Building Facade Modelling using the Kronecker Product: The problem of the automatic detection of repeated 2D patterns

The objective of this diploma thesis is the modification of an algorithm described in the paper titled "*Automatic Kronecker Product Model Based Detection of Repeated Patterns in 2D Urban Images*". The initial algorithm, given a rectified **2D building facade image**, begins by **clustering** the rows and columns of the image into those that contain or do not contain repeated patterns (i. e. windows). Subsequently, the two **autocorrelation sequences** of the cluster indices are calculated and, using them, the **spatial periods** of the patterns in the facade can be estimated. The image is segmented according to the periods, and **Kronecker Product SVD** (Singular Value Decomposition) is applied in order to produce a **low-rank model** of the original image.

In the context of this diploma thesis, in order to achieve a more precise period estimation, the **Self Quotient Image** of the original image is used, which is relatively insensitive to photometric distortion. Furthermore, clustering is applied to the upper levels of the image's **Gaussian pyramid**, where distracting details are absent. Lastly, **filtering is applied to the frequency spectrum of the autocorrelation sequences**, reducing the effect of misleading repeated elements of the facade.

Through testing on **52** images, the modified algorithm achieved **optimal modelling in 47%**, and **satisfactorily better modelling in 81%** more cases than the original version. In some cases the period estimation was slightly less precise than the original algorithm, leading to suboptimal results. The test images were selected from a handful of facade datasets, with misleading patterns, noise and photometric distortions in mind. Evaluation of modelling as 'optimal' or 'satisfactory' was unavoidably subjective to a minute degree, but was done with the general range of the algorithm's modelling output in mind.

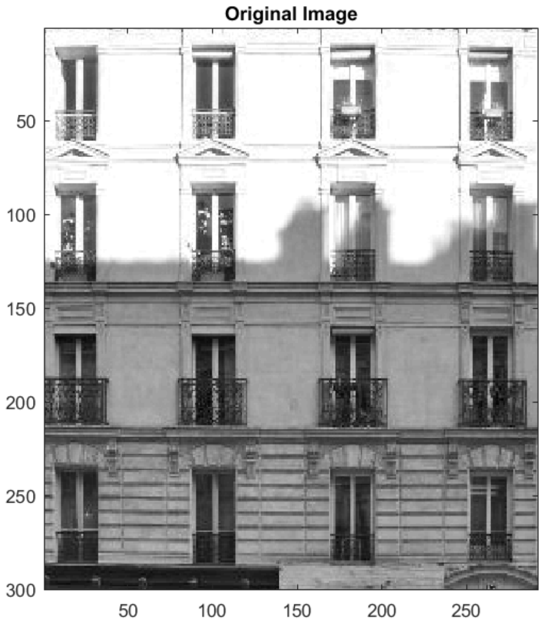
1. **Below is an example of a case which is problematic for the original algorithm, but is modelled flawlessly (with the original modelling procedure in mind) by the modified version.**

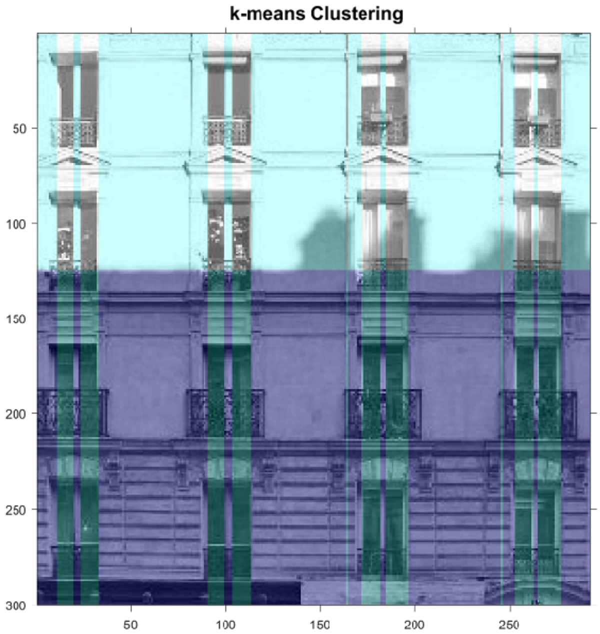
2. **Afterwards, demonstrations for the Self Quotient Image and the autocorrelation filtering procedures are given.**

3. **Lastly, a step-by-step example of the modified algorithm is given for a test image with optimal results.**

