



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Comparison of Multi-shot Models for Short-term Re-identification of People using RGB-D Sensors

Møgelmoose, Andreas; Bahnsen, Chris Holmberg; Moeslund, Thomas B.

Published in:

Proceedings of the 10th International Conference on Computer Vision Theory and Applications (VISIGRAPP 2015)

DOI (link to publication from Publisher):

[10.5220/0005266402440251](https://doi.org/10.5220/0005266402440251)

Publication date:

2015

Document Version

Peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Møgelmoose, A., Bahnsen, C., & Moeslund, T. B. (2015). Comparison of Multi-shot Models for Short-term Re-identification of People using RGB-D Sensors. In J. Braz, S. Battiato, & F. Imai (Eds.), Proceedings of the 10th International Conference on Computer Vision Theory and Applications (VISIGRAPP 2015) (Vol. 2, pp. 244-251). SCITEPRESS Digital Library. DOI: 10.5220/0005266402440251

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- ? Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- ? You may not further distribute the material or use it for any profit-making activity or commercial gain
- ? You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Comparison of Multi-shot Models for Short-term Re-identification of People using RGB-D Sensors

Andreas Møgelmoose, Chris Bahnsen, Thomas B. Moeslund

*Visual Analysis of People Lab, Aalborg University, Rendsburggade 14, 9000, Aalborg, Denmark
{am;cb;tbm}@create.aau.dk*

Keywords: Re-identification, systems, color features.

Abstract: This work explores different types of multi-shot descriptors for re-identification in an on-the-fly enrolled environment using RGB-D sensors. We present a full re-identification pipeline complete with detection, segmentation, feature extraction, and re-identification, which expands on previous work by using multi-shot descriptors modeling people over a full camera pass instead of single frames with no temporal linking. We compare two different multi-shot models; mean histogram and histogram series, and test them each in 3 different color spaces. Both histogram descriptors are assisted by a depth-based pruning step where unlikely candidates are filtered away. Tests are run on 3 sequences captured in different circumstances and lighting situations to ensure proper generalization and lighting/environment invariance.

1 INTRODUCTION

The task of person re-identification is about recognizing people that have been captured earlier by a camera in a surveillance network. The network may consist of one or more cameras, and can be placed in traditional surveillance contexts or more narrowly scoped areas, such as keeping track of a single queue of people. The objective is simple: When a person enters the field of view of a camera in the system, it must be determined whether or not this person has been seen before. Person re-identification is closely related to person tracking and person recognition. However, it has several extra challenges, that makes it less straight-forward (Møgelmoose et al., 2013b):

- There is no fully known gallery dataset. As opposed to traditional person recognition, the system must enroll new people on-the-fly, without them taking any action.
- Methods must be robust to pose changes. Since subjects are not required to participate actively, there are only weak constraints on pose and viewing angles.
- Sensor resolution is a big challenge. People simply passing by at various distances are to be re-identified, so it is not reasonable to use hard biometrics like fingerprints or face recognition.

- The database of known people must be continually cleaned up - when a person has not been seen for some period of time, they have most likely left the area and should be removed from the database.

There are two fundamentally different approaches to re-identification: Single-shot and multi-shot. Single-shot performs the re-identification on stand-alone frames. This is useful in situations where only a single probe image is available. However, very often the subject has been captured on video, and thus has several frames describing her. Multi-shot combines a full pass across the field of view into a single model, which is then used as probe in a gallery of similarly collected multi-shot models. Multi-shot gives the option of capturing more information about the subject than a single frame contains, and has the potential to make the system more robust to occlusions and sudden changes in lighting.

Person re-identification has been in active research for a while, but multi-modal systems have only recently come into play. The reason for this is twofold: 1) Algorithms have so far mostly been developed for use in existing surveillance infrastructure and 2) more advanced sensor capabilities, such as depth and thermal, have not been readily available. We believe that as sensor technology progresses, more modalities will show up in regular surveillance cameras, making the development of new multi-modal algorithms highly relevant.

