

# Final Report of Pedestrian Counting

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## 1. Introduction

Pedestrian detection and counting has been heavily researched in the last few years and people have made great improvement. Dalal's HoG (Histogram of Gradients) operator has been widely used in pedestrian detection with SVM, AdaBoost or other machine learning algorithms, which we use as the basic detector in our project.

However, detection is not enough to count the pedestrians in the ROI, therefore we have to track each person. Our basic idea is to use particle filter to track each specific person.

Particle filter is an approximation of Bayes inference and is widely used in tracking. Compared with Kalman filter, it can simulate any probability distribution. However its main drawback is the high complexity of computation. Which we will try to optimize with multiple threads.

This project is hosted as a private project on GitHub. You will find the [project page](#) and the [documents](#) on it.

## 2. Basic Plan

Here is our basic plan for this project.

- Code Reconstruction

The code offered by the teacher is not object-oriented, and is very difficult to modify and extend. Hence our first goal is to reconstruct the program so that we can easily build our particle filter on it.

- Merge Particle Filter

The main idea is from [1], in which there are mainly two new ideas. The first one is that instead of using one offline trained general classifier, they train one online classifier for each detected pedestrian and the classifier is only updated on non-overlapping detections. Secondly, the detections are used to guide the particles' propagation which is implemented to estimate the conditional likelihood of the new observation.

- Data Association Problem Use the greedy algorithm to find the  $pair(t_r, d)$  with maximum score in the matching score matrix and delete the columns and rows belonging to tracker  $t_r^*$  and  $d$

- Online Boosting

The online boosting classifier for each pedestrian is similar to that in [2] and we will select some features to train it.

- Optimization

With multiple threads or even GPU programming, we may achieve the real time interactive result.

## 3. Current Progress

- Code Reconstruction

First we reconstruct the code. We left kmeans and meanshift algorithm unchanged cause they are not important in our project. And we divide the whole project into these 5 parts.

- Utility

We implement some utility classes here. Mainly some geometry classes such as `Size`, `Rect`, `Point2D`. These are very similar to those in OpenCV library. However we still

implement them as sometimes we need overload some operators. We also implement a container called `Pool`, which is basically just a vector that never shrinks, in order to improve performance.

And we also reconstruct the `ConnectedComponents` here. It basically does the same thing as before.

- `IntegralImage`

As most of the features will be extracted using integral image to speed up, we implement an `IntegralImage` interface. This is an abstract class containing some virtual functions. The most important method is:

```
1 // Normal integral image.
2 virtual unsigned int GetSum(const Rect &roi) const;
3
4 // Used in HoG integral image.
5 virtual void GetSum(const Rect &roi, float *result) const;
```

Other integral image classes should overload these two functions according to their purpose. Here we mainly implement two integral images.

`GrayScaleIntegralImage` calculates the integral image for a grayscale image. It overloads the first `GetSum` function.

`HoGIntegralImage` calculates the 9 bins HoG for a grayscale image. Of course this is used to extract the HoG feature.

- `FeatureExtractor`

In this part we implement three classes: `Feature`, `HaarFeature`, `HoGFeature`.

`Feature` is basically just a container for the feature we extracted using the other two classes.

`HaarFeature` extracts a haar-like feature given an integral image and roi. When being constructed, it randomly chooses from the five haar-like features.

`HoGFeature` extracts a HoG feature given an `HoGIntegralImage` and roi.

- `Classifier`

Here we reconstruct the original AdaBoost classifier with the following classes.

First we build an `WeakClassifier` interface and it has two main virtual methods:

```
1 virtual bool Update(const IntegralImage *intImage,
2                   const Rect &roi, int target);
3 virtual float Evaluate(const IntegralImage *intImage,
4                      const Rect &roi);
```

`Evaluate` evaluates the roi with the feature inside this weakclassifier, while `Update` is used in training.

Then we implement a class called `WeakClassifierHoG`. It doesn't overload `Update` method therefore it can't be trained. It's only used in the offline AdaBoost classifier.

We construct the AdaBoost classifier using `WeakClassifierHoG`.

- `Detector`

With the AdaBoost classifier above we are able to build the detectors now.

