

# A System for Tracking and Recognizing Multiple People with Multiple Cameras

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## Abstract

*In this paper we present a robust real-time method for tracking and recognizing multiple people with multiple cameras. Our method uses both static and Pan-Tilt-Zoom (PTZ) cameras to provide visual attention. The PTZ camera system uses face recognition to register people in the scene and “lock-on” to those individuals. The static camera system provides a global view of the environment and is used to re-adjust the tracking of the system when the PTZ cameras lose their targets. The system works well even when people occlude one another. The underlying visual processes rely on color segmentation, movement tracking and shape information to locate target candidates. Color indexing and face recognition modules help register these candidates with the system.*

## 1. Introduction

One of the goals of building an intelligent environment is to make it more aware of the user's presence so that the interface can *seek out* and serve the user [1]. This work addresses the ability of a system to determine the presence of humans, recognize them, and track their locations in indoor environments (*e.g.*, business offices, class rooms, smart rooms, etc.).

A problem that persists in static camera systems that track people is that these cameras cannot provide a useful image resolution for further perceptual analysis (*e.g.*, face recognition and expression recognition). Another problem is the inability of the vision system to handle occlusions. One method for dealing with these problems is to have a number of cameras available to foveate on the targets of interest. Our system addresses both of these issues.

The two main avenues we are pursuing to achieve robust tracking of multiple people from multiple cameras are:

**Locating people:** Determine the location of people in a calibrated scene by color tracking and face recognition. Using this approach the static camera system

estimates coarse locations of the people in the scene and the PTZ camera system refines these estimates to improve tracking accuracy.

**Visual attention:** Develop a mechanism for visual attention such that the PTZ cameras “lock” on to each of the users and zoom in to acquire high resolution imagery of people's faces and expressions. The PTZ and static cameras track people and handle occlusions between people as they move around in real-time.

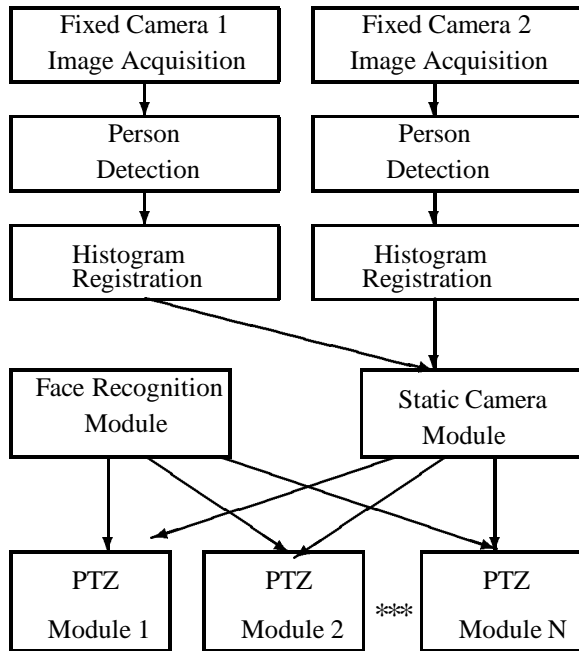
In the rest of the paper, we briefly discuss the related work in the area of tracking people followed by a technical discussion of our approach. We conclude by presenting experimental results of our work and possible future extensions.

## 2. Related Work

Many real-time systems have been developed for face and gesture tracking each varying in function and detail [3, 4, 6, 11, 12, 9, 15, 17, 18]. Most of these methods use a combination of skin-color segmentation, motion analysis, and feature detection to locate faces. Here we discuss only a few of these that are closely related to our work.

Crowley and Berard [6] present an architecture for real-time systems where a supervisory controller selects and activates various visual processes in order to ascertain a degree of confidence concerning observed data. These visual processes are blink detection, color histogram matching, and normalized cross correlation. Blink detection in particular requires a high degree of resolution from the input image and appears to be a limiting factor in their system.

Goodridge and Kay [11] present a system that uses a camera with a wide angle lens to gather a coarse representation of the environment and uses two microphones to perform auditory localization for pin-pointing the user location. This data is combined to control a single pan-tilt-zoom camera. Other significant work on foveating systems has been undertaken by [2, 5, 8].



