

# PEOPLE COUNTING AND TRACKING WITH XILINX ZC702 KITS

## **SUPERVISORS**

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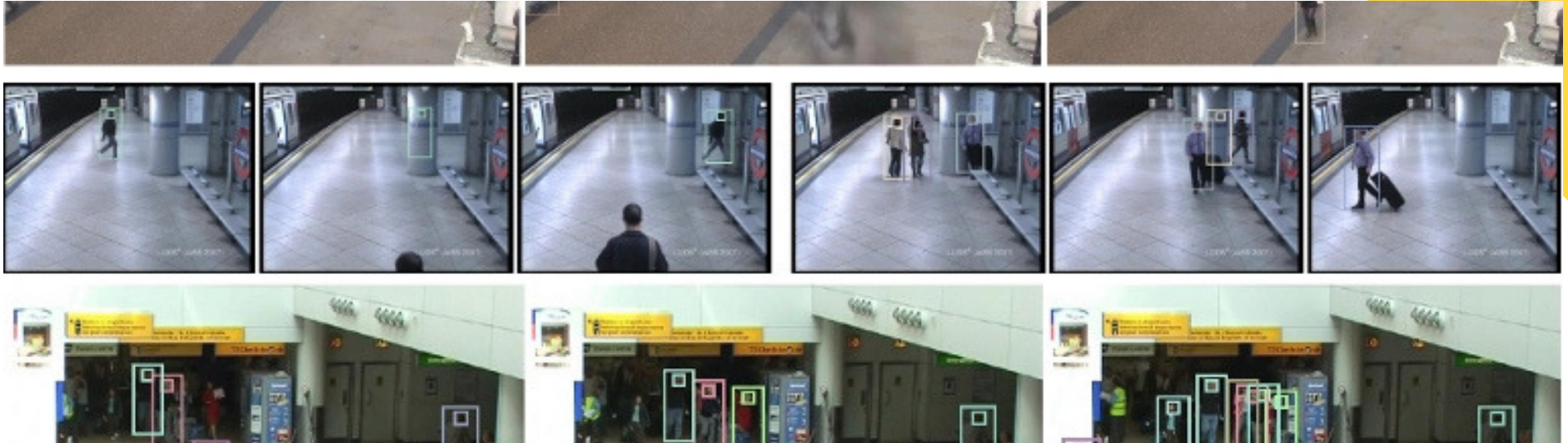
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# PROBLEM STATEMENT

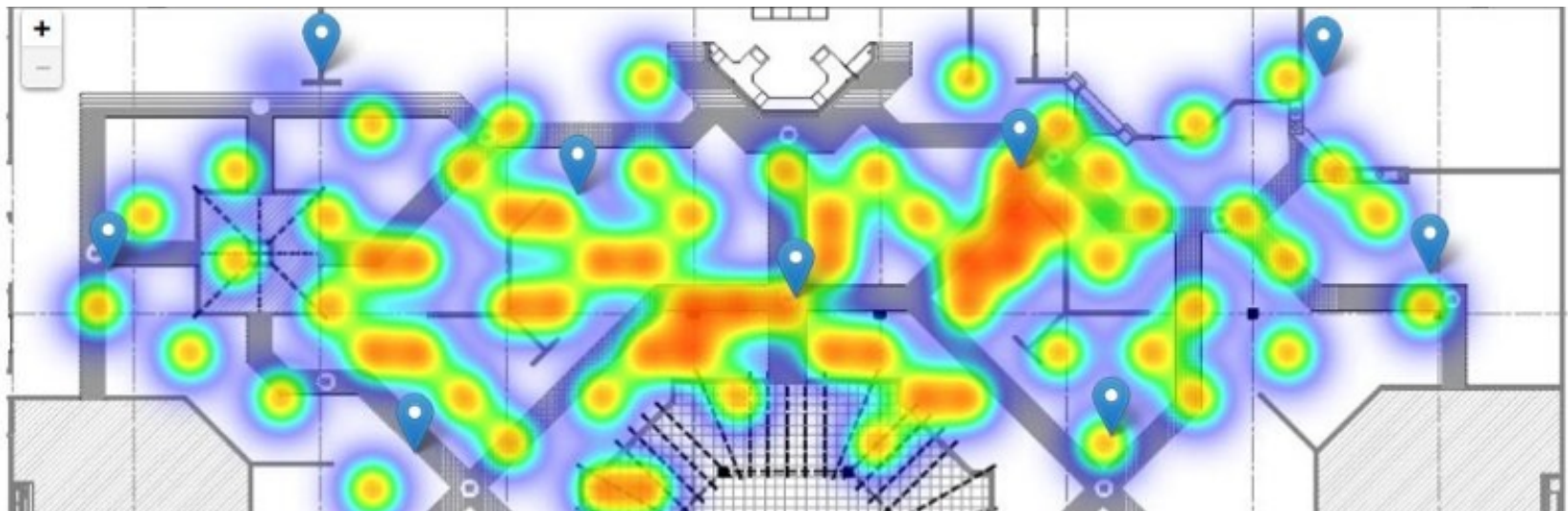


In a department store like environment, counting and keeping track of customers is a tedious task by just employing a number of cameras and a manual System.

Identifying the history of customers and recognizing areas with high customer density inside the areas of the department store can be critical for financial decisions.

# PRIMARY OBJECTIVES

- Develop a system that can count and track people moving in an environment like a department store using multiple cameras.
- Visualize the paths of the people informatively using heat maps of people density and history graph, etc.



Source: <http://v-count.com/>

# DELIVERABLES

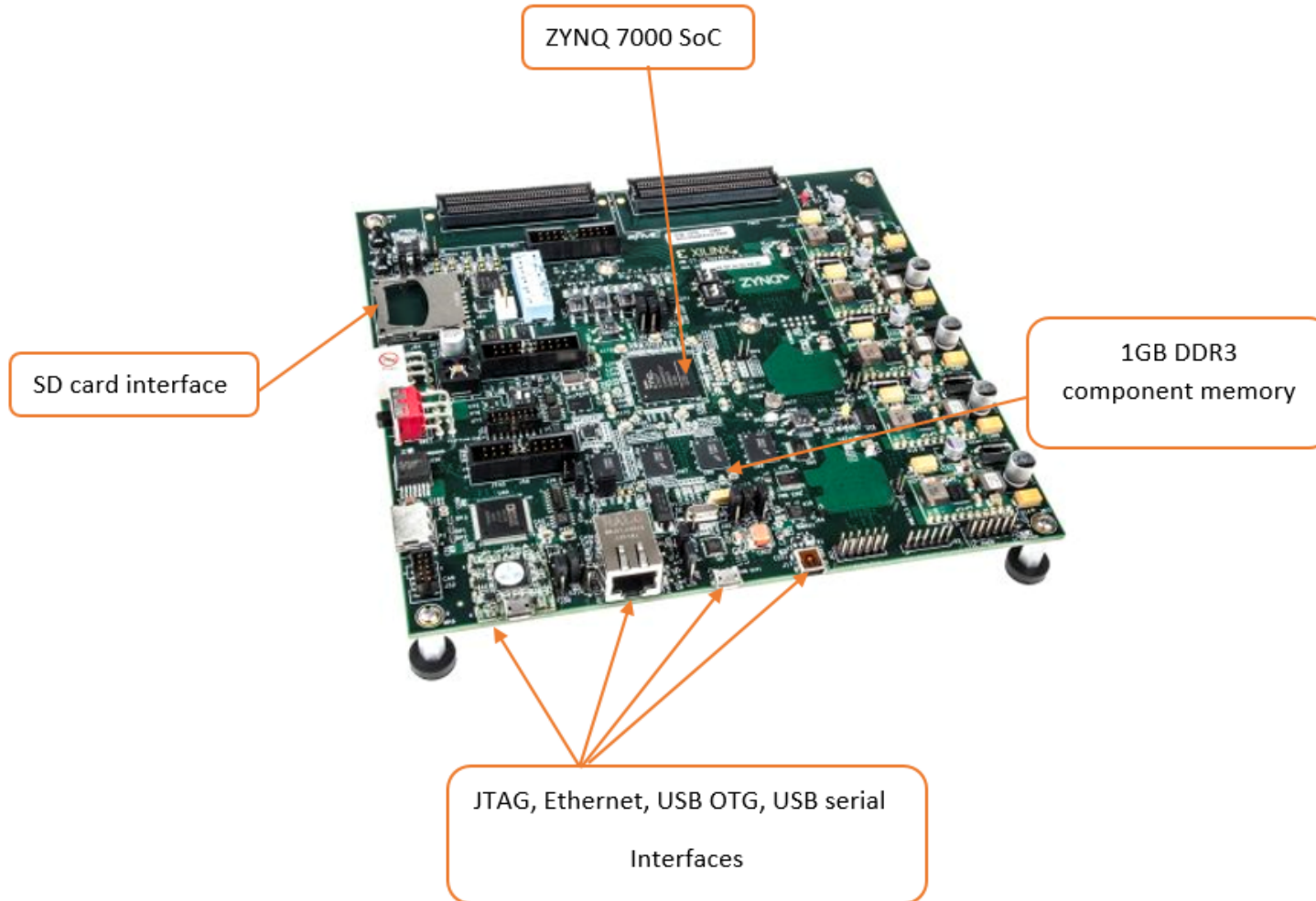
**PEOPLE DETECTION  
ALGORITHM IN  
XILINX ZC702 KIT**