This work builds on the method presented in (Møgelmoose et al., 2013b) and is a full RGB-D based re-identification system covering all parts of the pipeline from detection through re-identification to database maintenance. The main contributions are:

- While the earlier work was single-shot based, the method has been updated to a multi-shot approach. This work compares several different multi-shot person models.
- The earlier work relied on RGB-color histograms. This work presents a comparison of three different color spaces: RGB, HSV, and XYZ.
- More thorough testing. On top of testing on the original dataset from (Møgelmoose et al., 2013b), two more datasets have been captured to test the performance in different circumstances.
- The system is now free of arbitrary thresholds in the re-identification stage, as every threshold is learned from training data in a cross-validation scheme.
- In the original work, the height of subjects only had little influence on the re-id performance. We introduce a more thorough pruning step based on depth-adjusted height of subjects which increases re-id performance significantly.

The remainder of this paper is structured as follows: Section 2 gives an overview of related work in the field of re-identification. It also contains a description of existing datasets, as well as the ones captured and used in this work. Section 3 explains the algorithms used and goes through detection and segmentation, multi-shot person modeling, and re-identification. In section 4 the various methods presented are evaluated against each other. Section 5 concludes the paper.

2 RELATED WORK

Person re-identification as described above has been an active research area for about a decade and truly gained speed in the latter half of the 2000s. A relatively recent survey on person re-identification can be found in (Doretto et al., 2011), and in this section we highlight notable recent papers. As mentioned previously, re-identification approaches can be divided into single-shot and multi-shot. Furthermore, we distinguish whether multi-modal methods are used.

Zheng et al. (Zheng et al., 2011) and Zhao et al. (Zhao et al., 2013) both use single shot algorithms. The first use color and texture histograms,

whereas the latter uses dense color histograms and SIFT descriptors with the addition of using a saliency map to decide which parts of the person are the most descriptive.

Multi-shot is championed by Bak et. al. in (Bak et al., 2012) and Demirkus et. al. (Demirkus et al., 2010). Bak uses a large pool of features and the best one to describe a particular person is selected. Demirkus uses a set of more directly understandable soft biometrics, such as gender, hair color, and clothing color.

Moving away from the traditional visible light modality, Jüngling and Arens (Jüngling and Arens, 2010), presents a full single-shot re-identification pipeline based on infrared images. It detects candidates, then tracks and re-identifies them using SIFT-features. In the depth modality, Barbosa et. al. (Barbosa et al., 2012) re-identifies by comparing various physical body measurements (anthropometrics) obtained from the depth image. Velardo and Dugelay (Velardo and Dugelay, 2012) uses manually measured anthropometrics to prune the set of candidates for face recognition.

Finally, two papers combine several modalities. In (Møgelmoose et al., 2013b) RGB is used for detection and re-identification, and depth for segmentation and pruning of re-id candidates. This is the same basic approach as in this work. In (Møgelmoose et al., 2013a), thermal images and anthropometric measurements are added and the re-identification is performed in a truly multi-modal way with a combination of color histograms, SIFT features on thermal images, and anthropometric measurements obtained from depth images.

2.1 DATASETS

Several public datasets exist, though mostly sets captured with traditional visible light sensors.

In other modalities, not many exist. For depth, the RGB-D Person Re-identification Dataset (Barbosa et al., 2012) is one option. It contains 79 people in 4 different scenarios: Walking slowly with outstretched arms, two instances of walking from a frontal viewpoint, and walking from a rear viewpoint.

For this work, we use our own dataset with a surveillance-like camera setup. We have three sequences: Novi, Basement, and Hallway. They all contain sequences of persons walking diagonally towards and past the sensor twice. Novi, which was also used in (Møgelmoose et al., 2013b), contains 22 persons over 7800 frames (passes have varying lengths). Basement contains 35 persons over 7231 frames, and Hallway contains 10 persons over 4492 frames. Stats about the public as well as our own datasets can be

