it. The dataset that was used is called Tomato Detection, which was published by user @LARXEL. This dataset has 895 images of tomatoes licensed to use. To visualize the interface, see Figure 3 which shows the name of the dataset, as well as the user and some images belonging to it.

Figure 3 Dataset Tomato Detection



Source: Authors' Own Creation

4.2. Training tools

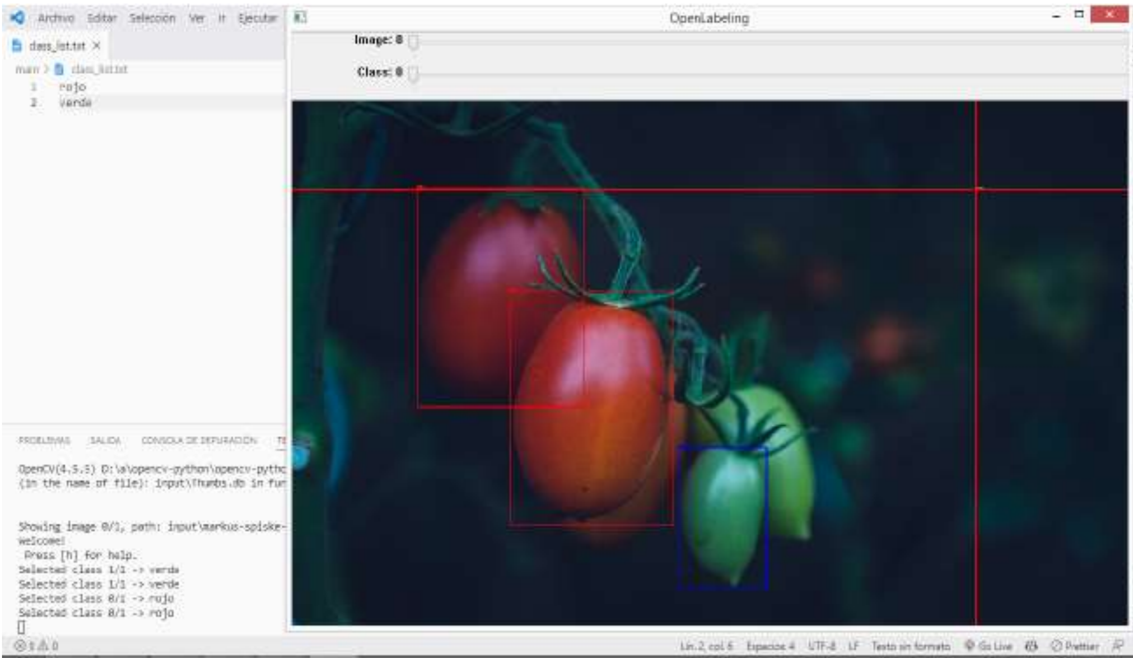
Three tools were used to train the model: Python. TensorFlow. Google Colab.

Python was used as a programming language, as it is widely used within Artificial Intelligence and can be used with TensorFlow. On the other hand, TensorFlow was also used to create the machine learning model, as this tool is based on the Keras API standard for neural network training. Last but not least, Google Colab was used, which allows you to run and program in Python from the web browser and use GPU and CPU of a cloud computer for free without the need to install anything extra.

4.3. Image Tagging

For the creation of the model, the images obtained from the dataset of the Kaggle platform were labeled. This labeling was necessary because it is based on this labeling that the images are classified to be assigned to the corresponding model layer. The labeling contains the class name and the outline box of the fruit, as shown in Figure 4.

Figure 4 Image Tagging



Source: Authors' Own Creation

4.4. Model training

For the training of the model, Mobilenet V2 SSD was used, which is a family of neural networks, which is designed for the detection and execution of deep networks in mobile devices, providing security and privacy to the user who uses it.

4.5. Learning Transfer

To train the model, the learning transfer technique is used, which seeks to use the architecture of an already created model and change only the first layer, which receives the class to be classified and then be able to make use of all the hidden layers. Figure 5 shows the training of the model, in this one you can see a path, this path has the PIPELINE CONFIG PATH parameter which indicates the path of the configuration file; MODEL DIR is the storage location of the training model; NUM TRAIN STEPS is the total number of training steps; SAMPLE 1 OF N EVAL EXAMPLES is the sampling frequency of the sample during the verification process, if it is 1, it means that all samples will be checked, usually set to 1. After the script file is generated, execution is initiated via sh train VOC.sh.