**MULTI-CAMERA  
PEOPLE TRACKING**

**BUSINESS  
INTELLIGENCE  
SOFTWARE**

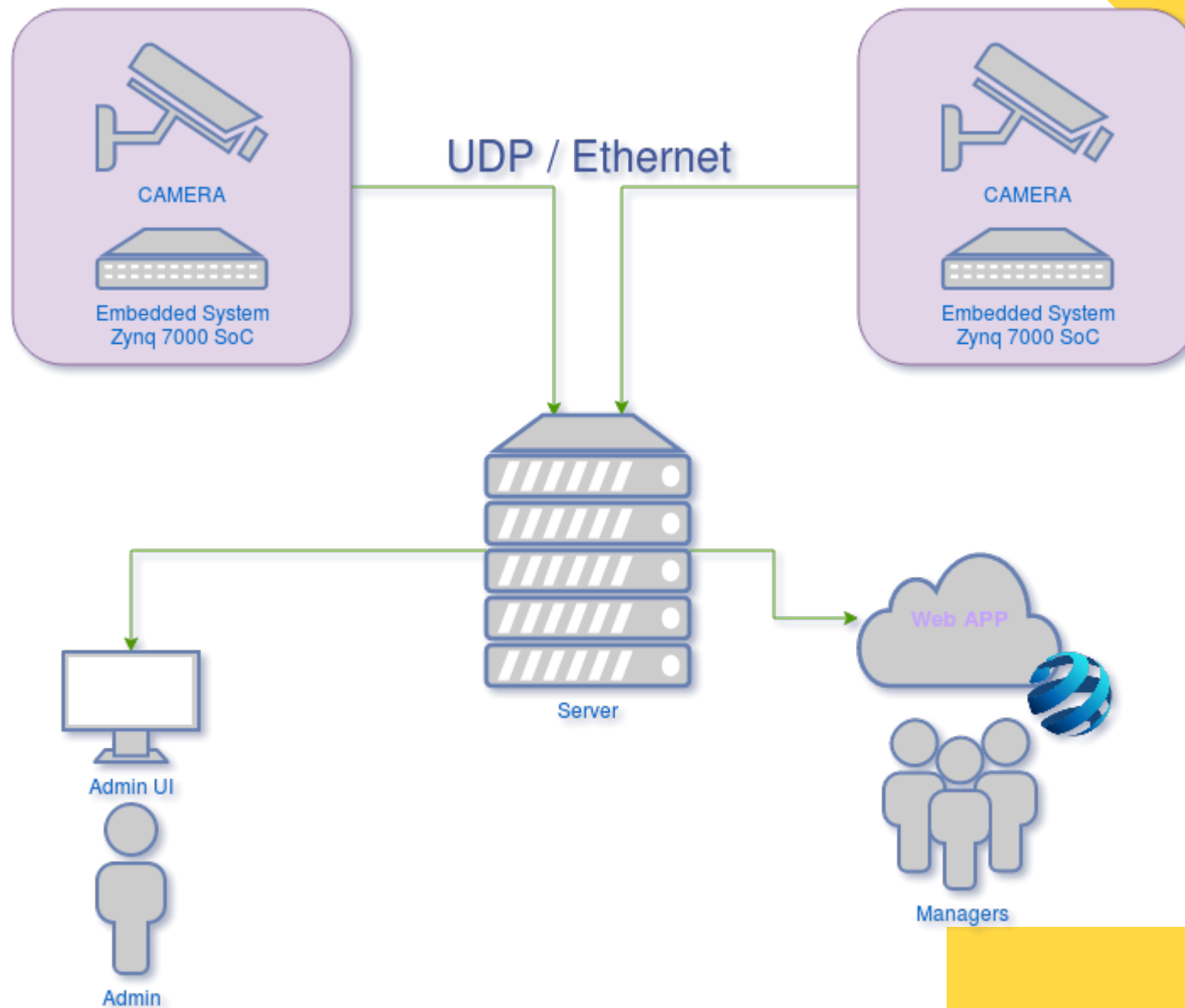
# Devices and Components Used

- Xilinx ZC702 Evaluation Kit

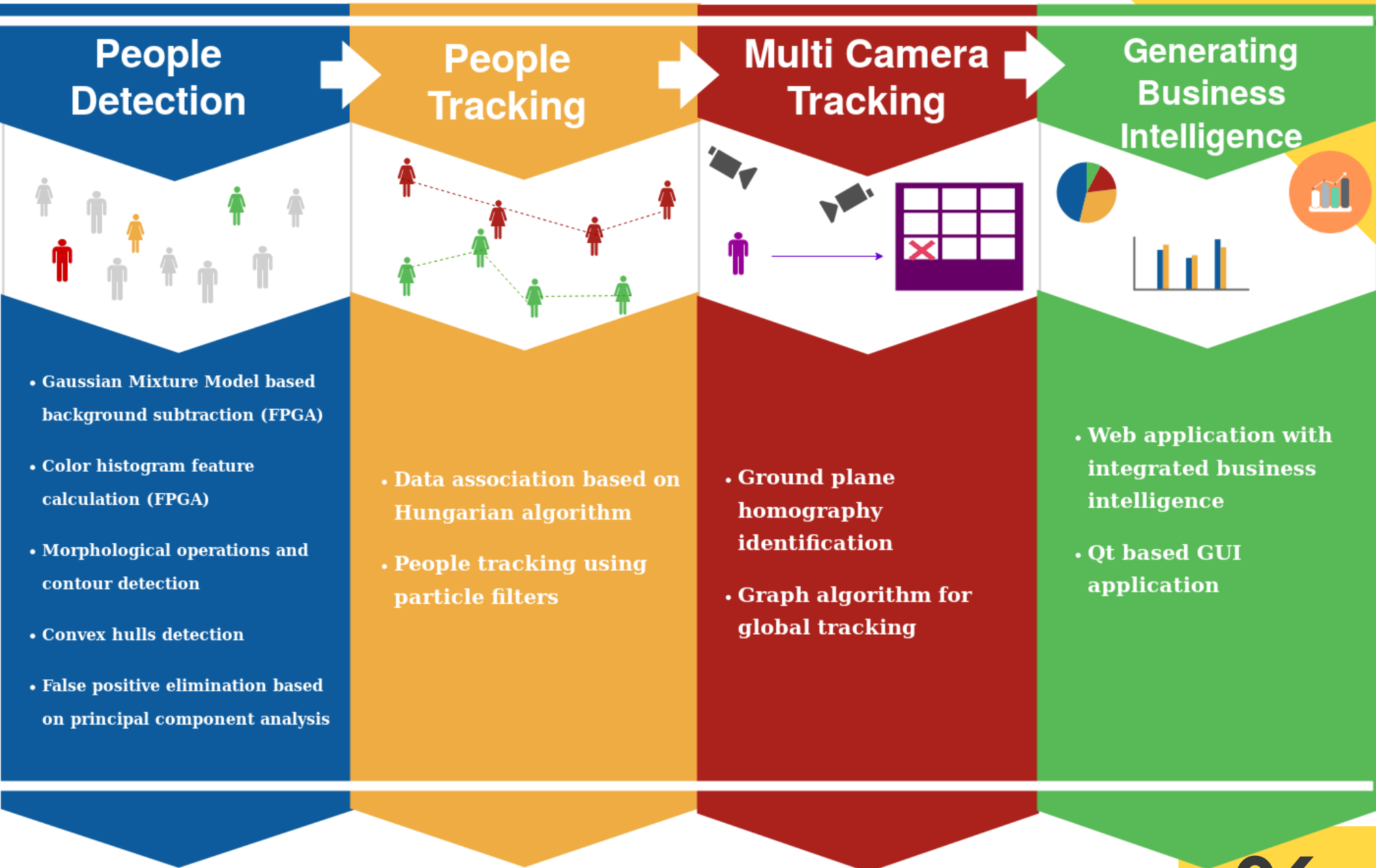


Source: <https://www.xilinx.com/>

# OVERALL ARCHITECTURE



# SYSTEM BLOCK DIAGRAM

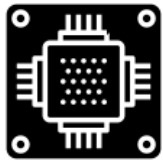


# M E T H O D O L O G Y



# LIST OF THINGS COVERED

## FPGA + SoC



- . Linux Distributions in Zynq ZC702 Evaluation Boards.
- . Generating Linux Boot files for Custom Hardware using Petalinux SDK.
- . Writing User-space Linux Drivers for Custom Hardware.
- . Gaussian Mixture Models based Background subtraction IP core
- . Feature IP core
- . People detection algorithm

## Server



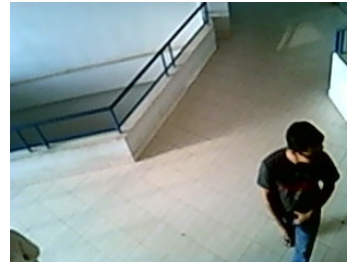
- . Building a Scalable Communication Protocol among leaf nodes and server
- . Principal Component Analysis for removing False Positives.
- . People Tracking Algorithm using Particle Filters and Hungarian Algorithm
- . Multi Camera People Tracking with Ground Plane Homography.

## Business Intelligence



- . Building Communication between the Server and Web Application using UDP Sockets.
- . Building the Web Application with integrated Business Intelligence.
- . Qt based GUI application
- .