**Figure 1.** The general system architecture could contain a number of PTZ modules.

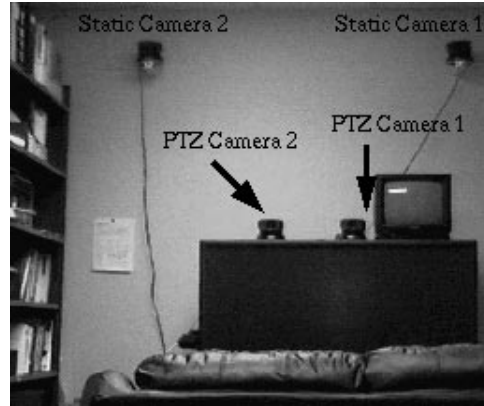
Yang and Waibel [15] and Wang and Chang [17] focus on tracking with a single camera and both use skin-color segmentation as the first level processing step.

Our system draws from parts of all the above mentioned systems to identify the presence of multiple people and uses a triangulation method to locate their coarse positions. A color-indexing method [13] and a face recognition system [14] help register people for consistency in tracking. As we show in this paper, our work integrates many different modules into a working system capable of tracking and recognizing multiple people with multiple cameras.

### 3. Multiple Cameras, Multiple People

We are interested in developing an architecture to track multiple people in complex scenes using multiple static and PTZ cameras. Figure 1 shows a general system configuration of two visual streams from static cameras feeding into the static camera module. Results from this module together with the face recognition module control the PTZ cameras. At present we are working on a system for tracking that uses two static and two PTZ cameras. Figure 2 shows a typical layout of the two static cameras and two PTZ cameras in the lab. Such a set-up is possible in any scenario, provided we can calibrate the space.

The static cameras send their data to different processes where face detection and local registration between frames



**Figure 2.** The camera configuration consists of two static cameras that are mounted at the top of the picture and two PTZ cameras on top of the big screen television.

occur. The target locations of faces in each image plane are sent to the static camera module for registration between the static cameras. The static camera module uses triangulation of the target locations acquired using skin-color segmentation to obtain world coordinates of the people being tracked (Figure 3). The world coordinates of each target are used to provide a coarse estimate of the pan angle and zoom factor for each PTZ camera. Next, the face recognition module refines these estimates to improve tracking accuracy and consistency. Once the PTZ camera locks onto the target, it continues to track the target based only on the input stream from the PTZ camera. If the face recognition module fails to recognize a person then the color indexing information from the static camera module is used to recover the person's location. If a person becomes occluded or leaves the scene, the PTZ camera remains at the last updated location until the person re-appears.

Currently, our system works for only two people in the viewing area. Our initialization step requires that these two people are not wearing the same color of shirt or blouse. Swain and Ballard's algorithm [13] is used in the histogram registration process which forces us to restrict changes in the illumination intensity. Users are also required to train their faces on the face recognition system.

In the following sections we describe the methodology and implementation issues in greater detail. The person detection and histogram registration sections describe the processing performed on a single data stream from each static camera, and the static camera module section describes the integration of the data from these cameras.

### 3.1 Person Detection

Skin-color segmentation is a key step in many existing real-time people tracking systems. Our system uses skin-color segmentation based on the work of Yang and Waibel [15] to get an initial set of candidate faces. Yang, Lu, and Waibel [16] have shown that human skin colors cluster in a small region in a normalized color space and that under certain lighting conditions, the skin-color distribution can be characterized by a multivariate normal Gaussian distribution.

The image pixels from the static cameras are projected into a normalized color space defined by

$$g_r = \frac{g_R}{g_R + g_G + g_B}, \quad (1)$$

$$g_g = \frac{g_G}{g_R + g_G + g_B}. \quad (2)$$

A pixel  $g$  is represented by its red ( $g_R$ ), green ( $g_G$ ), and blue ( $g_B$ ) components in RGB space.  $g_r$  and  $g_g$  represents the projected components of the pixel into this normalized space.

The Gaussian model parameters (means and variances) are obtained by processing skin-tone samples captured offline. Next, a Gaussian distribution is created from these parameters and is used to generate a Look-Up Table (LUT) of values to be stored during system initialization. The LUT is used to accept or reject pixels as skin pixels based on the pixel's proximity to the Gaussian peak.

Next, salt-and-pepper noise is removed from the image frame by using a median-filtering technique. The resulting image  $I(x, y)$  from this process is smoothed and a horizontal projection of the skin pixels in the image is calculated. The coordinate system of the image frame is expressed with  $x$  in the horizontal direction and  $y$  in the vertical direction.

$$Proj(x) = \sum_{y=0}^{height-1} I(x, y) \quad x = 0, 1, \dots, width-1 \quad (3)$$

$Proj(x)$  looks like a range of mountains with peaks and valleys. The region surrounding each mountain peak is likely to contain a face. The peaks and their surrounding areas of  $Proj(x)$  above some threshold are extracted to produce a set of vertical slices  $\Theta$  of the image. Next, a vertical projection is created from these slices to determine the face candidate regions.