Figure 5 Learning Transfer

Source: Authors' Own Creation

4.6. Model exported to TensorFlow Lite

The model was exported to a TensorFLow Lite file from a normal TensorFlow model, it was done this way, since this is a lightweight file type (FlatBuffer format) that allows mobile devices to run them. In addition, the Python API was used, which facilitates the conversion of models to optimize them. Figure 5 shows the lines of code that were used to generate the .tflite file.

Figure 6 Exported model

Source: Authors' Own Creation

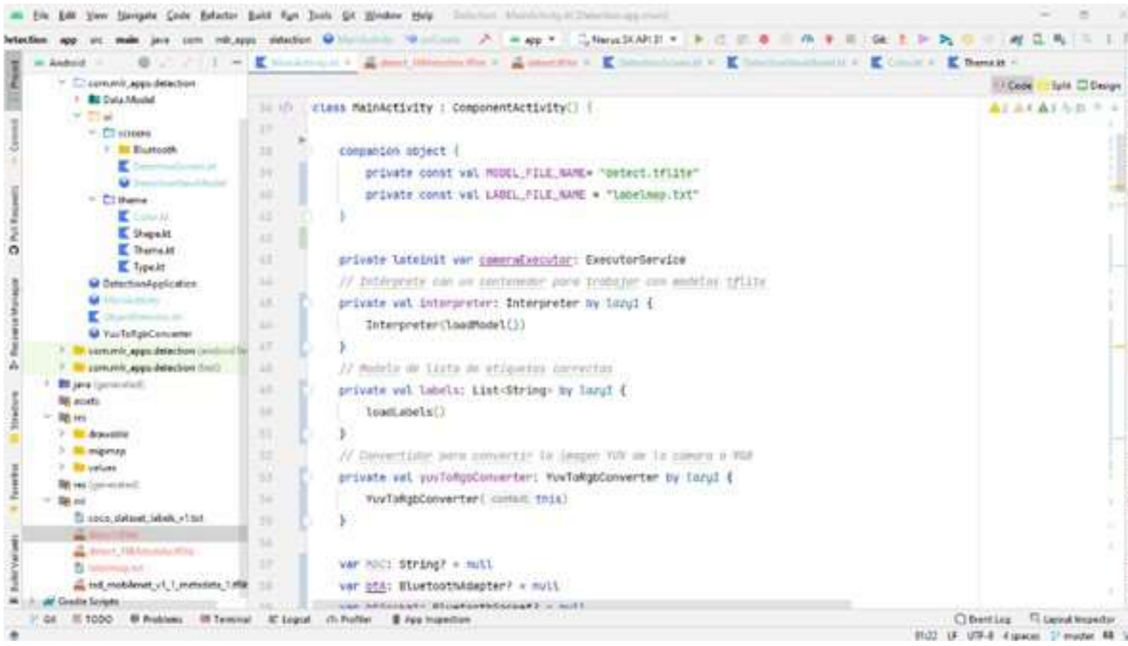
4.7. Programming tools

For the implementation of the model within the mobile device (cell phone), some tools were used, including: Kotlin TensorFlow Lite C++ Kotlin was used as the programming language to generate the mobile application that will allow the implementation of the model generated with TensorFlow Lite. We chose to use this language because it allows us to develop applications on the Android operating system and also allows us to develop graphical interfaces. In addition to this tool, TensorFlow Lite was also used, which allows machine learning models to be implemented on mobile devices and microcontrollers, this tool was used in the model previously generated with TensorFlow to later convert it into a compressed FlatBuffer file and thus generate the final file with .tflite extension, once compressed the model is loaded on the mobile device. Finally, the C++ programming language was also used to program and execute code in Arduino, the latter is in charge of controlling the tomato sorting mechanism physically.

4.8. Mobile App Development

The mobile application was programmed in the Kotlin programming language, figure 7 shows a snippet of the application's code, in this snippet you can see the use of the detect.tflite file that contains the model generated in TensorFlow as well as the file that has the labeling information of the images in the dataset. In addition to this, you can also see the lines of code to make use of the camera of the mobile device so that the tflite model can be used to be able to convert the YUV images into RGB from the input of the same through the camera.