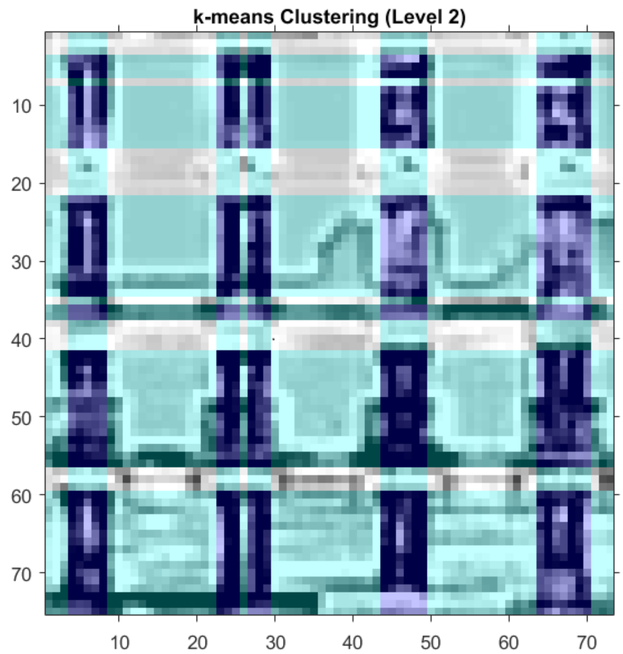
1. Algorithm Results

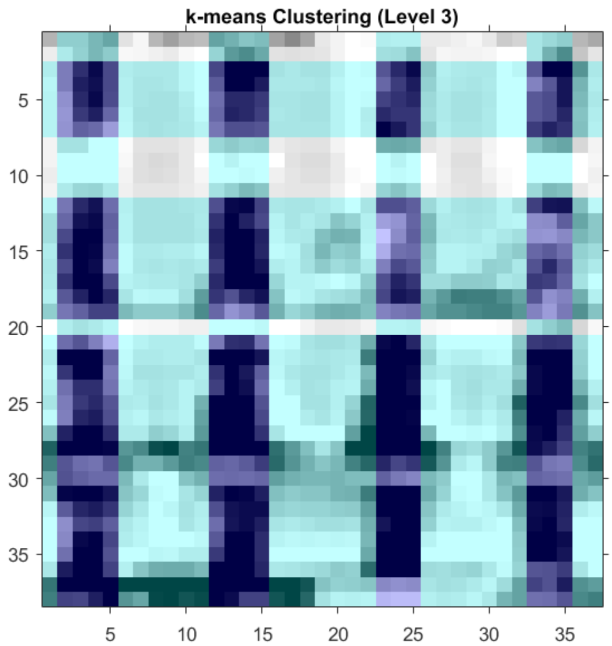
k-means Clustering (Original version) (Cyan for 1st class, transparency for 2nd , dark blue for overlap of 1st in both directions)