$$Proj(y) = \sum_{x \in \Theta} I(x, y) \quad y = 0, 1, \dots, height - 1 \quad (4)$$

Extraction of the peaks and surrounding areas of  $Proj(y)$  results in an initial set of candidate faces. Using heuristics

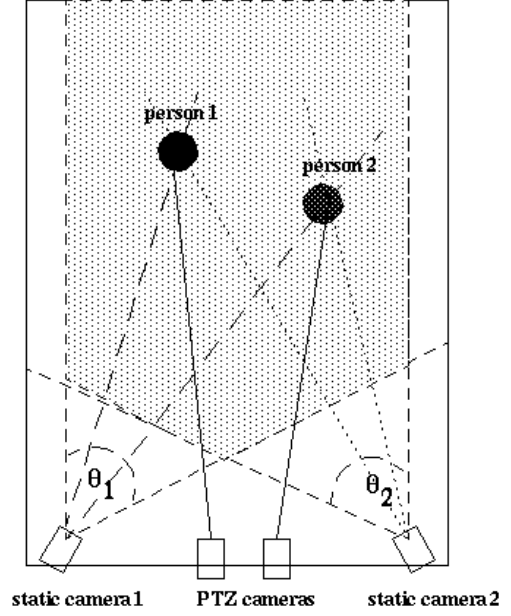


Figure 3. A bird's eye view of the Field of View (FOV) angles used for triangulation.

for the size and the aspect-ratio of human faces<sup>1</sup>, many of the non-face candidates can be eliminated.

The two static cameras perform inter-frame registration of the people based on color, size, velocity, and aspect ratio attributes (with the assumption that they do not change faster than the video capture frame-rate). A scoring method is used to combine this data to produce a single numerical score of the likelihood that a candidate region is indeed a face. If this number is greater than a preset threshold, it is declared a face object and is added to a list of face objects.

After the system is initialized and a face has been detected, a rectangular region or swatch is automatically cropped below the face object and is used to generate a color histogram which is stored in the face object's data structure. This is based on the assumption that a person is standing upright, which results in this swatch extracting the information about the person's clothes. The object's histograms is used to register and provide tracking consistency. The registration process is described in detail below.

### 3.2 Histogram Registration

A registration process of people between the static cameras is needed to achieve consistent tracking with the PTZ

<sup>1</sup>The golden ratio (artistic-ese) is used as the comparison aspect ratio and is defined as:  $\frac{height}{width} \equiv \frac{1+\sqrt{5}}{2}$ .

cameras and for calculating the locations of people. Registration is performed in the Histogram Registration module for each stream and an identification number is assigned to each face object before the face object list is sent to the camera server shown in Figure 1.

The registration process is first initialized by getting swatch samples from each person. The system then creates color histograms from those swatches that are later used to register people as they move about the scene. The success of this registration method relies on the differences of cloth colors.

Color histograms are constructed by counting the pixels of a given value in an image. The color space used consist of three axes B-G, G-R, and R+G+B. Each axis is coarsely partitioned into 16 bins. The time to construct a histogram is proportional to the number of image pixels in the swatch.

During initialization, model histograms  $M_1$  and  $M_2$  are created from the area below face regions of person 1 and person 2. After that, in each frame, the person detection module outputs some number of candidate regions  $K$ . Candidate histograms  $C_1, C_2, \dots, C_K$  are constructed in the same way as model histograms. The histogram intersection then is computed between the model histogram  $M_1$  and a list of candidate histograms.

$$score_m = \frac{\sum_{i=1}^N \min(M_1(i), C_m(i))}{\sum_{i=1}^N M_1(i)} \quad m = 0, 1, \dots, K \quad (5)$$

The best match for person 1 is the maximum score that is above some threshold  $T$ . We do the same for the model histogram of the second person  $M_2$  to get the best match. Once the histogram registration step is complete, the two most likely regions are then identified as person 1 and person 2. The histogram module then sends the  $(x, y)$  centroid coordinates in the image space of these two regions and their respective person identifiers to the server.

### 3.3 The Static Camera Module

The static camera module accepts processed data in the form of a face object list from the two static cameras. The module process waits until it receives a list from both cameras before it begins the location procedure. Next the module uses the person identification numbers of each face object from each static camera to register the faces between cameras. Simple geometry is used to triangulate the face objects to obtain world coordinates of these objects in two dimensions  $(x, y)$ . Figure 3 shows the Field of View (FOV) angles used for triangulation. The calibration of the space requires measuring the base distance between the static cameras and calculating the angle of the frustum. Camera 1 is labeled as the origin in world coordinates and the other camera positions are measured relative to the origin.

