Tiny Machine Learning for Classifying Specialty Coffees

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***Abstract*—The consumption of specialty coffee has increased around the world. Specialty coffee is free from impurities and defects. Specialty coffee is produced in smaller quantities and its production process is much more laborious and expensive. Traditional coffee beans have defects that you affect the flavor of the coffee. It is essential to correctly select the type of coffee to guarantee the best cost and quality. When a human manually classifies the type of coffee, there may be interference due to the human condition. This process has the disadvantage to be subjective. There are few studies that used Machine-Learning methods for predicting specialty coffee classification by analyzing images. This article proposes a framework for classifying specialty coffees, applying Tiny Machine-Learning techniques. We development a model that can help analyse the classify coffee process accurately and inform the degree of coffee quality without human interference. We achieved 100% accuracy, and we believe that our model can be used systematically and efficiently in the coffee industry.**

***Index Terms*—Artificial Intelligence, Tiny Machine-Learning, Classification, Coffee**

I. Introduction

The importance of coffee classification is linked to the fact that coffee is one of the most popular and appreciated drinks around the world, with an industry that generates billions of dollars annually. According to Brazilian Coffee Industry Association (ABIC), it is estimated that coffee industry sales in 2022 reached 100 billion of dollars, an increase of 54.6% compared to 2021. Also according to ABIC, the volume of Brazilian coffee exports increased by 4% between 2021 and 2022. More than 34,000 bags of specialty Arabica coffee were exported in 2022 from Brasil [1]. According to the Brazilian Ministry of Agriculture and Livestock, the price of Arabica coffee increased by 88% compared to 2020 [2].

Coffee classification is a fundamental role in determining quality, market value and identifying the sensory characteristics of the drink. Over the years, coffee classification has evolved, being influenced by factors such as the growing demand for specialty coffees, the search for more objective evaluation methods and the need for standardization of international trade.

Coffee classification is based on visual and physical criteria, such as size, shape and color of the beans. The industry has developed different classification systems and methods to meet its needs, establishing quality parameters and facilitating communication between the links in the coffee production chain.

In Brazil, one of the main coffee producing countries, the classification system known as “Peneira” was implemented. In this system, the grains are separated according to size and a visual analysis to identify possible defects.

Defects and impurities in coffee beans reduce their quality, as defective beans affect the flavor of the coffee and, therefore, devalue it and affect the producer’s profitability. Several factors can cause these defects, such as problems in production and storage and physiological and genetic changes. The identification of defects makes it possible to improve management and prevent the occurrence of these defects, which depreciate the coffee.

According to Normative Instruction Number 8 of the Brazilian Ministry of Agriculture and Livestock [3], the criteria for classifying the type of coffee, specialty or traditional, are: the species, the shape of the bean, the granulometry, the aroma and flavor, the drink, the color and the quality. Table 1 indicates the classification criteria according to the aroma and flavor of the coffee.

TABLE I
ARABICA COFFEE CLASSIFICATION

Groups	***Subgroups***	***Description of Aroma and Flavor***
Specialty Coffee	Strictly soft	Extremely smooth and sweet.
Specialty Coffee	Soft	Pleasant smooth and sweet.
Specialty Coffee	Just soft	Slightly sweet and smooth, without astringency.
Specialty Coffee	Hard	Astringent and harsh, without strange flavors.
Traditional Coffee	”Riada”	Light typical iodorfomic flavor.
Traditional Coffee	”Rio”	Typical and sharp iodoform flavor.
Traditional Coffee	”Rio Zona”	Very strong aroma and flavor of iodoform or phenol.

This study takes into account the criteria of bean shape, particle defects, impurities, size and color to classify the type of coffee: Specialty and Traditional.

Specialty coffees go through a more laborious production process and require special care from planting to roasting and are made up of pure, unmixed, high-quality coffees. The traditional coffee has inferior and defective beans. This mixture reduces the quality of the coffee as it changes its flavor and reduces its cost. The difference between specialty coffee and traditional coffee can be seen in Figures 1 and 2.

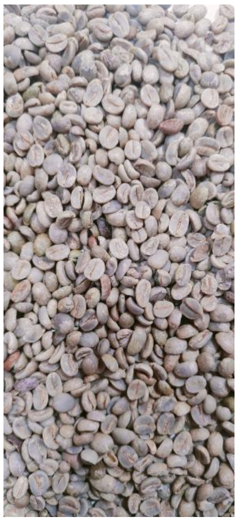

Fig. 1. Example of Specialty Coffee.

Fig. 2. Example of Traditional Coffee.

Artificial intelligence (AI) can help farmer in many aspects in the coffee market [4]. AI has been extensively researched in recent decades and has proven to be important and efficient in people's daily lives.