`ImageDetector` uses the AdaBoost classifier and slide windows to detect pedestrian in the whole image.

`BKGCutDetector` inherits from `ImageDetector`. It cuts the background and uses the `ConnectedComponents` to speed up the detection. When it is not sure whether a connected component is a pedestrian or not, it calls `ImageDetector` to judge.

`VideoDetector` receives a pointer of `ImageDetector` and use it to detect pedestrian in every two frames. Notice that with virtual function we can use `BKGCutDetector` here as well.

Besides, while reconstructing the program, we rewrite some parts of the program in a more memory friendly way, which leads to quite tremendous improvement. The original video detector on the first training video takes 212s, while our reconstructed program takes 66s with one main thread. After optimizing some parameters it reduces to 27s without deteriorating its precision.

Here are some results from our reconstruction: Figure 1. We can see that with background cut we have less false positive.

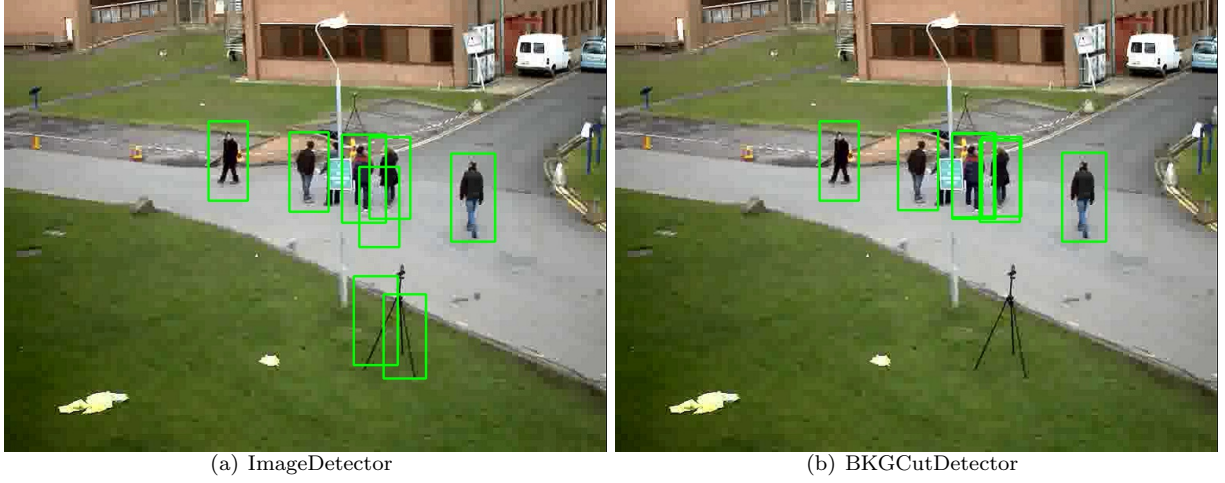


Figure 1: Detection Results

- Online Boosting

After the reconstruction, we start to work on the online boosting algorithm to track a single target. The main work is focus on Classifier part. We implement the following new classes.

- **EstimatedGaussianDistribution**

Given a feature  $f(\mathbf{x})$ , the probability of  $P(1|f(\mathbf{x}))$  and  $P(-1|f(\mathbf{x}))$  is estimated as Gaussian distribution[2]. This Gaussian distribution is estimated with Kalman filter[4]. We use the following update equations for adaptive estimation from [2]:

$$K_t = \frac{P_{t-1}}{P_{t-1} + R} \quad (1a)$$

$$\mu_t = K_t f(\mathbf{x}) + (1 - K_t) \mu_{t-1} \quad (1b)$$

$$\sigma_t^2 = K_t (f(\mathbf{x}) - \mu_t)^2 + (1 - K_t) \sigma_{t-1}^2 \quad (1c)$$

$$P_t = (1 - K_t) P_{t-1} \quad (1d)$$

- **ClassifierThreshold**

It estimates the Gaussian distribution for both positive features  $N(\mu_+, \sigma_+)$  and negative features  $N(\mu_-, \sigma_-)$ . Then it uses a simple distance threshold to a new feature to whether positive or negative:  $h(\mathbf{x})$  for "hypothesis"

$$h(\mathbf{x}) = \min_{+, -} (D(f(\mathbf{x}), \mu_+), D(f(\mathbf{x}), \mu_-)) \quad (2)$$

where  $D(f(\mathbf{x}), \mu)$  is just the Euclidean distance in feature space.