The results from this module represent the approximate locations of the people in the scene and are sent to the PTZ camera module for further refinement.

### 3.4 The Face Recognition Module

The face recognition module locates and identifies the person from the input stream of the PTZ camera. It then sends this information to the PTZ camera module for further processing.

We based our implementation of this module on Visionics' FaceIt developer kit [14]. This system is a real-time continuous face recognition system that performs identification by matching against its database of people it has seen before or pre-enrolled users. This module sends the location  $(x, y)$ , the name, and a confidence value of the face identified and recognized to the PTZ camera module.

### 3.5 The PTZ Camera Module

This module integrates and processes the data from the static camera and face recognition modules. The static camera module provides coarse locations of people from a global view whereas the face recognition module provides more accurate locations of people from a local view. When available, the data from the face recognition module is used to update the PTZ camera direction from frame to frame. The face recognition module occasionally loses its target because of fast target movement or occlusions. When this occurs, target information available from the static camera module is used to guide the PTZ camera back on track.

The PTZ camera movement is controlled by the output of either the static camera or face recognition module. Both modules, however, output target locations in different coordinate systems. The static camera module specifies target locations in scene coordinates whereas the face recognition module specifies them in coordinates relative to the current frame. The target locations in scene coordinates are used along with the calibrated coordinates of the PTZ camera to update the camera pan and zoom factors. Since the face recognition module can only identify the relative shifts of the face in the current image plane, then the current pan angle of the PTZ camera must be retained for calculating the global shift of the face in scene coordinates. Once the PTZ camera movements are determined, this module sends serial commands to the PTZ cameras to update their current position.

## 4. Experimental Results

Figure 4 shows the output of an earlier implementation of our system without the PTZ cameras. The resolution of the cropped face alone in most cases was not adequate



**Figure 4.** An earlier implementation of our system tracking and identifying 3 people in a scene using only two static cameras. People are recognized by the color of their clothes. Note that in such images face recognition is very hard as each face image has a resolution of about 25x40 on average (the image size is 320x240).



**Figure 5.** The static camera module is initialized by creating swatch histograms of two people once they are present in the scene.



**Figure 6.** This is the output from the face recognition module.

for further analysis (e.g., face recognition, gaze tracking, or expression recognition). In this case, we used the color information of the swatch to identify the people.

At present, we incorporate PTZ cameras allowing the system to foveate to objects of interest in the scene. Such visual attention results in an increase in resolution of the object being tracked (in our case the faces of the users). Additionally we use a histogram matching technique and face recognition software to achieve tracking consistency. This method makes it possible to reliably track multiple people even when they occlude one another. Figure 5 shows the initialization step of our system, and Figure 6 shows the output of the face recognition module. The two people must first face the camera for a good swatch to be extracted and for the face recognition system to determine their identities. This is done automatically when the system is started. Figure 7 (A) and (B) shows the view of each of the static cameras with the faces and swatches marked. The swatch area is represented by a white bounding box under the face.

Once the initialization step is complete, the PTZ cameras follow their registered guest as they move about the



**Figure 8.** This is a view from one of the static cameras when two people cross paths. Tracking continues despite occlusions.

room. Figure 8 shows the view of one of the static cameras when the two people cross paths. And finally, Figure 7 (C) and (D) shows the views from the two PTZ cameras.

Our system at present runs in real-time using two Silicon Graphics (SGI Indy R5000) workstations and two pentium-II PCs. We use SONY EVI-D30 PTZ cameras. The PTZ cameras are controlled through their serial ports.



**Figure 7.** (A) & (B) Views from two static cameras showing the result from the person detection module. (C) & (D) Views from two PTZ cameras. We use the results of the triangulation process to decide the zoom scale factor (i.e., the distance from a person to the PTZ camera).

## 5. Conclusions & Future Work

In this paper we present an approach that uses skin-color segmentation, color indexing methods, and face recognition to locate multiple people in a calibrated space. By combining multiple static cameras and PTZ cameras we have developed an architecture that provides higher resolution imagery of faces for face processing applications. The tracking methods we have proposed work well under simple occlusions that occur when people cross one another in the scene. We demonstrate a real-time system that tracks two people reliably using two static and two PTZ cameras.

We are working on several extensions to improve the system's ability to detect faces and to increase the accuracy of the tracking and registration processes. A few of these extensions are to:

- use real-time stereo vision to acquire 3D position of the users,
- apply Kalman filtering techniques to improve the tracking by the PTZ cameras,
- incorporate audio information to develop phased-array microphones for auditory localization, AND
- experiment with this system in more complex scenarios like classrooms and meeting rooms.

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