One of the uses of AI that has helped several areas is the classification of images using patterns [5]. Artificial Neural Networks (ANNs) are based on the structure of a biological brain [6]. ANNs work through several connections that symbolize inputs and outputs and information is processed throughout all layers. ANNs have characteristics that have attracted the attention of researchers, such as the ability to map input patterns to associate them with output patterns.

Image classification is done through ANNs that are trained to find patterns. For training with ANNs to have the desired effect, it is necessary to exclude the characteristics of the objects that will be analyzed, and then classify these characteristics into patterns. To perform image classification, it is necessary to annotate characteristics to the annotated classes.

The objective of this article is the development of a specialty coffee classifier, using Edge Impulse platform. The classifier developed in this article can be embedded in both microcontrollers and smartphones, using Tiny Machine-Learning technique.

II. Background

A. Tiny Machine-Learning

Tiny Machine-learning (TinyML) is an emerging area of artificial intelligence where machine-learning algorithms are implemented in systems with low computational power, such as smartphones and microcontrollers, to perform automated tasks [7]. This is a movement that can benefit the creation of low-cost devices and popularize them. Most research on tiny focuses on CNN networks.

Convolutional Neural Network (CNN) is a machine-learning model used to extract features in various computer vision tasks like image classifications.

The advantages and motivations for building a classification model based on tiny techniques are: local device intelligence, distributed computation, energy consumption and flexibility [8].

III. Related Works

Few studies in the literature classify specialty coffee beans. [9] classifies green coffee beans in different regions of Brazil as specialty or traditional. Coffee samples were collected from different regions of Brazil and a multispectral camera captured images of the beans at different wavelengths. Four machine learning models were used (SVM, KNN, RF and MLP). The SVM model obtained the best performance, with an accuracy of 97.5%, followed by MLP with 96.9%, RF with 95.6% and KNN with 94.4%.

IV. Material and Methods

The project is positioned in the Experimental Development stage, whose main objective will be to test the proposed solution in the laboratory and validate the idea in a systematic and practical way.

A. Edge Impulse

Edge Impulse is a Software-as-Service (SaaS) platform created in 2019 to facilitate the development of machine learning projects using edge computing [10]. Users can develop Tiny Machine-Learning projects in a user-friendly environment. After training the project on Edge Impulse, users will be able to load the model on a microcontroller or on a smartphone.

B. Roboflow

Roboflow Platform that can be used to annotate the images for this work [11]. It is an online platform that allows you to create computer vision models using Artificial Neural Networks and Deep Learning techniques. Using the Roboflow framework, it is possible to train a neural network to recognize any object in real time.

Roboflow uses the 'You Only Look Once' (YOLO) algorithm to recognize objects in images/videos, which consists of creating labels (annotations) on the objects that you want to identify. YOLO is a popular annotation format and there are several variants of the algorithm developed for real-time object identification.

C. Data acquisition

The data acquisition phase involved the acquisition of images from the field using a high-resolution digital camera and with the help of a coffee specialist who helped in identified the types of coffee. In total, 109 image coffee beans were collected.

Arabica coffee samples were collected in the city of Santa Rita do Sapucaí, Minas Gerais, Brazil.

D. Labeling

All images were annotated to create "specialty" and "traditional" classes using the Roboflow platform. Image annotation is the process of attaching predetermined class labels. The model used a database with 298 images after data augmentation techniques.

E. Data pre-processing

Data augmentation techniques was done on the images in order to transformer the dataset into a larger set of data. The data augmentation techniques that were used in this work include flipping, cropping, and shearing. Flip was done horizontally. In the case of crop, an 20% maximum zoom was used. Shear added variability to perspective to help your model be more resilient to camera and subject pitch and yaw. Saturation was not used because this feature changes the color of the images. Figure 3 below show an example image after data augmentation.

F. Model Creation

To identify the type of coffee, it was necessary to create a Artificial Intelligence that identifies specialty coffee and traditional coffee through photos. Edge Impulse platform was used to creation the model.

After accessing the Edge Impulse Platform, it was created the project in developer mode. Developer mode has some usage limitations, such as working time and data size. After the project created, it is defined what the types of data to be worked on, which can be audio, movement, or in the case of this work, images. After defining the classification as "images", the previously created database was provided and defined the categorization of objects, "traditional" and "specialty".

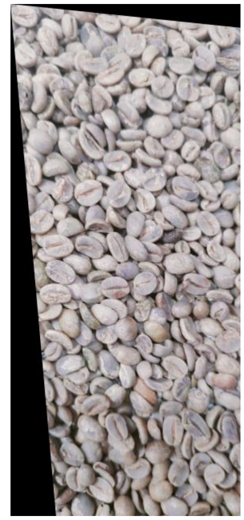

Fig. 3. Example of Data Augmentation Techniques.

G. Data Training

This phase consists of training the CNN with database collected in first phase, using Edge Impulse platform.