# PEOPLE DETECTION USING BACKGROUND SUBTRACTION



Original Frame



Background Subtraction



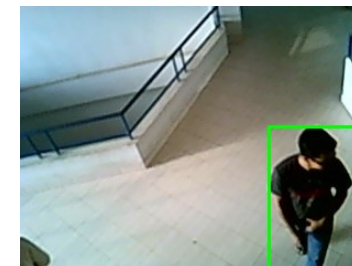
Dilation



Erosion

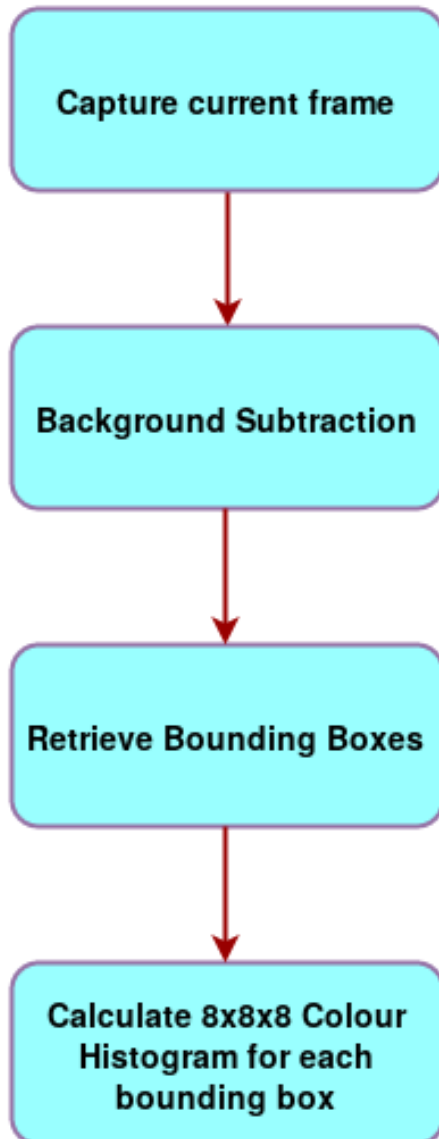


Contour Detection