Figure 7 Application Development

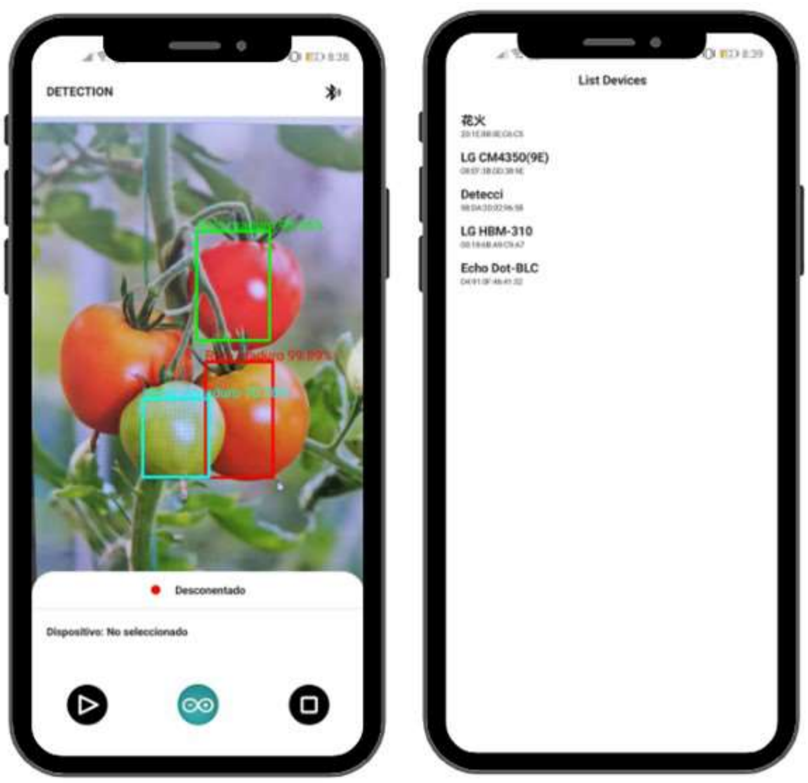


Source: Authors' Own Creation

4.9. Graphical Interface View

The view of the graphical interface is shown in figure 8, this interface has a display which shows the data input that the camera and frames the tomatoes according to the layers of the model, in addition to this it also has 4 buttons, the buttons at the bottom are buttons that allow you to start and pause the system as well as connect to the Arduino, The button at the top right allows you to open the interface to select the Bluetooth device you want to connect to so that the connection to the Arduino can be made.

Figure 8 Graphical Application Interface



Source: Authors' Own Creation

5. Results

The searches carried out to detect physical anomalies in tomato vegetables, taking as their main characteristic the color of the fruit, is one of the methods that has taken great interest to be optimized at the local level, since farmers do not have enough resources to have the new technologies for the harvesting and classification of these fruits. Therefore, the study of techniques based on artificial vision suggests an optimal way to carry out the analysis of the images of the fruit, however, it suggests having solid knowledge to be able to implement this technique. On the other hand, the use of neural networks and probabilistic studies to determine the level of maturity of the tomato begins to represent an effective way to determine if there are defects in the fruit without making use of an image analysis but of the fruit. Finally, the use of image processing with Open Cv and Matlab also suggests a more economical way with a less steep learning curve than the other techniques.

Conclusions

The review of research articles referring to tomato detection and classification systems taking into account the physical anomalies of the fruit, it is concluded that currently the tomato fruit plays a fundamental role in the food industry, since it is frequently used in homes for the preparation of food and some by-products such as tomato sauce. ketchup, tomato paste, etc.

For the production of the fruit, some aspects are taken into account such as the physical changes that occur in the environment where it develops, one of these aspects is the temperature of the environment, since the tomato has climacteric characteristics, that is, it can continue to ripen, even if it has already been cut and for this reason tomatoes that have already been cut are more sensitive to low temperatures.

Both manual and mechanical processes are used for the treatment and classification of the fruit. For the manual classification processes, the work of trained personnel is used for the manipulation and identification of the state of the fruit, in this way the staff classifies it into ripe, rotten and cooking state.

The quality of the fruit is greatly influenced by the way in which it is handled and the ability of the workers to identify the physical defects that it may have. The disadvantage of manual sorting is that after a while it ceases to be efficient due to the wear and tear generated by the workers. On the other hand, mechanical sorting is more efficient in terms of work and time, since, as there is no physical wear and tear on the part of the workers, the sorting can increase, but the disadvantage of this process is that it is not accurate, since the algorithms developed to identify the physical state of the fruit have some limitations depending on the physical conditions of the environment, such as the level of light. humidity and the quality of hardware used.

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