CLASIFICADOR DE NARANJAS POR TAMAÑO Y COLOR IMPLEMENTADO EN FPGA USANDO APRENDIZAJE SUPERVISADO

Defensa de Tésis

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Universidad Politécnica de Victoria
"Construyendo Conciencia"

Outline

Orange production

According to Food and Agriculture Organization, Mexico is part of the top 5 citrus producers in the world.
Also, Tamaulipas is the 2nd citrus producer of Mexico's states.

In 2011, total production was approximately 500,000 tonnes.
Automatic fruit grading systems are needed to classify those quantities.

Computer vision and machine learning

Computer vision is the process of understanding digital images and videos using computers. It seeks to automate tasks that human vision can achieve. This involves methods of acquiring, processing, analyzing, and understanding digital images, and extraction of data from the real world to produce information.

Machine learning is the study of algorithms and statistical models, which is a subset of artificial intelligence. Systems use it to perform a task without explicit instructions and instead rely on patterns and inference.

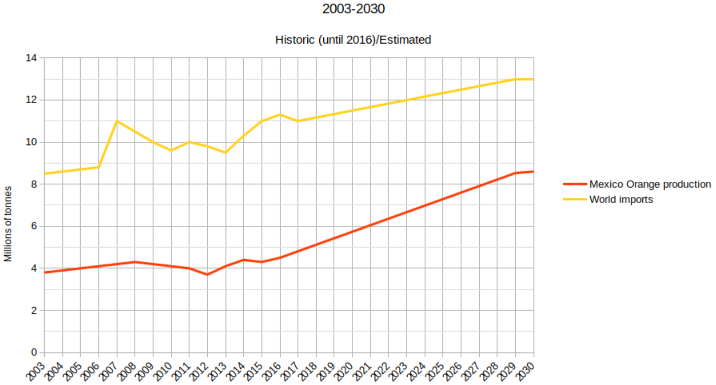
Decision trees (DTs) is a powerful and popular machine learning tool for classification and prediction.
A tree can be "learned" by splitting the source set into subsets based on an attribute value test.
Some popular algorithms for DT training are: J48, CART, ID3, C4.5 and Random Forest.

FPGA implementation advantages

The most important advanges implementing an automatic fruit grading machine in a FPGA:

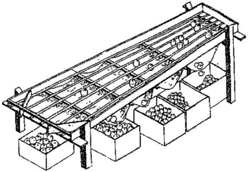
- Reduced Power consumption
- Real-time responsive
- Industrial property protection
- Reduced dimension of the hardware
- Multiple processing lines with one device

Orange offer and demand



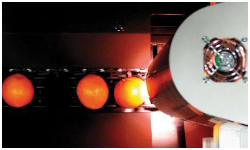
International Orange consumption / Mexico Orange Production expectation. According to Mexico's Ministry of Agriculture and Rural Development (SAGARPA).

Planteamiento del problema



(a) Mecánica

(b) Manual



(c) Automática

Figure: Tipos de clasificaciones

Planteamiento del problema

Principales problemas:

- Manejo de empleados
- Sistemas informáticos obsoletos
- Sistemas que golpean la fruta
- Inconsistencia de clasificación
- Atascos
- Lentos

Solución: Un hardware que:

- Sea fácilmente configurable
- Rápido
- Bajo uso de recursos computacionales

Objetivos

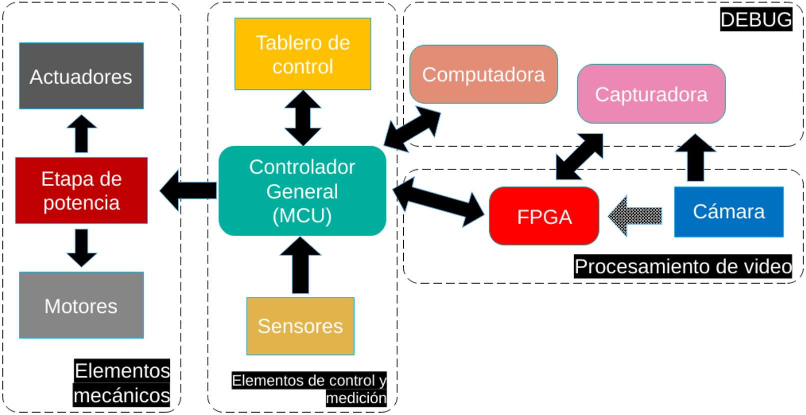
Objetivo general

- Desarrollar una implementación de hardware en FPGA capaz de clasificar naranjas con una precisión del 90% con una rapidez de 1 naranja por segundo.