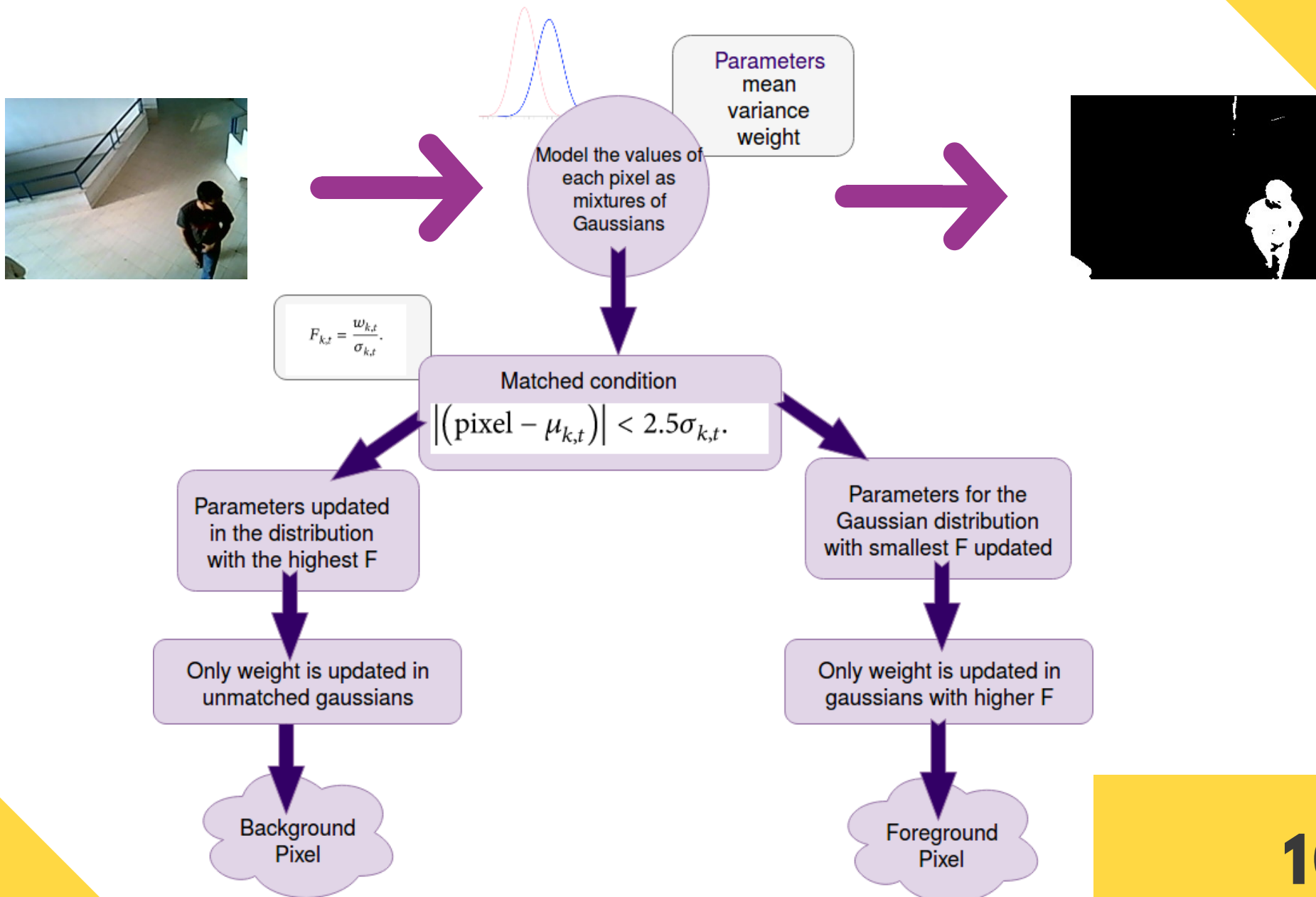
Bounding Boxes

# COLOUR HISTOGRAM FEATURE CALCULATION

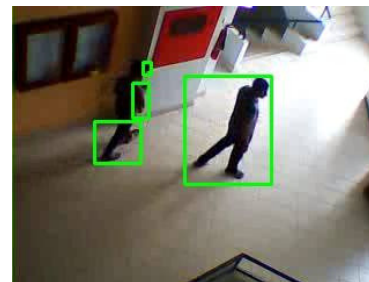
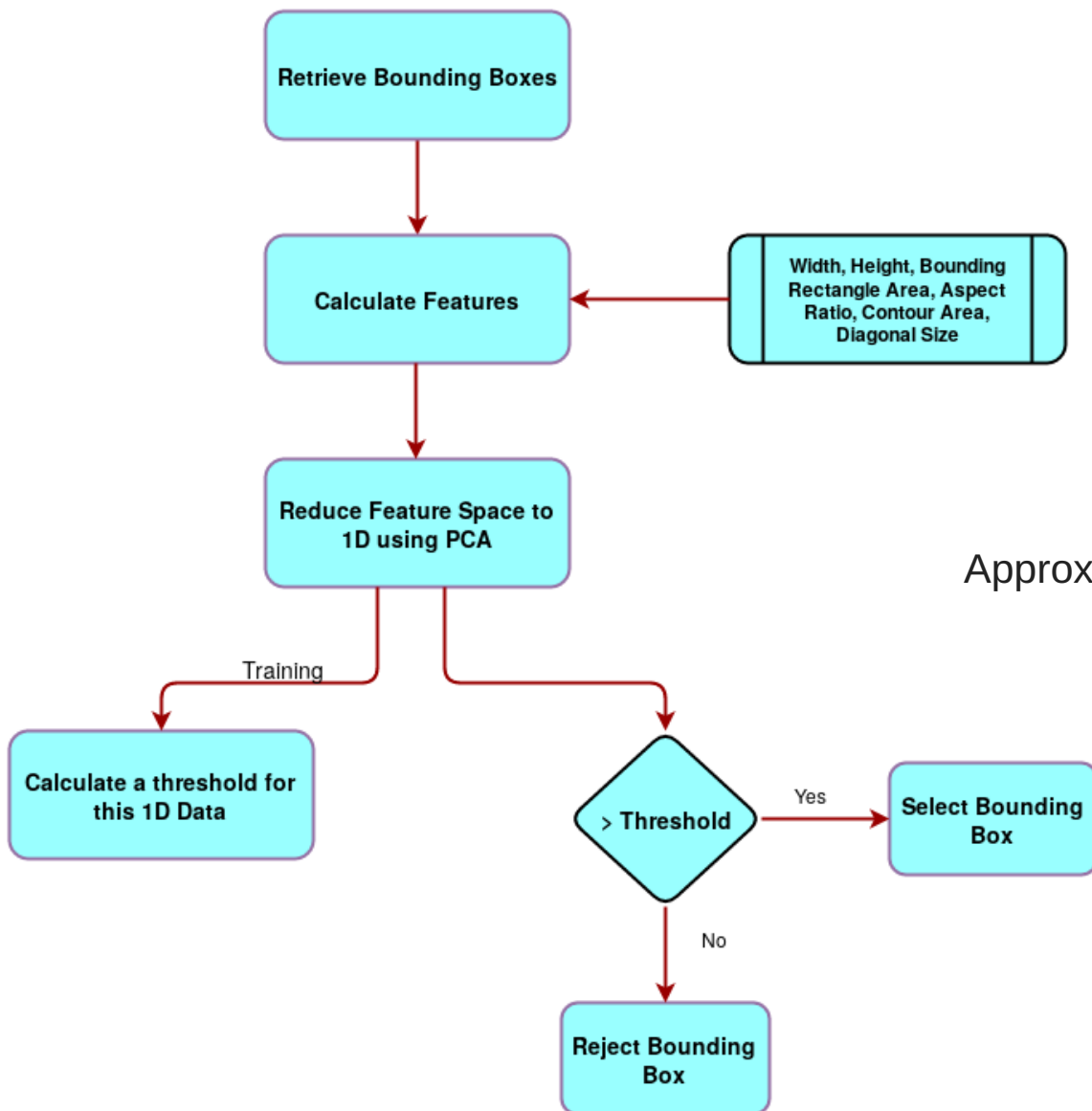


Colour Histogram Features are calculated in the FPGA for Feature calculation.