The first model was automatically generated by the Edge Impulse platform. This model had two 2D convolution layers. The first layer with 32 filters and the second with 16 filters. Furthermore, a dropout technique was applied to omit parts of the network and avoid overfitting. This model presented 72.9% accuracy. The confusion matrix of the first model is shown in Figure 4.

	ESPECIAL	TRADICIONAL
ESPECIAL	66.7%	33.3%
TRADICIONAL	20.8%	79.2%
F1 SCORE	0.71	0.75

Fig. 4. Confusion Matrix First Model

The second model we used the EON Tuner. EON Tuner is a Edge Impulse's feature. EON Tuner analyzes other potential neural network architectures that may perform better than the first automatically trained model. O second model used MobileNetV2 and presented 100% accuracy. The final layer has 16 neurons and 0.1 dropout. The confusion matrix of the second model is shown in Figure 5.

	ESPECIAL	TRADICIONAL
ESPECIAL	100%	0%
TRADICIONAL	0%	100%
F1 SCORE	1.00	1.00

Fig. 5. Confusion Matrix Second Model

The comparison between the two models is presented in Table II. In our first model, the the loss was 0.52. In the second model, the loss was 0.05.

TABLE II
PERFORMANCE

Model	***Training Accuracy***	***Test Accuracy***	***Loss***
Fist	72.9%	54.6%	0.52
Second	100%	100%	0.05

H. Live Classification

The Live Classification is a Edge Impulse feature that allows to test the created model in the real world using smartphones or a microcontroller. In this experiment, we use a smartphone to evaluate the model. The Figure 6 below shows the smartphone screen classifying the type of coffee in real time.

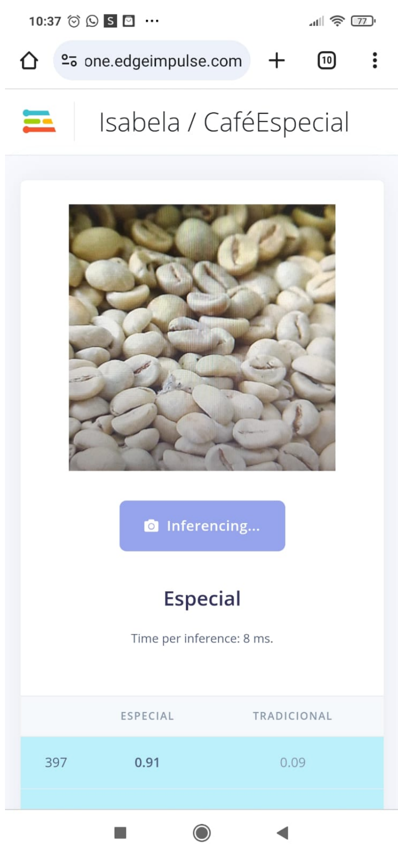

Fig. 6. Live Classification

V. RESULTS

The results of classification using the coffee beans image dataset are presented. We conducted experiments using the augmented dataset. We originally had 109 images, after augmented, we had 298 images. The dataset was divided it into two sets (i.e., training and test) with input axes 96 x 96. Therefore, the two datasets have 239, and 59 images, respectively. Note that each image has various beans, meaning that our task is not a detection problem, but a binary classification problem on two classes (i.e., traditional and specialty).

Tiny machine learning is an ideal approach to the task of object detection in a simple, safe and low-cost way. Training the object of interest was simplified using Roboflow and Edge Impulse platforms. The final model demonstrated excellent results, such as 100% accuracy.

VI. CONCLUSION

In this work, we propose a novel framework to classify coffee beans in two classes: specialty and traditional.

Coffee classifier is, undoubtedly, one of the most essential aspects of the coffee business. Coffee has an important place in the global economy and has a huge global market size. Therefore, correctly classifying coffee is a very important task and must be taken seriously.

The methodology presented consisted of evaluating the problem of classification specialty coffees. The proposed solution was developed on the Edge Impulse platform and tested on smartphones. The results reached a value of 100% accuracy. This result confirms that the Tiny Machine-Learning can to produce excellent results.

The model that presented the best accuracy was the second model that uses the MobileNetV2 architecture.

The proposed methodologies for classifying coffee can be applied to assist farmers in detection of the coffee type and in making decisions for the best time to sell coffee.

However, it is possible to further improve the results found by adding more training and testing examples. In the future we will try to collect more data from coffee beans with the aim of identifying multi-classes: Soft, Just Soft, Hard, ”Riada”, ”Rio” e ”Rio Zona”.

A limitation of the platform would be the need for Internet access for its operation. Future studies can also compare other deep learning algorithms with other pre-trained models.

We believe that the proposed model is crucial to reduce the subjectivity that exists in coffee classification carried out by humans.

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