Objetivos específicos

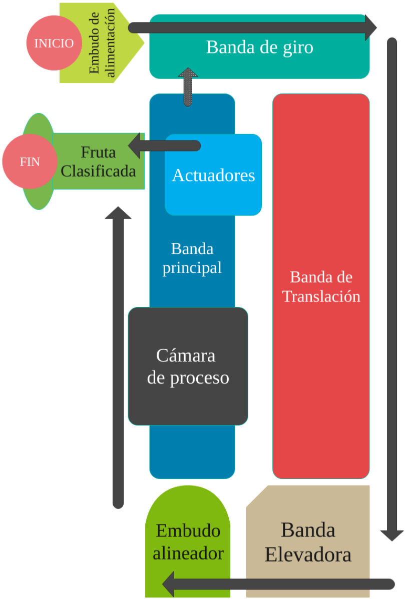
- Implementación en FPGA de un clasificador por árbol de desición.
- Implementación en FPGA de un procesador de video extractor de características.
- Implementación de hardware auxiliar para mejorar el tiempo de desarrollo (microcontrolador).

Vista del sistema

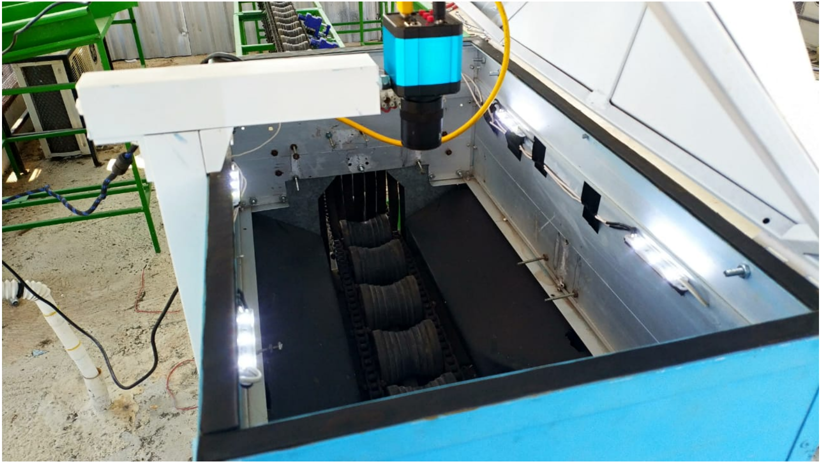


Project platform

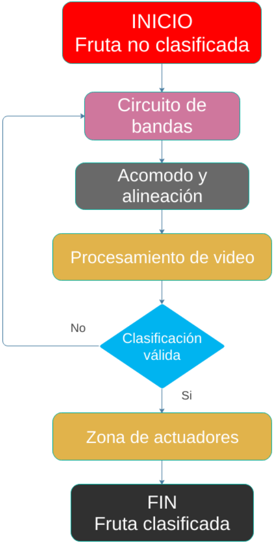
Project platform



Dark cabin



Project platform



Hardware components

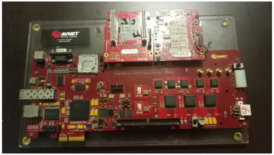
Resources.

The hardware elements used for the proposed system are:

Atmega328 μC.

Industrial camera YW2307.

Avermedia-C875.



Industrial Video Processing Kit (IVPK) Spartan6.

Software components

Resources.

The software used for the proposed system are:

- Weka(v3): used for feature analysis and model generator.
- Python(v3.6): used for text parsing, and feature analysis.
- OpenCV(v4): used for image processing and data acquisition.
- Xilinx ISE (v14.7): used for HDL synthesis and hardware debugging.
- Vivado (v2019.2): used for HDL synthesis and hardware debugging.

Project methodology

To preform this project the following methodology was implemented:

a) Decision Tree model Build (PC stage)
   1. Data set acquisition (Orange images from machine platform runtime)
   2. Segmentation
   3. Feature extraction (R, G, B, H, S, V, Gray)
   4. Data set acquisition (Pixels)
   5. Feature relevance analisys
   6. Model generation (Training and Testing)

b) Hardware modules (FPGA stage)
   1. Pixel buffer
   2. HSV conversion
   3. Grayscale conversion
   4. DT based segmentation
   5. Morphological operations
   6. Mask drawer

c) Integration
   1. FPGA segmentation recording (Capturer)
   2. Segmentation comparison and measurements