# GAUSSIAN MIXTURE MODEL BASED BACKGROUND SUBTRACTION



# PRINCIPAL COMPONENT ANALYSIS FOR FALSE POSITIVE REDUCTION



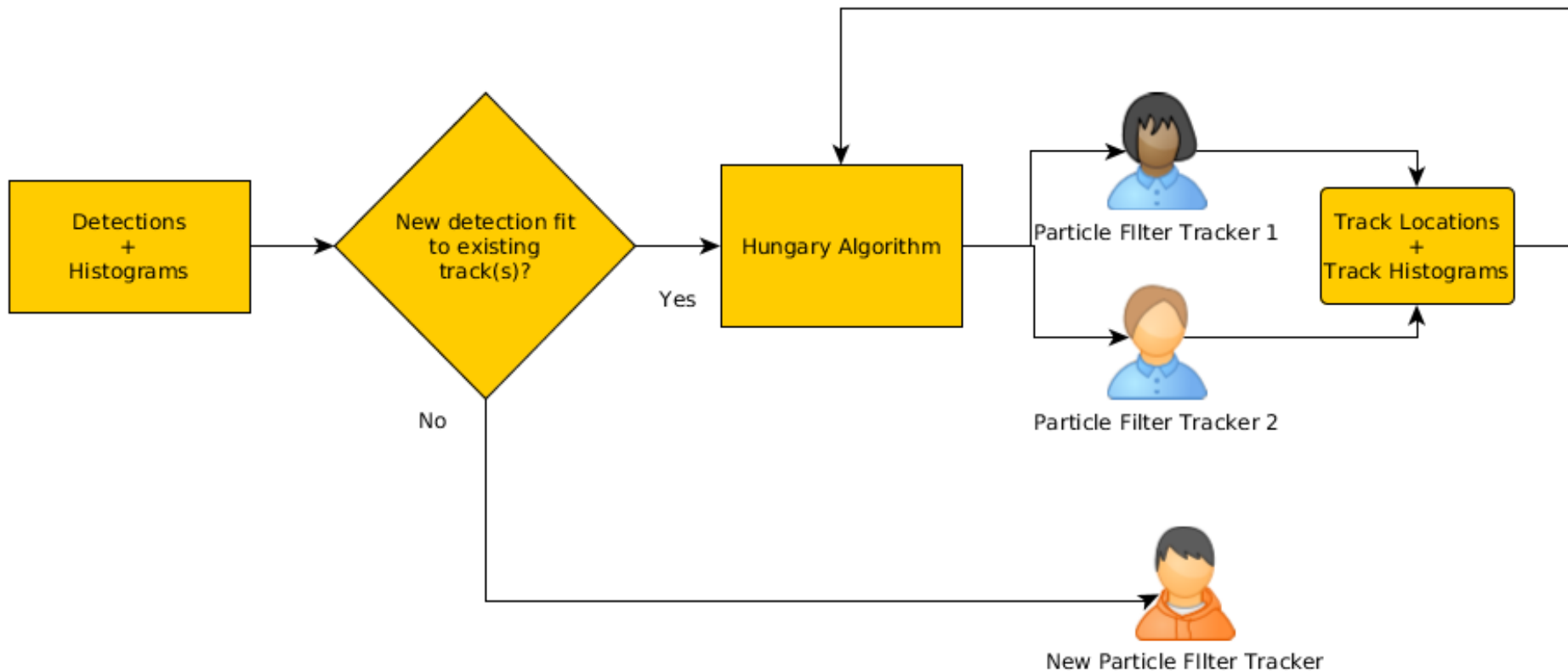
Before Training



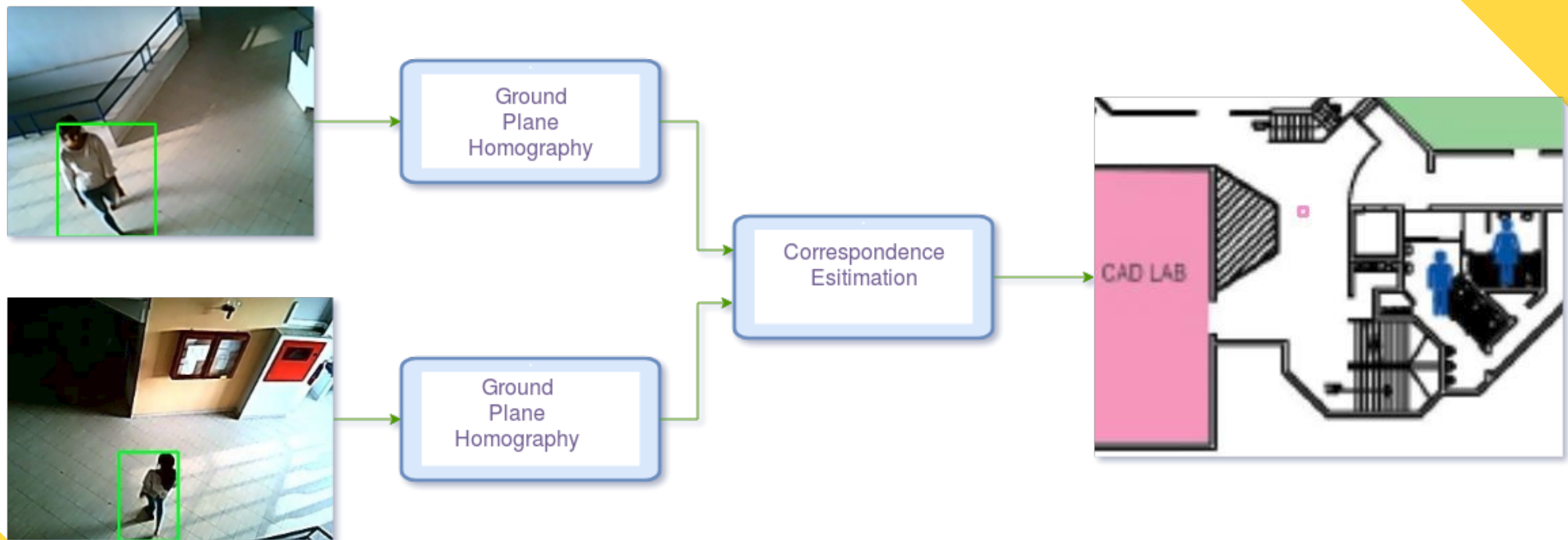
After Training

Approximately 99% of Feature Space is explained by 1st Principal Component

# PEOPLE TRACKING USING PARTICLE FILTERS



# MULTI CAMERA PEOPLE TRACKING - CORRESPONDENCE ESTIMATION



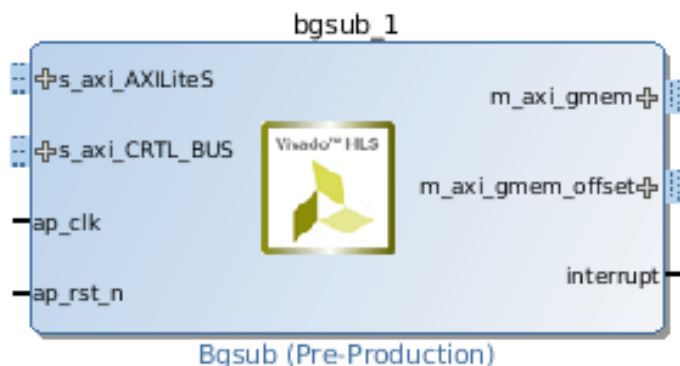
# DESIGN FLOW FOR FPGA BASED SYSTEM

- IP core design - Xilinx Vivado HLS
- Overall hardware design - Xilinx Vivado
- Hardware testing and debug - Xilinx SDK
- Linux boot files generation for created hardware - Xilinx PetaLinux SDK
- Linux userspace input/output (UIO) driver development - C/C++

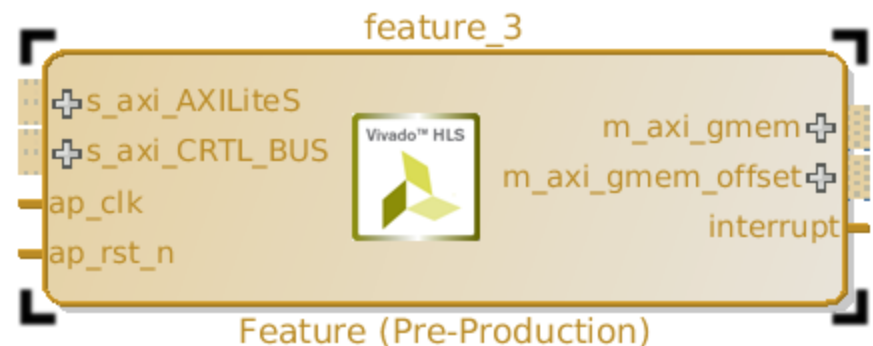


# HARDWARE DESIGN

- Designed using C++
- Equivalent RTL design was synthesized using Xilinx Vivado HLS.
- Memory interface for accessing SDRAM is AXI Master.
- AXI Lite interface was used for IP core configuration.