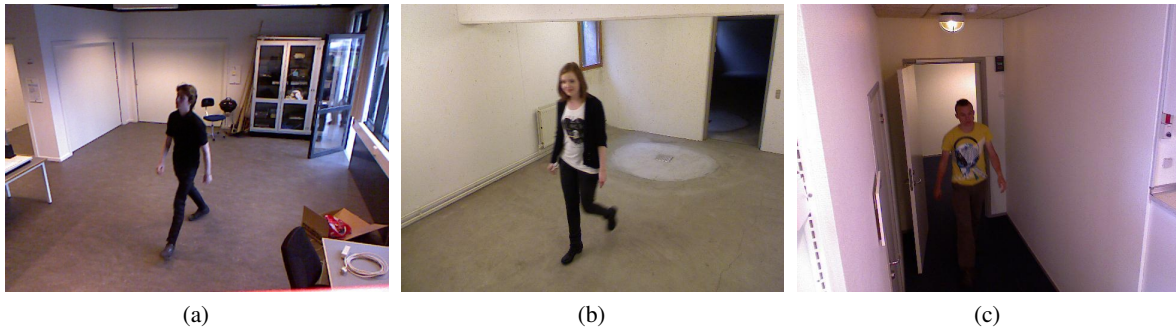


Figure 1: Example images from our own (a) Novi, (b) Basement, and (c) Hallway sequences.

	Novi	Basement	Hallway
Number of persons	22	35	10
Number of frames	7800	7231	4492
Contains image sequences	Yes	Yes	Yes
Available modalities	RGB, depth	RGB, depth, thermal	RGB, depth, thermal

Table 1: Statistics on the three data sequences used in this work.

seen in table 1. The sequences were captured with Microsoft Kinect for Xbox. Example pictures from each sequence can be seen in fig. 1.

3 ALGORITHM OVERVIEW

This paper describes a full re-identification system which takes a raw RGB-D feed as input and outputs whether or not a passing person has been seen before, and if so, what the previous ID was. This is different from many other re-identification papers which most often describe a core algorithm without much focus on all the other system parts that must be in place to have an actual working system. The process requires several steps: Persons must be detected and segmented, they must be modeled, and finally re-identified. On top of the re-identification process comes the process of keeping tabs on the person database. A flow-chart is shown in fig. 2.

3.1 Detection and segmentation

The detection is done with a standard HOG-detector as first proposed by Dalal and Triggs (Dalal and Triggs, 2005). The detector is trained on the INRIA Person Dataset introduced by the same paper. The detector runs on the RGB images and returns person bounding boxes.

The detected persons need to be segmented in fur-

ther detail. The bounding box is not sufficient, since we do not want to capture features from the background. Segmentation is achieved with a flood fill in the depth image. Persons not crawling on the floor are conveniently separated from the background in the depth modality, so a flood fill to similar pixels starting at the points

$$\mathbf{X} = \begin{bmatrix} 2/5 & 1/4 \\ 2/5 & 1/3 \\ 2/5 & 2/5 \\ 1/2 & 1/4 \\ 1/2 & 1/3 \\ 1/2 & 2/5 \\ 3/5 & 1/4 \\ 3/5 & 1/3 \\ 3/5 & 2/5 \end{bmatrix} \begin{bmatrix} b_w & 0 \\ 0 & b_h \end{bmatrix} + \begin{bmatrix} b_x & b_y \\ \vdots & \vdots \\ b_x & b_y \end{bmatrix}_{9 \times 2} \quad (1)$$

where \mathbf{X} is a 9×2 matrix containing the x and y coordinates of the flood fill points, b is the bounding box with subscript x , y , w , and h meaning top-left x -coordinate, top-left y -coordinate, width, and height respectively. The flood fill is performed at multiple positions to ensure that we have a stable object in the depth modality. A person is classified as stable if at least j depth points converge, i.e. the flood fill of these points fill out the same volume. For this implementation, $j = 4$.

3.1.1 Ground plane estimation

One problem with the flood fill is that at the feet of the subject, the fill is likely to spill onto the floor. To counter this, ground plane pixels on the depth image are removed. When the system is started initially, a ground plane is defined in the depth image. This is done by marking a number of points on the ground and performing a least squares solution of the bivariate polynomial:

$$z_{\text{poly}} = a_{00} + a_{01}x + a_{02}x^2 + a_{10}y + a_{20}y^2 + a_{11}xy \quad (2)$$

Although the floor is planar, the measurements of the floor from the Kinect depth sensor are representing