Data set acquisition procedure

1. Record video
2. Region of interest (ROI) cropping
3. OpenCV segmentation
4. Center detection
5. Automated orange image acquisition
6. Manual image classification
7. Feature extraction (HSV and Grayscale conversion)
8. Pixel data set acquisition (Segmentation vs Features)

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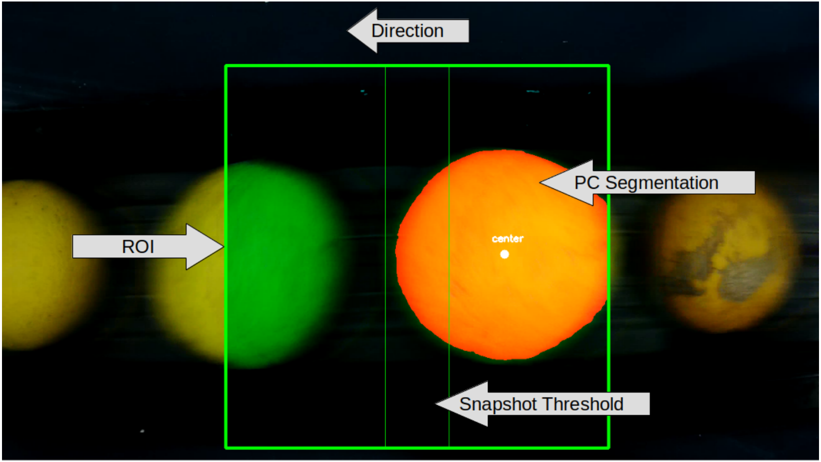
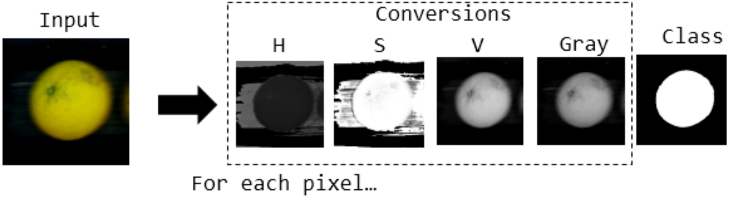
Data set acquisition (Orange images)



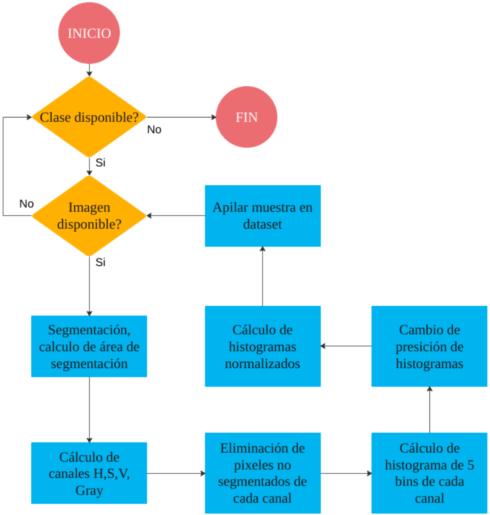
Data set acquisition (Pixels)

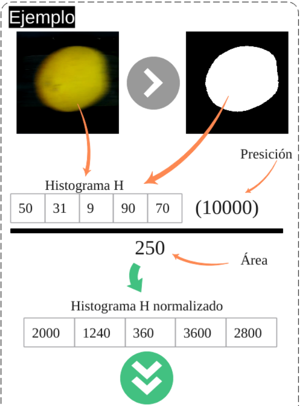
Feature extraction from every channel from RGB, HSV, and Grayscale color spaces.



R	G	B	H	S	V	Gray	Class
180	56	25	10	12	180	163	0
181	54	15	13	1	181	164	1
...	...	...	...	...	...	...	...

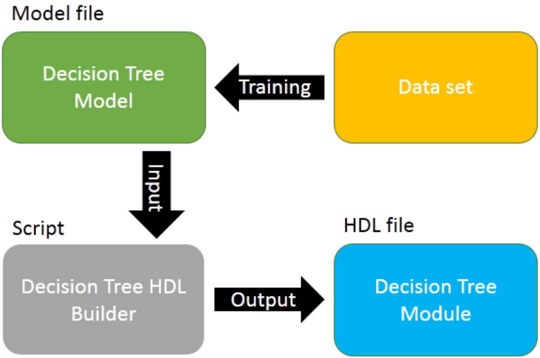
Adquisición Data set de color





Muestra	H0	H1	H2	H3	H4	Clase
1	2050	2050	0	900	5000	1
2	0	0	0	2000	8000	0
3	0	2500	2500	2500	2500	0
4	7500	500	1000	500	500	1