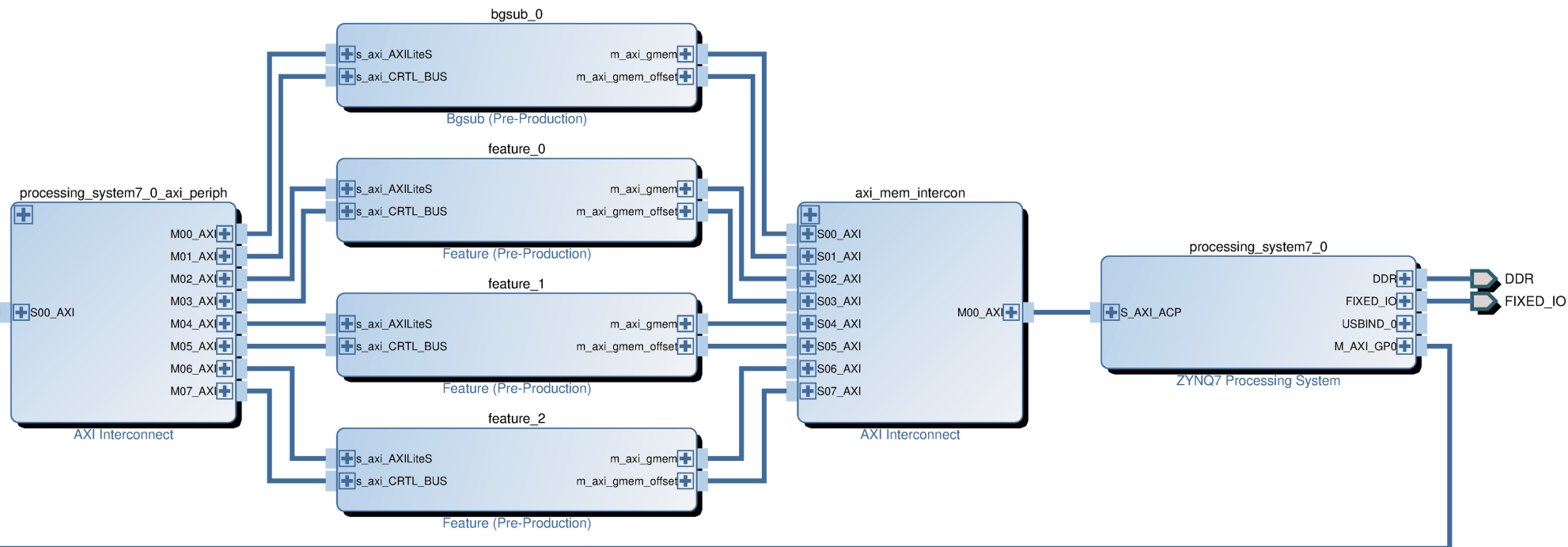


GMM IP Core



Histogram Feature IP Core

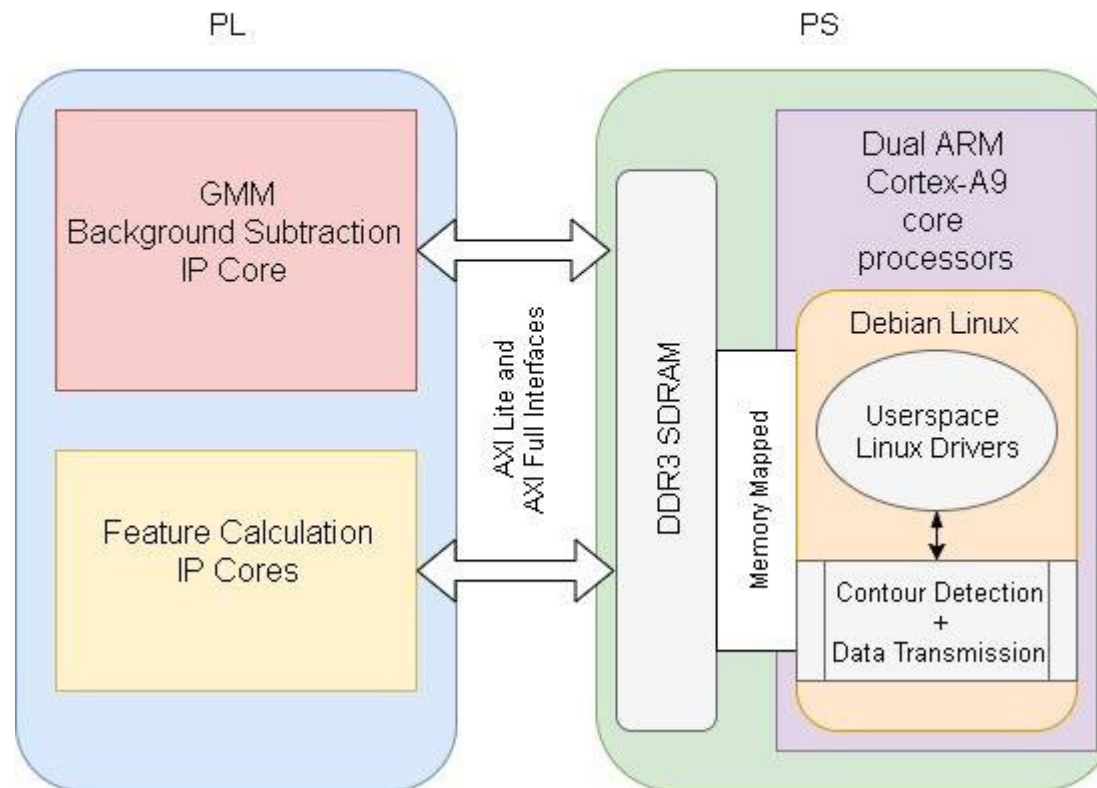
# OVERALL HARDWARE DESIGN



# LINUX USERSPACE INPUT/OUTPUT (UIO) DRIVER DEVELOPMENT

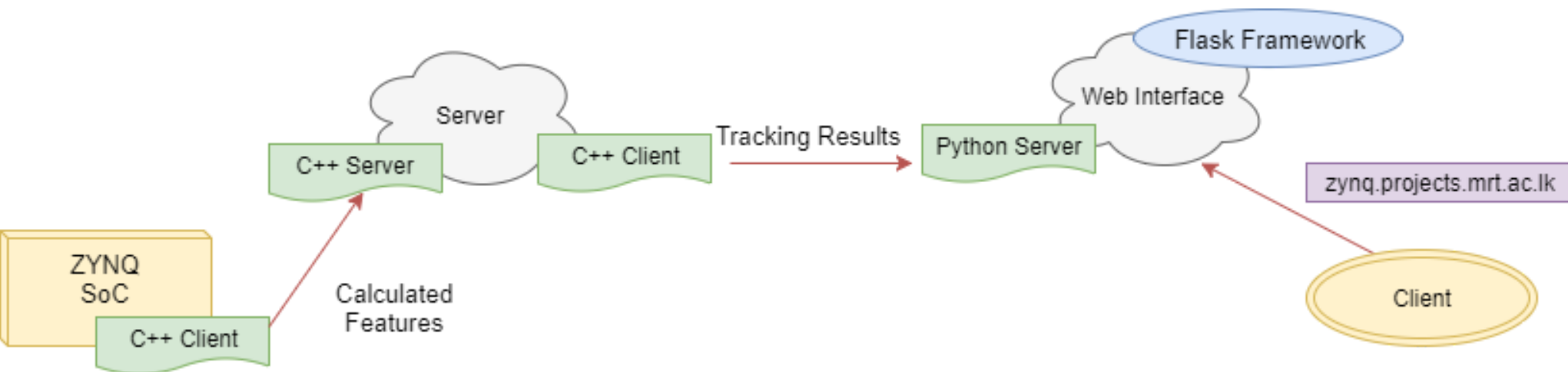
Configure Linux device-tree to use “generic-uio” kernel space driver for Background Subtraction and Feature calculation IP cores (AXI Lite ports).  
Develop an UIO driver controlling the IP cores from Linux user space.

Xilinx ZC-702  
Development Board



# COMMUNICATION AMONG FPGA NODES AND SERVER

- Two separate code structures using C++ and python.
- The communications protocol used is UDP (User Datagram Protocol) to ensure low latency and reduce the processing overhead.