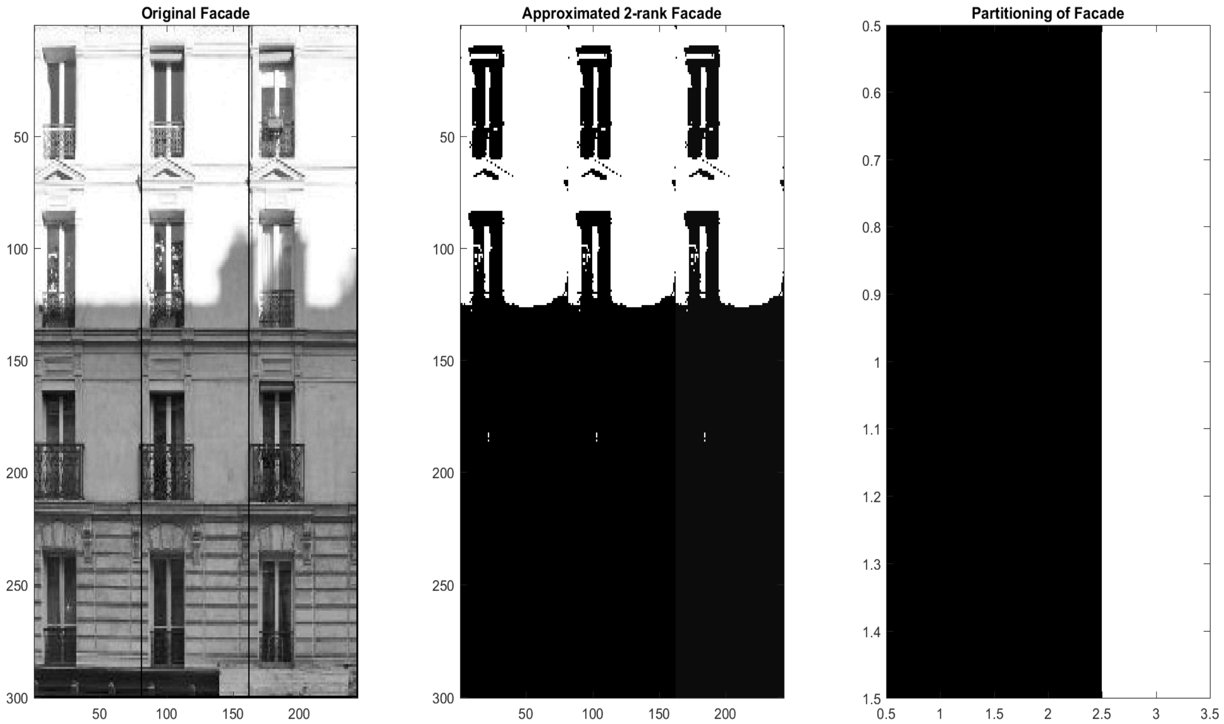


k-means Clustering (Modified Version) (last two levels of the Gaussian pyramid):

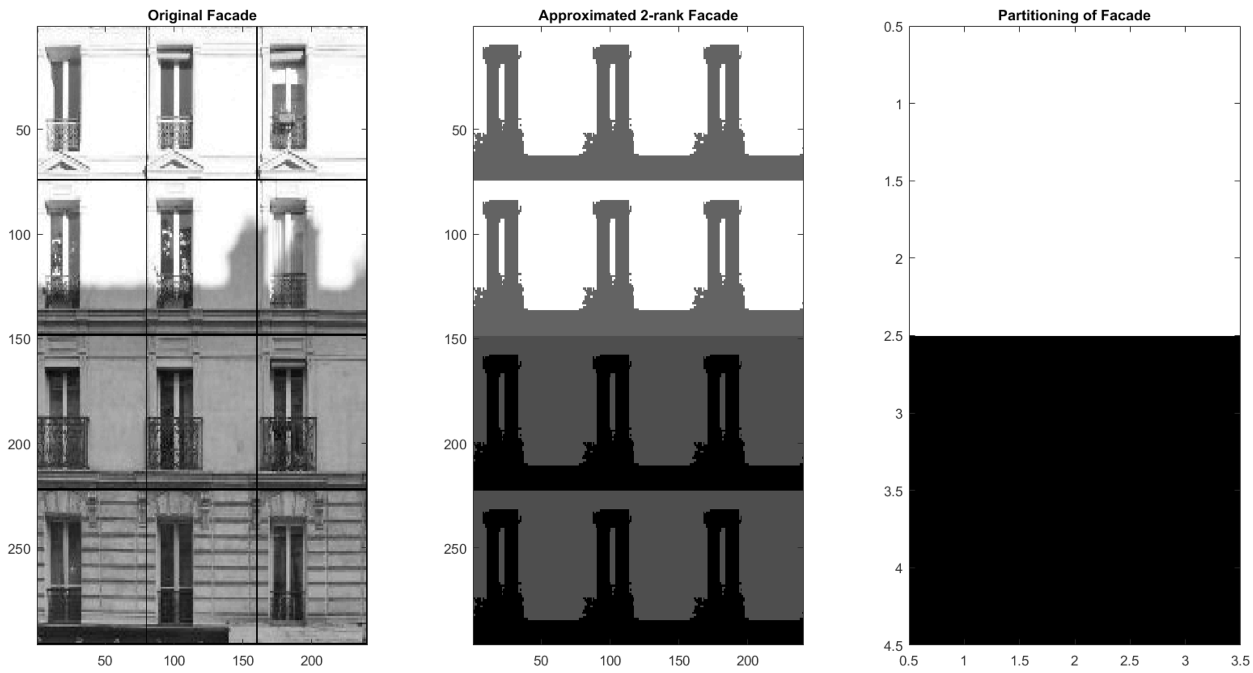




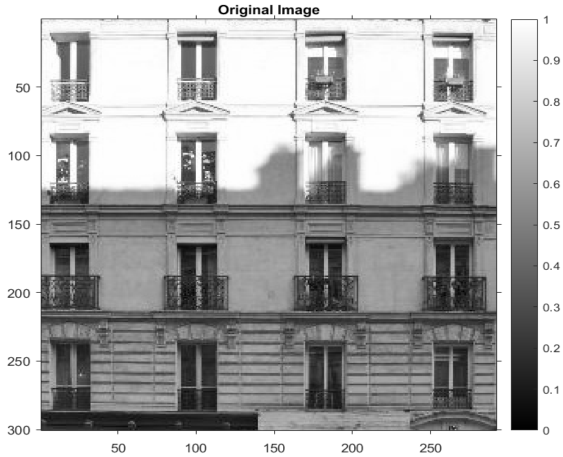
Facade low-rank modelling (Original Version):