Model generation



Feature relevance analisys

A feature analysis to obtain the best features for building the model was performed. The following analysis were used:

1. Relative Absolute Error (RCA).
2. Correlation Attribute analysis (CAA).
3. Info Gain Attribute Evaluation (IGAE).
4. Gini impurity (GI)
5. Entropy (E)

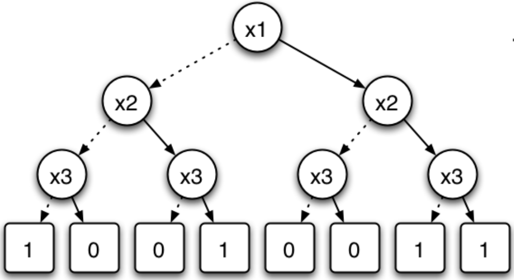
Segmentation module

The module was generated with Decision Tree HDL Builder script (SCHADD). The algorithm only can solve decision trees with binary nodes, also the output only can be binary (only can be classified 2 classes).

This approach has the following advantages:

- Reducing and mantaining the combinational path to be the same in all of its parts.
- Tree depth to be less significative, since it only needs more comparators.

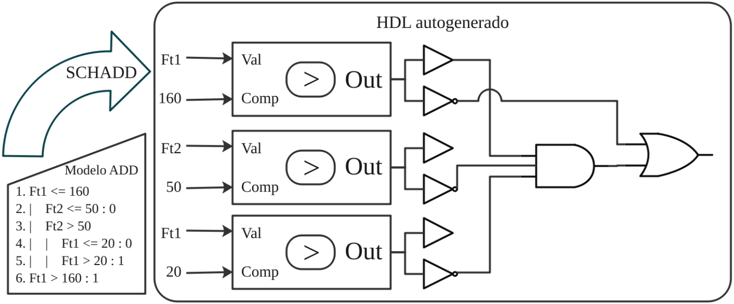
Decision Tree (DT)



x1	x2	x3	*f*
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	1

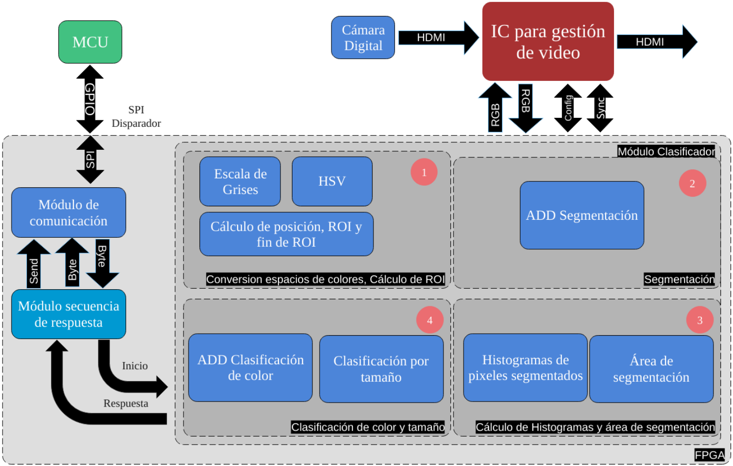
- Easy hardware implementation (only uses comparators).
- No complex arithmetic operations.
- No resource expensive.
- Can be solved as a parallel circuit (equal combinational path).

Model generation



SCHADD: Script Constructor HDL de Arbol de Desición

Arquitectura general



Data sets acquired

Resource	N. samples	Description
Video	3	Low speed (0.5 ops) (720p,60fps)
Video	3	Medium speed (2 ops) (720p,60fps)
Video	3	High speed (5 ops) (720p,60fps)
Images	1836	Oranges photos (600x600)
Images	1836	Segmented Oranges photos (600x600)
Pixels	136886	Pixel samples (7 features, 2 classes)

Videos were recorded with different speeds (measured in oranges per second or **ops**) on platform machine runtime. Images taken from videos automatically by script. Pixels taken by every image (duplicated pixels removed).

Feature relevance analysis

FEATURE RELEVANCE ANALYSIS

Analysys/feature	R	G	B	H	S	V	Gray
RAE	0.0255	**0.0194**	0.0195	0.226	0.0262	0.0166	**0.0143**
CCA	0.3211	**0.5164**	0.113	0.2362	0.0489	**0.4733**	0.4652
IGAE	0.1363	**0.2596**	0.0696	0.2004	0.1210	0.2311	**0.2370**
GI	0.1211	**0.2031**	0.1024	0.1552	0.1111	0.1387	**0.1681**
E	0.1235	**0.1909**	0.1144	0.1598	0.1167	0.1332	**0.1611**

Values shown in bold are the top 2 best values. The result shows G and Gray channels are the best features.