# CHALLENGES FACED

19

**PROCESSING IN REAL  
TIME**

**TIME TO DEBUG**

**COMPLEXITY OF  
IMPLEMENTING  
PEOPLE DETECTION  
ALGORITHM IN  
HARDWARE**

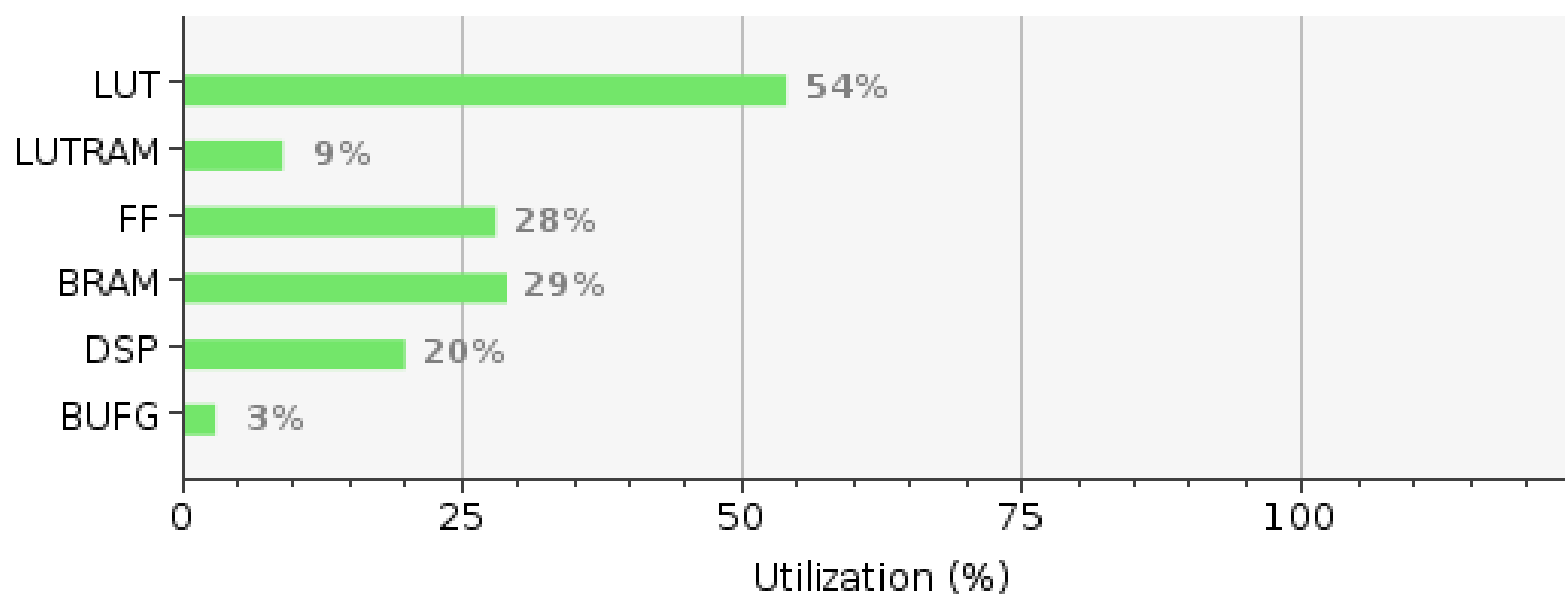
**LIMITED RESOURCES  
AVAILABLE IN THE  
FPGA**

**WRITING CUSTOM  
LINUX DRIVERS**

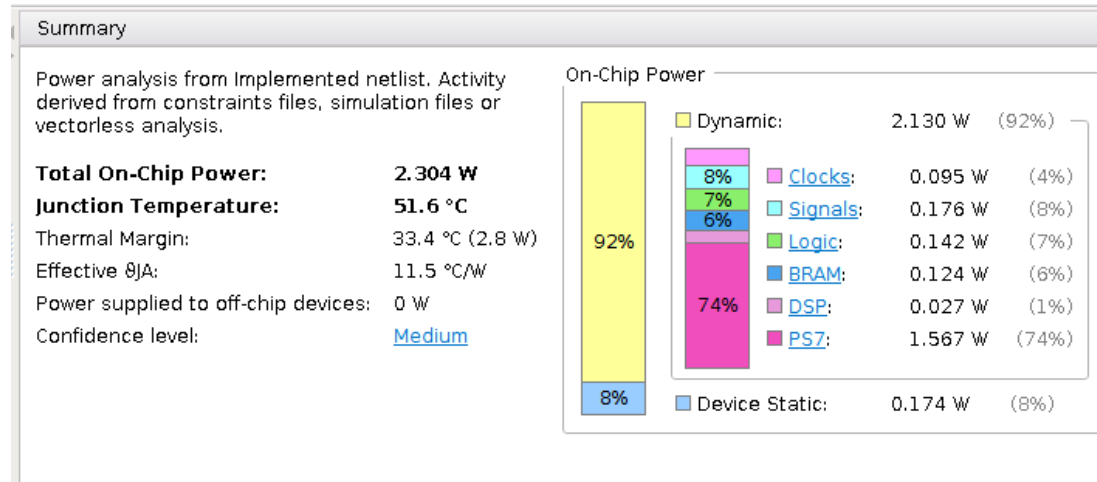
# RESULTS

# OVERALL HARDWARE UTILIZATION

Utilization - Post-Implementation



# TOTAL ON CHIP POWER AND BANDWIDTH REDUCTION





On Chip Power

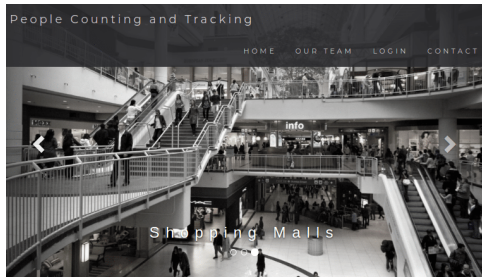
Bandwidth Reduction : 78.67%



# LATENCY AND DETECTION ACCURACY

	Average Latency
People Detection Software Simulation	30650us
People Detection in Hardware	21365us
Percentage Acceleration	30 29% 

	False Positives	False Negatives	Accuracy
EPFL Dataset - Terrace			
EPFL Dataset - Campus 			
EPFL Dataset - Passageway			
Our Dataset			



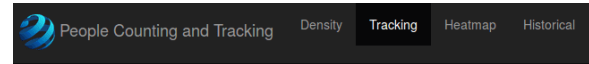
## People Counting and Tracking

Zyng ZC702

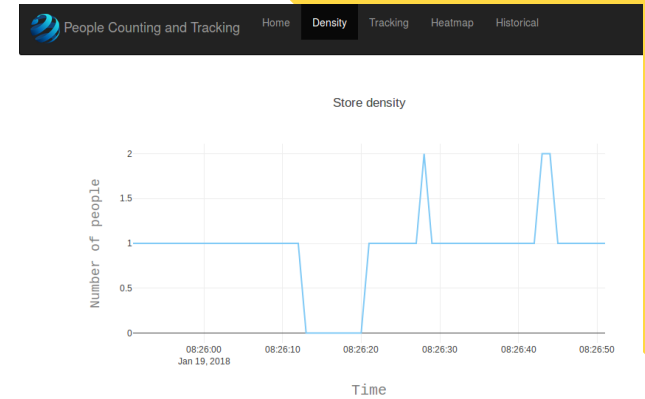
In the contemporary society making correct decisions is vital for any business organization to stay on par with competitors. For that intent identifying and understanding the customers is a must. Tapping into the customer's subconscious is the preeminent way of making correct business decisions and for that an organization should track and analyze customer behavior. For retail stores and shopping malls gathering customer insight could be done by analyzing the behavior of day to day customers.