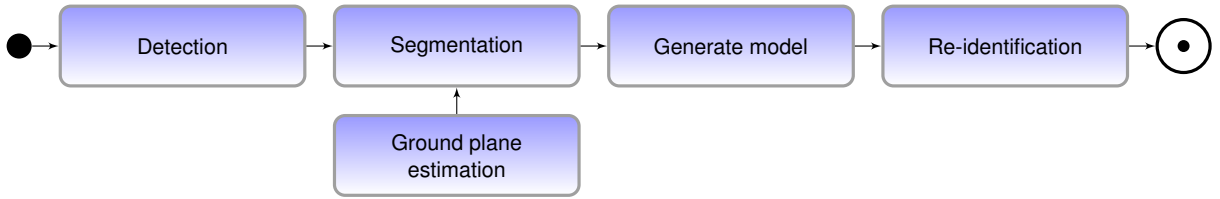


Figure 2: Illustration of the flow through the system.

the plane as a hyperbolic plane, thus stating the need for a bivariate polynomial. When the coefficients are determined, any pixel in the depth image close to the ground plane is colored black. Those pixels are the ones fulfilling the inequality in equation (3), where p is the pixel in question and t_{depth} defines the distance from the theoretical ground plane that is still considered part of that plane.

$$|z_{\text{poly}} - p_z| < t_{\text{depth}} \quad (3)$$

3.2 Person model

One of the objectives of this paper is to compare two types of multi-shot person models. They are both based on the two-part color histogram used in (Møgelmoose et al., 2013b): After a person is segmented, a color histogram is computed for the upper part of the body and the lower part of the body (as illustrated by the blue boxes in fig. 3). Each color channel is divided into 20 bins, the individual channel histograms are concatenated, and finally the two part histograms are concatenated for a feature vector of $20 \cdot 3 \cdot 2 = 120$ dimensions in the case of a 3 channel color space. In addition to the two modeling paradigms, 3 different color spaces were tested: RGB, HSV, and XYZ. For HSV and XYZ the luminance channels were removed to enhance lighting invariance, so in those cases the final histogram would be 80-dimensional and contain just the HS- and XZ-channels, respectively.

Two multi-shot schemes have been tested:

- 1) Mean histogram of all frames in a pass.
- 2) All frame-histograms saved individually.

In 1) the mean histogram is computed when a pass is over. Each bin is simply averaged:

$$m_i = \frac{1}{n} \sum_{j=0}^n h_{i,j} \text{ for } 0 \leq i < k \quad (4)$$

where m is the mean histogram, n is the number of frames in the pass, k is the number of bins in the histograms and $h_{i,j}$ is the value of bin i in histogram j .

In 2) no averaging takes place. Instead a pass is modeled after each histogram in it. See the following section on how each model is matched against the person database.

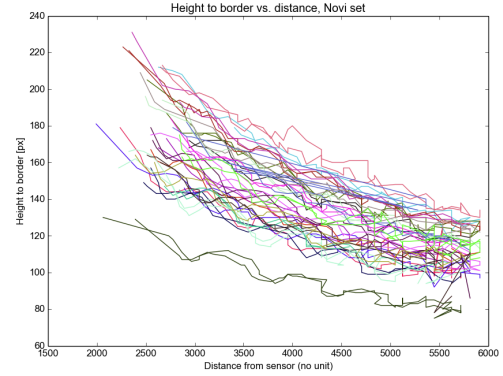


Figure 4: Curves depicting height-to-border versus distance for all tracks in a sequence. The curves are colored in pairs, such that two tracks of the same color are two passes by the same person. It can be seen that most lines are close to their partner of the same color, showing that the height measurement is stable across passes.

Both of the color-based models are augmented with a measure of the person's height. We use normalized height-to-border. This is the distance in pixels from the top of the person in the image, to the bottom of the frame, normalized by the depth of the observation. This reduces noise, as only one of the bounds of the height is now determined from the noisy depth sensor. It also allows for clipping.

In fig. 4 height-to-border versus depth is plotted. Because the surface and field-of-view is the same for all who pass by the camera, the only change that will happen to the curve for people of different heights is a shift in its y-axis intercept. Instead of approximating the full curve, we go for the less computationally heavy option of modelling each pass with the mean of the depth-normalized height-to-border, designated γ , for all instances in the pass:

$$\gamma = \frac{1}{n} \sum_{i=0}^n g_i \cdot d_i \quad (5)$$

where g_i is the height-to-border for observation i in the pass, and d_i is the distance to the person in that observation. While the person is not completely flat, for the purpose of this normalization, we use the depth of the seed point described in equation 1.