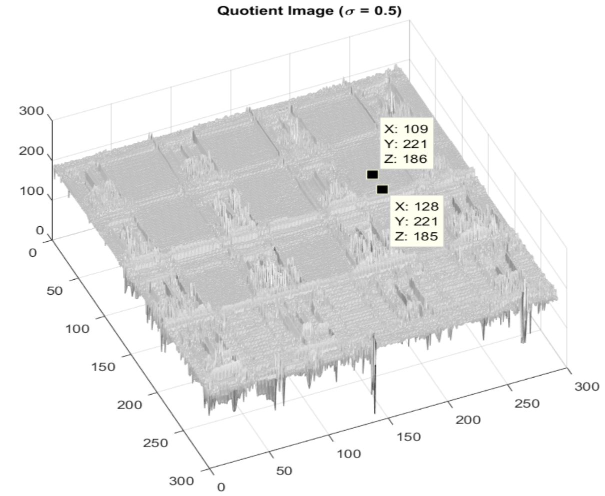


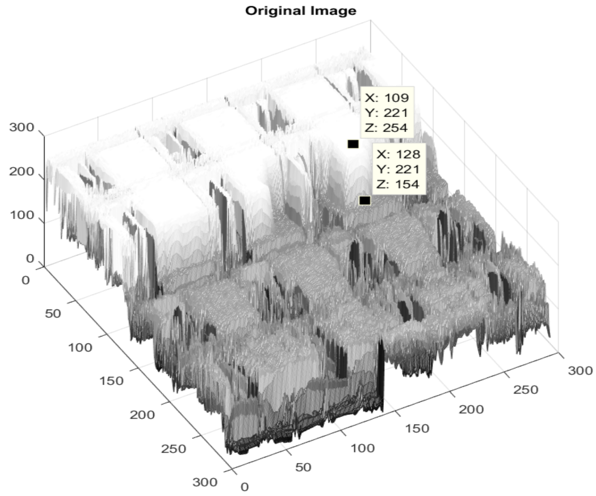
Facade low-rank modelling (Modified Version):