- **WeakClassifierHaar**

It uses the Haar-like feature above and the **ClassifierThreshold** to build a weak classifier. For classify, it uses **HaarFeature** to extract the feature and sends it to **ClassifierThreshold** to classify. For training, it uses the Kalman filter in **EstimatedGaussianDistribution**.

- **ClassifierSelector**

Given a pool of weak classifiers, the **ClassifierSelector** selects the best one with lowest error rate.

- \* Training

Each training feature  $f(\mathbf{x})$  has an importance  $\lambda$ , and we use the idea from [3] to draw a random variable  $k \sim \text{Poisson}(\lambda)$  and this feature is trained for  $k$  times.

- \* Selecting

For each weak classifier, we maintain two variables  $\lambda_{correct}$  and  $\lambda_{wrong}$ :

$$\lambda_{correct} = \sum_{i_{correct}} \lambda_i \quad (3a)$$

$$\lambda_{wrong} = \sum_{i_{wrong}} \lambda_i \quad (3b)$$

And the error rate is estimated by:

$$err = \frac{\lambda_{wrong}}{\lambda_{correct} + \lambda_{wrong}} \quad (4)$$

Then we choose the best weak classifier with lowest error rate.

\* Replacing

To improve the performance, each time we not only choose the best weak classifier but also replace the worst one with a randomly generated new weak classifier.

– **StrongClassifier**

The **StrongClassifier** has  $N$  **ClassifierSelectors**, each with a voting weight  $\alpha_i$ . The final hypothesis is:

$$h^{strong}(\mathbf{x}) = \text{sign}\left(\sum_{i=1}^N \alpha_i \cdot h_i^{selector}(\mathbf{x})\right) \quad (5)$$

Suppose  $err_i$  is the error rate of the  $i^{th}$  selector, and then the voting weight is:

$$\alpha_i = \ln\left(\frac{1 - err_i}{err_i}\right) \quad (6)$$

And the importance of this sample is updated with:

$$\lambda_{i+1} = \lambda_i \cdot \sqrt{\frac{err_i}{1 - err_i}}, \quad \text{if } h_i^{selector} \text{ correct} \quad (7a)$$

$$\lambda_{i+1} = \lambda_i \cdot \sqrt{\frac{1 - err_i}{err_i}}, \quad \text{if } h_i^{selector} \text{ wrong} \quad (7b)$$

- Particle Filter

After we have the online boosting strong classifier. We try to combine it with particle filter.

– **SingleSampler**

Given a target, it samples around it the positive and negative samples using Gaussian noise. Here is the samples: Figure 2, red for negative samples and blue for positive ones. This is used in training the classifier.

– **ParticleFilter**

This is a basic particle filter. The state space is just the position  $[upper, left]$ . The motion model is also very simple:

$$p_t = p_{t-1} + N(0, \sigma) \quad (8)$$

where  $N(0, \sigma)$  is a Gaussian random variable with variance proportional to the size of the target.

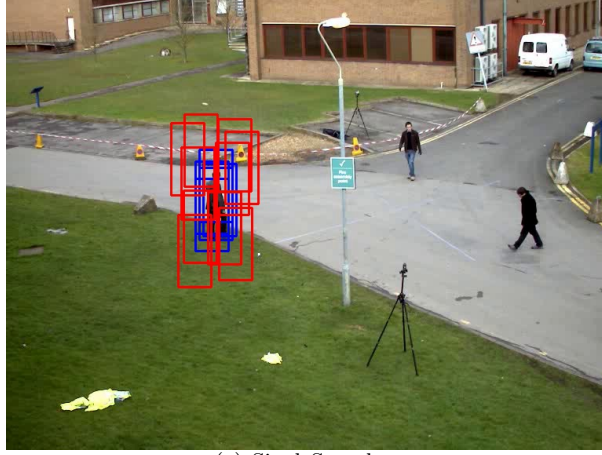
As for observation, it just use the scores given by strong classifier as the weight of the particles and resample it. We may improve the motion model later.