Figure 3: The left image illustrates a detection. On the right, the person has been segmented in the depth image, and the blue boxes illustrates the boxes which are used as basis for the color histograms.

3.3 Re-identification

A pruning stage based on the height measurement is used before the re-identification. The height of the probe is compared to the gallery by means of the absolute difference in their heights. If the mean normalized height-to-border is more than t_h away from a candidate, the candidate is not considered a match for this subject. t_h is found from analyzing training data before running the system. The threshold t_h is set to the mean of the height difference between wrong matches in the training set.

When re-identifying, the model of the current pass is compared to those of the persons in the database, which is initially empty, but will be built as time progresses. Both the mean histogram and the histogram series model use the Bhattacharyya distance (Bradski and Kaehler, 2008):

$$d(H_1, H_2) = \sqrt{1 - \sum_I \frac{\sqrt{H_1(I)H_2(I)}}{\sqrt{\sum_I H_1(I) \cdot \sum_I H_2(I)}}} \quad (6)$$

where $d(H_1, H_2)$ is the distance between the histograms H_1 and H_2 , and $H(I)$ is the value of bin I in the histogram H . The result is a number between 0 and 1, where 0 is a perfect match.

With mean histograms, where only two histograms - probe and gallery - are involved, the distance itself is used, and the subject is either re-identified, ignored, or added to the database. With histogram series, the model comprise a series of histograms. In this case, each histogram in the probe model is compared to each histogram in the database. The probe then casts a vote for the ID of the gallery-model which contains the histogram it is closest to, if that is within a separately trained ignore threshold. The gallery-model with the most votes is selected as the best candidate, provided it has the majority (more than 50%) of the possible votes.

3.4 Mean histogram

The re-identification process is governed by two thresholds:

$$t_n: \text{New threshold: Subjects with } d(H_1, H_2) > t_n \text{ are added as new persons} \quad (7)$$

$$t_i: \text{Ignore threshold: Subjects with } d(H_1, H_2) \leq t_i \text{ are re-identified} \quad (8)$$

This implicates that subjects with $t_i < d(H_1, H_2) \leq t_n$ are ignored, because they are too similar to other subjects, without being similar enough to trust the identification.

The thresholds are learned beforehand by observing a training set. The distances between all mean histograms in the training set are computed and stored in the set \mathcal{D} and divided into two sets \mathcal{D}^c and \mathcal{D}^w where \mathcal{D}^c contains distances between different observations of the same person and \mathcal{D}^w contains distances between histograms of different persons:

$$\mathcal{D}^c = \{\mathcal{D} | id(H_1) = id(H_2) \text{ in } d(H_1, H_2)\} \quad (9)$$

$$\mathcal{D}^w = \{\mathcal{D} | id(H_1) \neq id(H_2) \text{ in } d(H_1, H_2)\} \quad (10)$$

where $id(\bullet)$ is the person id connected with a histogram. The thresholds are then computed as:

$$t_n = \overline{\mathcal{D}^w} - 2 \cdot \sigma(\mathcal{D}^w) \quad (11)$$

$$t_i = \overline{\mathcal{D}^c} + \sigma(\mathcal{D}^c) \quad (12)$$

where $\bar{\bullet}$ denotes mean and $\sigma(\bullet)$ denotes standard deviation.

3.5 Histogram series

The re-identification for the histogram series model uses many of the same principles of the mean histo-

gram model, but is adapted to use many more histograms for each subject to encompass variations in lighting and pose. A histogram is computed for each frame in the pass of a subject and they are then compared to all histograms already in the database. When the shortest distance d_s to any gallery-histogram is less than t_i , the associated person id, p_s receives a vote. Thus, each subject histogram contributes with up to 1 vote, for a theoretical total of $len(\mathbf{H})$ votes: the number of histograms in the current pass. If there are no histograms in the pass, the subject is ignored. If any person in the gallery has received more than half the theoretical maximum, the subject is re-identified as him. If no gallery person satisfies this requirement, the subject is added as a new person.

It is worth noting that this method has no explicit option of ignoring the subject in case it is uncertain, other than in the case where no histograms exist.