DT model training

TREE MODEL DETAILS

Model	Features	Validation type	Validation accuracy
M0	Gray & Hue	10-fold 70%-Test 30%-Train	83.24% 83.17%
M2	Gray & Green	10-fold 70%-Test 30%-Train	81.67% 81.50%
M4	All	10-fold 70%-Test 30%-Train	**83.52%** **83.41%**

Models tested with different feature combination. *MO* was considered the best since H channel is good for color segmentation. The training results show the best model is *M4* .

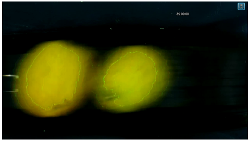
Decision Tree models

MODEL SEGMENTATION DESCRIPTIONS.

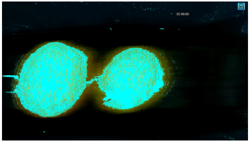
Model	Composition	Kernel size
M0	None	None
M1	M0+Closing+Dilate	7×7
M2	None	None
M3	M2+Closing+Dilate	7×7
M4	None	None
M5	M4+Closing+Dilate	7×7

Only odd number models have Morphologic operations, to get a better segmentation performance.

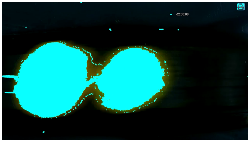
FPGA+DT model segmentation result



Sample frame.

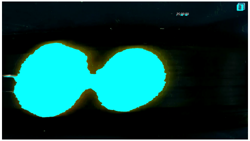


$M0$ segmentation.

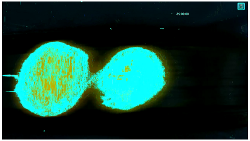


$M1$ segmentation.

$M2$ segmentation.



$M3$ segmentation.



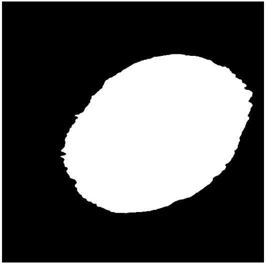
$M4$ segmentation.

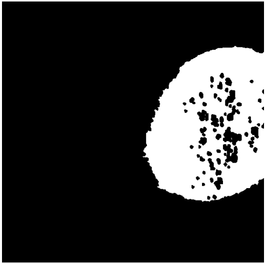
$M5$ segmentation.

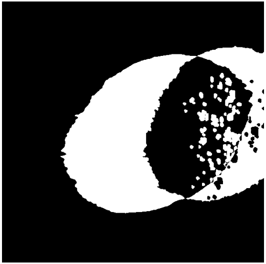
Thresholding algorithm comparison

PC segmentation | FPGA + DT segmentation | Error

Thresholding algorithm comparison shifting


PC segmentation


FPGA + DT segmentation


Error

Segmentation

MODEL SEGMENTATION ACCURACY RESULTS

Model	Samples	% Range	Accuracy
M0	145	73.61% - 96.46%	84.54%
M1	145	80.01% - 99.02%	96.22%
M2	155	87.77% - 99.18%	**97.10%**
M3	153	88.22% - 99.09%	96.64%
M4	151	70.69% - 98.76%	87.36%
M5	138	64.81% - 98.71%	94.14%

*M*2 result as the best model, according to the feature relevance analysis. *M*1 and *M*5 got better results than they non-MOM complements. Morphologic Operations models get a better result but is more important to get a model with the most important features. Different number of sample since shifting in some cases.

Model resource usage

Model	Used Slices	Usel LUTs
M0	5987 (3%)	6012 (6%)
M1	**6110** (3%)	**6111** (6%)
M2	5987 (3%)	5899 (6%)
M3	6110 (3%)	5959 (6%)
M4	5810 (3%)	5377 (6%)
M5	5988 (3%)	5588 (6%)

Almost all models uses same amount percent of the resources of the FPGA.

Clasificación de color

Naranjas analizadas: 549

- Naranjas: 475
- Verdes: 74

Aciertos: 513

- Naranjas: 445
- Verdes: 68

Presición: 93.44%

- Naranjas: 93.68%
- Verdes: 91.89%

- The proposed decision-tree model: uses very few resources, another processing line can be processed in same device.
- La clasificación por color es posible mediante modelos de árboles de decisión.
- The proposed architecture results show that the system will be able to classify 5 ops by color and size. This represents 1 fruit-ton of classified fruits in approximately 18 minutes.

Acknowledgment

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