– **ParticleFilterTracker**

This class just combines everything together, use particle filter and strong classifier to track a target.

- Result

With the following configuration we tested our single tracker on a small video clip. The result can be found [here](#).



(a) SingleSampler

Figure 2: Detection Results

- The online boosting classifier is built with grayscale haar-like feature.
- The particle filter just selects the best particle as the target and resamples around it.
- 500 particles.
- User initializes the target bounding box.

We can see that the classifier works quite good in Figure 3. After observation, the particles are drawn with their confidence. The brighter the particle is, the more confidence it has. Notice that the particle is at the upper-left corner of the target.



(a)

Figure 3: Particles Confidence

- RGI feature

From Figure 4 we can see that the current classifier can still not distinguish different pedestrians. We think this is due to the grayscale haar-like feature doesn't contain enough information. [1] reports that with RGI (Red, Green, Intensity) histogram feature, 3 bins for each channel the results are quite good.

Hence we implement `RGIIntegralImage`, `RGIFeature` and `WeakClassifierRGI`. These classes use RGI feature to construct the weak classifier. The resulting video can be found [here](#). From this video and Figure 5 we can see that the classifier is more robust and can handle some situation as two people crossing each other. However in Figure 5(b) the classifier still goes for wrong pedestrian! Well they wear the same jeans I guess...

Well we need more code to solve this data association problem.

#### 4. Further Plan





Figure 4: With grayscale haar-like feature, the tracker lost its target.(Black for original target)



Figure 5: With RGI feature, the tracker is more robust, but still lost its target finally. (Black for original target)

- Mean-shift to find the target  
Now the particle filter just selects the best particle as the target, and resamples around it. However this loses almost every advantage of particle filter. So our next plan is to use mean-shift to find the target from all these particles.
- Multi-target Tracker  
This is our final object. The main problem is data association. We are not sure we will be able to finish this. But we will see.

## 5. Experiment

All the experiment is executed on Dell Inspiron 14R SE with the following configuration. All the experiment result can be found [here](#).

- Intel Core i7-3612QM 2.10GHz
- 8.00GB RAM
- System: Windows 8.1 x64
- OpenCV: 3.00

For video we have three clips: [1.avi](#), [2.avi](#), [3.avi](#).

For single image detection we only use [test.jpg](#), which is from [1.avi](#).

The original baseline program is tested with all default settings.

- HoG Detector.

We first use the simple HoG detector to detect a single picture.

	Time	Accuracy	False Positive
Original	3.43s	5 / 6	3
Reconstructed	3.20s	5 / 6	2

- Background Cut Detector.

We use the simple Background cut detector to detect pedestrain in a single picture.

	Time	Accuracy	False Positive
Original	1.76s	6 / 6	0
Reconstructed	1.27s	5 / 6	0

- HoG Detector for Video.

We use the simple HoG detector to detect pedestrain in a video.

	Time	Accuracy	False Positive
Original	1051s		
Reconstructed	900s		

- Background Cut Detector for Video.

We use the simple Background Cut detector to detect pedestrain in a video.

	Time	Accuracy	False Positive
Original	207.36s		
Reconstructed	159.14s		

## References

- [1] Michael D. Breitenstein, Fabian Reichlin, Bastian Leibe, Esther Koller-Meier, and Luc Van Gool. Robust tracking-by-detection using a detector confidence particle filter. In *IEEE International Conference on Computer Vision*, October 2009.
- [2] Helmut Grabner and Horst Bischof. On-line boosting and vision. In *Proceedings of the 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition - Volume 1*, CVPR '06, pages 260–267, Washington, DC, USA, 2006. IEEE Computer Society.
- [3] Nikunj C. Oza and Stuart Russell. Online bagging and boosting. In *In Artificial Intelligence and Statistics 2001*, pages 105–112. Morgan Kaufmann, 2001.
- [4] Greg Welch and Gary Bishop. An introduction to the kalman filter. Technical report, Chapel Hill, NC, USA, 1995.