4 EVALUATION

6 permutations of the system have been tested on 3 different sequences (see section 2.1). The 2 different multi-shot models have both been tested in 3 different color spaces: RGB, HSV, and XYZ. HSV and XYZ have been tested since they both model color closer to how the human eye sees it, and more specifically because they allow for exclusion of the luminance so that differing lighting conditions should affect performance less. That means that for the following tests all three RGB channels were used, in the HSV case only HS were used, and with XYZ only XZ were used.

The performance of the system varies with the order the persons are passing by the camera. If a person that is very hard to re-identify passes by the camera in the first two passes without any other entries in the database, odds are that he will be correctly re-identified. However, if a similar person enters the database before the second pass of person 1, they might be confused with each other and thus lower the performance. To even out this effect, all results presented below are averages of 100 runs where the subjects enters the system in random order. That should sufficiently even out any “lucky” or “unlucky” orderings and provide accurate results. For each run, all thresholds have been trained on a random subset of 20% of the sequence, which is then excluded from the rest of the run. The effect of the training set selection should also average out.

The re-identification performance can be characterized with 5 parameters:

1. Correct new

2. Wrong new

3. Correct ID

4. Wrong ID

5. Ignored

The first two describes how well the system distinguishes between known persons and new persons. Ideally, there should be no wrong new, as they are persons that are already in the database and should have been re-identified. Correct ID and wrong ID comprises the subjects that are neither ignored, correct new, nor wrong new, but are re-identified. Finally, ignored are the ones that are not handled because they are neither close enough to an existing person to be re-identified, nor different enough from the existing persons to be added to the database.

The results of the tests can be seen in table 3. Sequence length and detection performance varies greatly between sequences, as seen in table 2. Note that the Hallway sequence contains many shorter tracks, meaning that generalization, as well as the benefit from the multi-shot approach, declines heavily.

Generally, the mean histogram and histogram series approaches perform equally when looking at the percentage rates of the identification. The differences between the two approaches are most profound in the Basement and Novi sequences. The histogram series approach contains no ignore category which leads to a higher number of wrong new identifications than compared with the mean histograms. However, the method returns a significantly lower number of wrong identifications in both sequences. It is seen from the standard deviation of that the mean histogram exhibits a more stable performance than the histogram series on correct identifications whereas the opposite seems to be the case for wrong identifications. The number of wrong identifications is low across the board, so the weak spots are the wrong new- and ignored-counts which are rather high. Most new passes are correctly classified as such, at around 29-32 of 35 in the basement sequence, 8/10 and 21/22 in the Hallway and Novi sequences respectively.

The benefit of the ignore-functionality in the mean histogram model is illustrated in fig. 5. Blue columns are a histogram of distances between mean histograms of the same person, while red columns are a histogram of distances between different persons. The overlap between these shows that it is not possible to achieve perfect classification with a 1d decision boundary in this case. To counter this, an ignore zone is introduced - the space between the green and the yellow line, the thresholds, which can to some extent mitigate the effects of this overlap. In reality, when training on a subset of the data, the ignore

	Basement seq.	Hallway seq.	Novi seq.
Mean observation length:	25.5	10.3	40.7
Median observation length:	24	11.5	41
Minimum observation length:	4	2	5
Maximum observation length:	38	25	57

Table 2: Statistics on the amount of observations of captured persons for each sequence. The numbers are based on the amount of times a single person was detected and modeled in a single pass.

Basement sequence								
		Correct new	Wrong new	Correct ID	Wrong ID	Ignored	% correct	% wrong
RGB	Mean histogram	29.31 (2.92)	4.53 (7.10)	11.76 (5.34)	1.22 (2.50)	8.18 (6.82)	90.62 %	9.38 %
	Histogram series	32.61 (1.44)	8.64 (7.37)	13.00 (7.07)	0.74 (2.14)	0.00 (0.00)	94.60 %	5.40 %
HS	Mean histogram	28.75 (3.23)	3.20 (7.36)	12.57 (5.81)	1.18 (2.83)	9.30 (6.78)	91.43 %	8.57 %
	Histogram series	32.71 (1.37)	8.13 (7.77)	13.49 (7.51)	0.67 (2.27)	0.00 (0.00)	95.24 %	4.76 %
XY	Mean histogram	29.02 (3.26)	4.72 (7.12)	11.24 (5.15)	1.68 (3.01)	8.34 (7.35)	86.97 %	13.03 %
	Histogram series	32.54 (1.45)	8.88 (7.34)	12.59 (6.87)	0.98 (2.33)	0.00 (0.00)	92.78 %	7.22 %