However counting and keeping track of customers is a tedious task for a large store structure by just employing a number of cameras and a manual System. As a possible solution, we have developed a people tracking and counting system adaptable to any large scale store structure. Our system is able to process

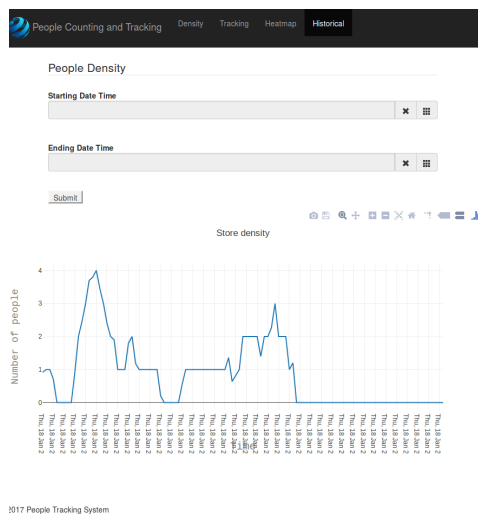
## Homepage



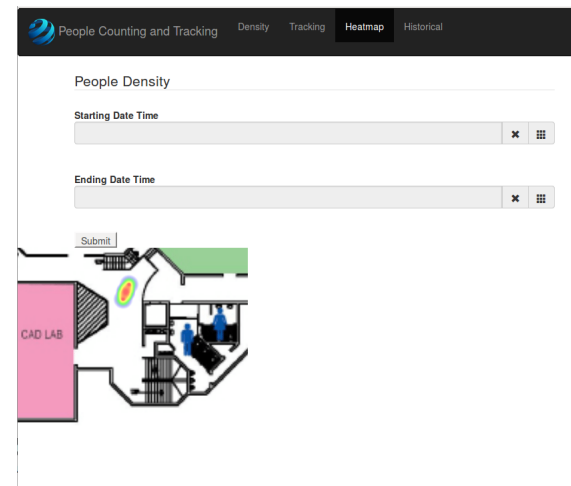
## Real time tracking



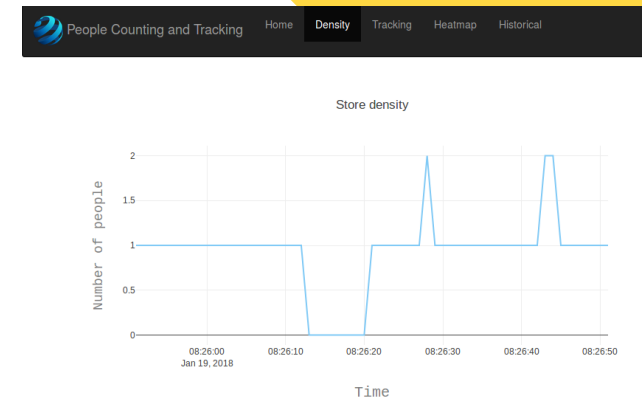
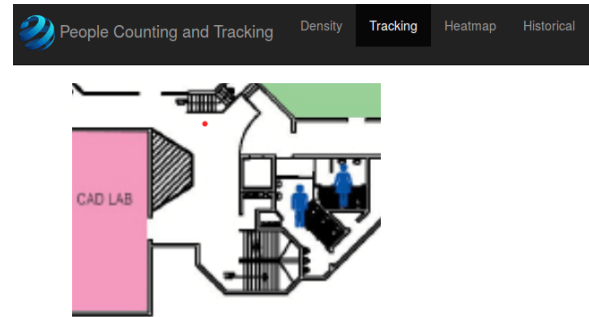
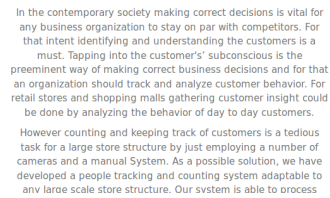
## Real time Counting



## Density over a period



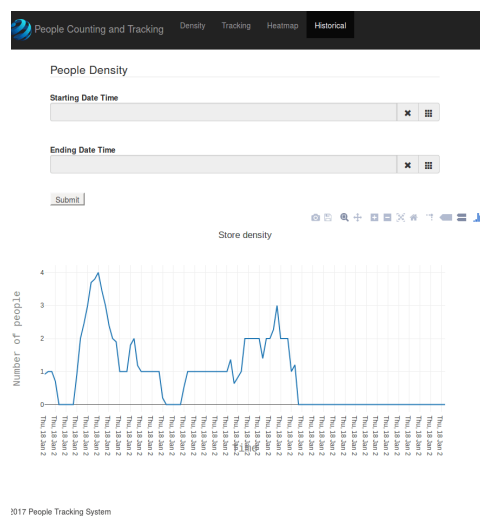
## Heatmap



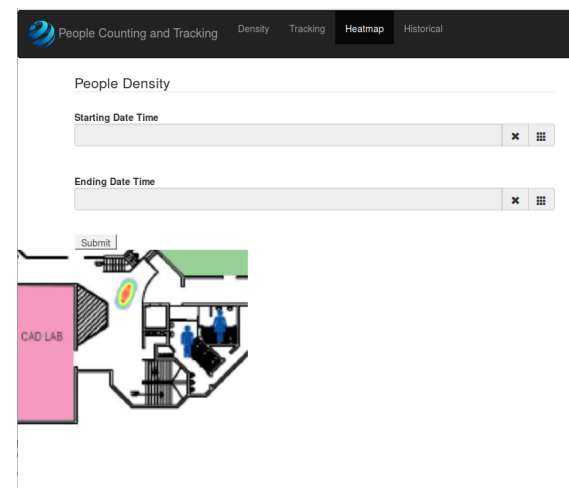
# Homepage

## Real time tracking

## Real time Counting



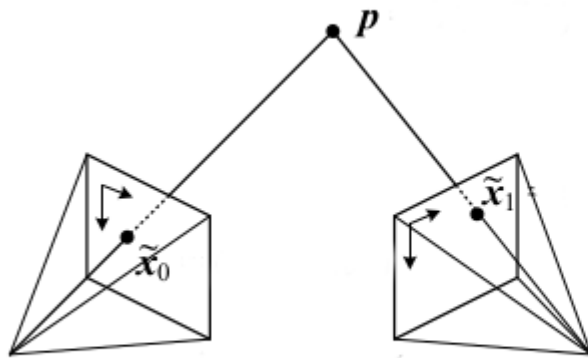
## Density over a period



# Heatmap

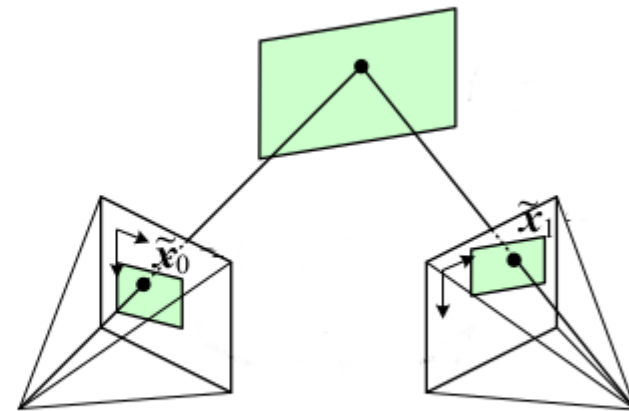
Task	Dulanga	Chathura	Dilin	Supuni
Installing Linux distribution in Zynq ZC702 evaluation boards				
Generating Linux boot files for custom hardware using petalinux SDK				
Writing user space Linux drivers for custom hardware				
Gaussian mixture model based background subtraction IP core				
Multi camera people tracking with ground plane homography				
Feature IP core				
People Detection algorithm				
People Tracking algorithm using particle filters				
Building Scalable communication Protocol among leaf nodes and server				
Principal component analysis for false positive detection				
Building communication between the server and Web Server using UDP sockets				
Building web application with integrated business intelligence				
Qt GUI application				

# MULTI CAMERA PEOPLE TRACKING-USING CALIBRATED CAMERAS



(a)

Figure a: Estimating the 3D coordinate of a point from 2D image coordinates obtained from 2 cameras



(b)

Figure b: Estimating 2D coordinates on an arbitrary plane

Source: Szeliski, Richard, and Richard Szeliski. Computer vision: algorithms and applications. New York, Springer, 2011.

# PEOPLE DETECTION ALTERNATIVES

## Using Background Subtraction and Blob Detection

- Less resources required but less reliable

- FPGA implementation is achievable with real-time requirement

## Using Neural Network Features

- Can achieve high accuracy level

- Woks even with occlusions

- FPGA implementation is difficult with limited resources available