Hallway sequence								
		Correct new	Wrong new	Correct ID	Wrong ID	Ignored	% correct	% wrong
RGB	Mean histogram	8.36 (1.00)	4.07 (2.34)	1.15 (1.37)	0.61 (1.01)	0.81 (1.62)	65.34 %	34.66 %
	Histogram series	8.59 (0.77)	4.45 (2.10)	1.30 (1.57)	0.66 (1.18)	0.00 (0.00)	66.33 %	33.67 %
HS	Mean histogram	8.15 (1.17)	3.95 (2.41)	1.34 (1.61)	0.39 (0.78)	1.17 (2.13)	77.46 %	22.54 %
	Histogram series	8.61 (0.62)	4.44 (2.14)	1.44 (1.72)	0.51 (0.76)	0.00 (0.00)	73.85 %	26.15 %
XY	Mean histogram	8.37 (0.96)	4.11 (2.29)	1.15 (1.37)	0.63 (1.10)	0.74 (1.58)	64.61 %	35.39 %
	Histogram series	8.57 (0.71)	4.33 (2.14)	1.37 (1.58)	0.73 (1.22)	0.00 (0.00)	65.24 %	34.76 %

Novi sequence								
		Correct new	Wrong new	Correct ID	Wrong ID	Ignored	% correct	% wrong
RGB	Mean histogram	21.15 (1.40)	3.79 (2.98)	9.68 (2.73)	0.25 (1.31)	1.13 (1.89)	97.48 %	2.52 %
	Histogram series	21.51 (0.70)	9.12 (4.21)	5.31 (4.24)	0.06 (0.42)	0.00 (0.00)	98.88 %	1.12 %
HS	Mean histogram	20.64 (1.86)	2.42 (2.13)	10.52 (2.38)	0.44 (1.45)	1.98 (3.21)	95.99 %	4.01 %
	Histogram series	21.48 (0.77)	9.18 (4.53)	5.23 (4.59)	0.11 (0.91)	0.00 (0.00)	97.94 %	2.06 %
XY	Mean histogram	21.14 (1.17)	4.89 (3.48)	8.83 (3.10)	0.34 (1.26)	0.80 (1.74)	96.29 %	3.71 %
	Histogram series	21.46 (0.87)	10.12 (3.91)	4.31 (3.93)	0.11 (0.91)	0.00 (0.00)	97.51 %	2.49 %

Table 3: Re-identification performance of the 6 system configurations on 3 different sequences. All numbers are averaged over 100 runs with random enrollment order. The standard deviation of the results are shown in parenthesis.

		Without height		With height		Difference	
		% correct	% wrong	% correct	% wrong	% correct	% wrong
Basement	Mean histogram	82.17 %	17.83 %	90.67 %	9.33 %	8.50 %	-8.50 %
	Histogram series	87.28 %	12.72 %	94.21 %	5.79 %	6.93 %	-6.93 %
Hallway	Mean histogram	64.64 %	35.36 %	69.14 %	30.86 %	4.50 %	-4.50 %
	Histogram series	67.34 %	32.66 %	68.47 %	31.53 %	1.10 %	-1.10 %
Novi	Mean histogram	92.03 %	7.97 %	96.59 %	3.41 %	4.56 %	-4.56 %
	Histogram series	96.50 %	3.51 %	98.11 %	1.89 %	1.61 %	-1.61 %
Average		81.66 %	18.34 %	86.20 %	13.80 %	4.53 %	-4.53 %

Table 4: Comparison of re-identification performance with and without the height-based candidate pruning step.

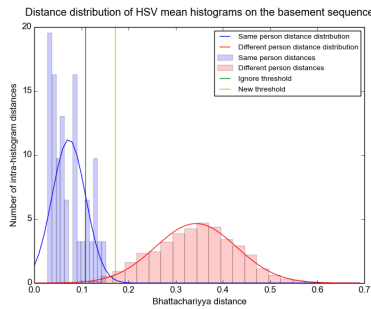


Figure 5: Distribution of distances between histograms in the full basement sequence. There is a clear overlap of distances between histograms from the same person and histograms from different persons. When using a distance threshold to classify, this will result in wrong identifications. The ignore-threshold allows to remove the distances that are the most affected by this overlap.

zones are generally wider than in this example. It is possible that a classification in a higher dimensional space would work better and allow discarding the ignore zone.

Table 4 shows how the height-based pruning step improves the re-id rates across all methods. By discarding obviously wrong candidates based on height, the correct re-id rate goes up by 4.53 percentage points on average.

We have been unable to compare our results to the work of others, as they do not present full-flow systems, but rely on tightly pre-cropped images of persons. Furthermore, our system needs depth images as well as RGB, so no existing dataset has been compatible. We also do not present CMC-curves as that ranking system works poorly for on-the-fly enrollment systems, where, in many cases, there are simply not enough entries in the database to do a proper ranking.

We can, however, compare some of our results to the work previously presented in (Møgelmoose et al., 2013b). Not all stats are directly comparable, but the correct and wrong ID rates are. In that work, they are 68% and 0%, with an ignore rate of 24%. The system presented here has a much higher correct ID rate, but at the cost of a somewhat higher wrong ID rate.

5 CONCLUSION

This work presented a re-identification system using RGB-D data and compared several model and color space configurations. It introduces 3 new, different re-identification sequences for testing, and goes through all stages from candidate detection to identification. Furthermore, it investigates how to handle

online enrollment of subjects, a subject few previous works have touched. Future work includes more sophisticated multi-shot models, and enhancing the system to cope with multiple, co-occluding subjects in crowded environments.

REFERENCES

- Bak, S., Charpiat, G., Corvée, E., Brémond, F., and Thonnat, M. (2012). Learning to Match Appearances by Correlations in a Covariance Metric Space. In *ECCV (3)*, volume 7574 of *LNCS*, pages 806–820. Springer.
- Barbosa, I. B., Cristani, M., Bue, A. D., Bazzani, L., and Murino, V. (2012). Re-identification with RGB-D Sensors. In *ECCV Workshops (1)*, volume 7583 of *LNCS*, pages 433–442. Springer.
- Bradski, G. and Kaehler, A. (2008). *Learning OpenCV*, chapter 7, pages 201–202. O’Reilly.
- Dalal, N. and Triggs, B. (2005). Histograms of Oriented Gradients for Human Detection. In *CVPR*.
- Demirkus, M., Garg, K., and Guler, S. (2010). Automated person categorization for video surveillance using soft biometrics. pages 76670P–76670P–12.
- Doretto, G., Sebastian, T., Tu, P. H., and Rittscher, J. (2011). Appearance-based person reidentification in camera networks: problem overview and current approaches. *J. Ambient Intelligence and Humanized Computing*, 2(2):127–151.
- Jüngling, K. and Arens, M. (2010). Local Feature Based Person Reidentification in Infrared Image Sequences. In *AVSS*, pages 448–455. IEEE Computer Society.
- Møgelmoose, A., Clapés, A., Bahnsen, C., Moeslund, T. B., and Escalera, S. (2013a). Tri-modal Person Re-identification with RGB, Depth and Thermal Features. In *9th IEEE Workshop on Perception Beyond the Visible Spectrum*. IEEE.
- Møgelmoose, A., Moeslund, T. B., and Nasrollahi, K. (2013b). Multimodal Person Re-Identification using RGB-D Sensors and a Transient Identification Database. In *International Workshop on Biometrics and Forensics*.
- Velardo, C. and Dugelay, J. (2012). Improving Identification by Pruning: A Case Study on Face Recognition and Body Soft Biometric. In *WIAMIS*, pages 1–4. IEEE.
- Zhao, R., Ouyang, W., and Wang, X. (2013). Unsupervised Saliency Learning for Person Re-identification. *CVPR*.
- Zheng, W., Gong, S., and Xiang, T. (2011). Person re-identification by probabilistic relative distance comparison. In *CVPR*, pages 649–656. IEEE.