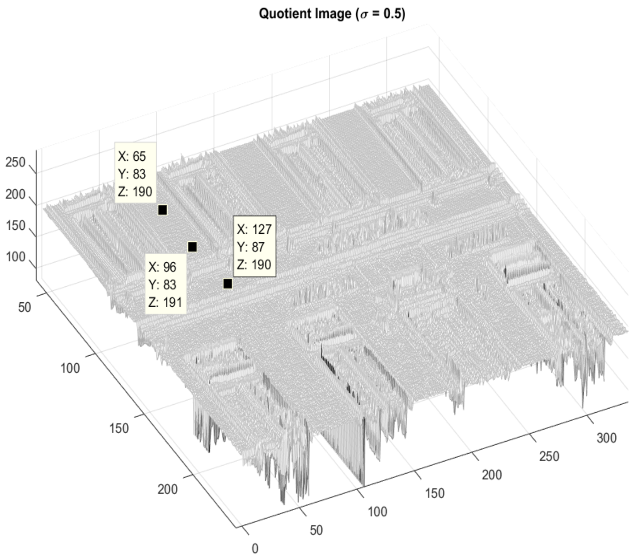


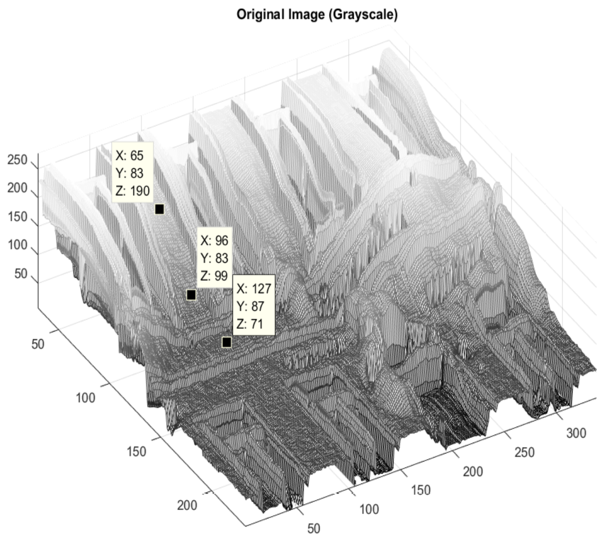
2a) Self Quotient Image Demonstration



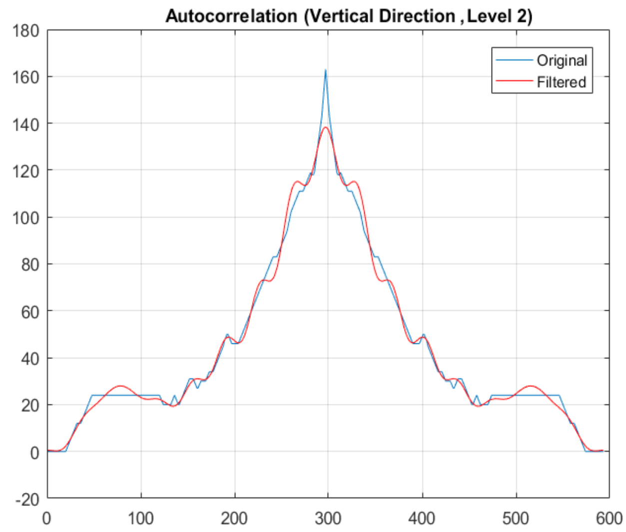


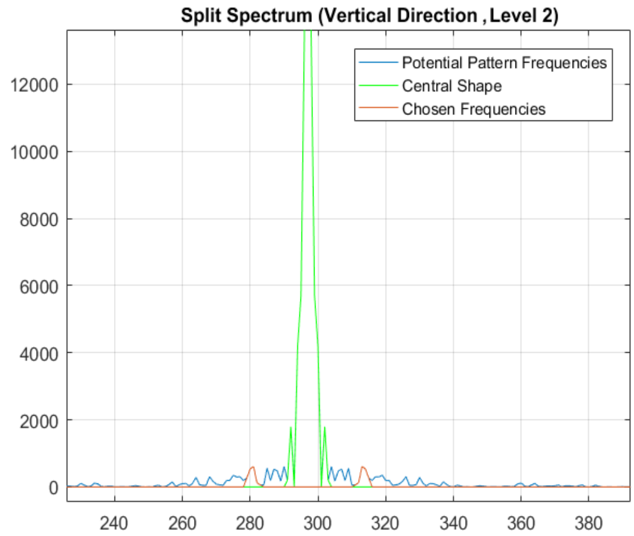


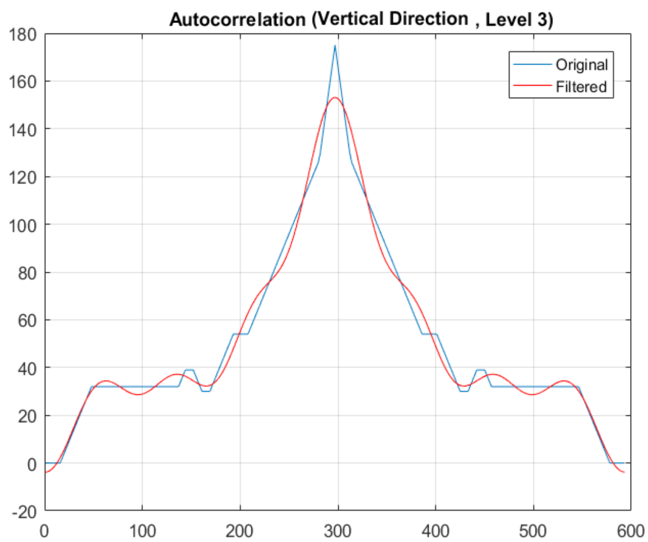


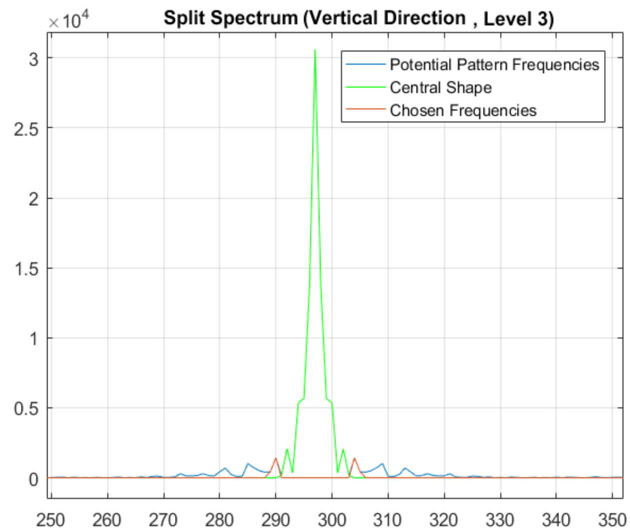


2b) Autocorrelation Spectrum Filtering Demonstration



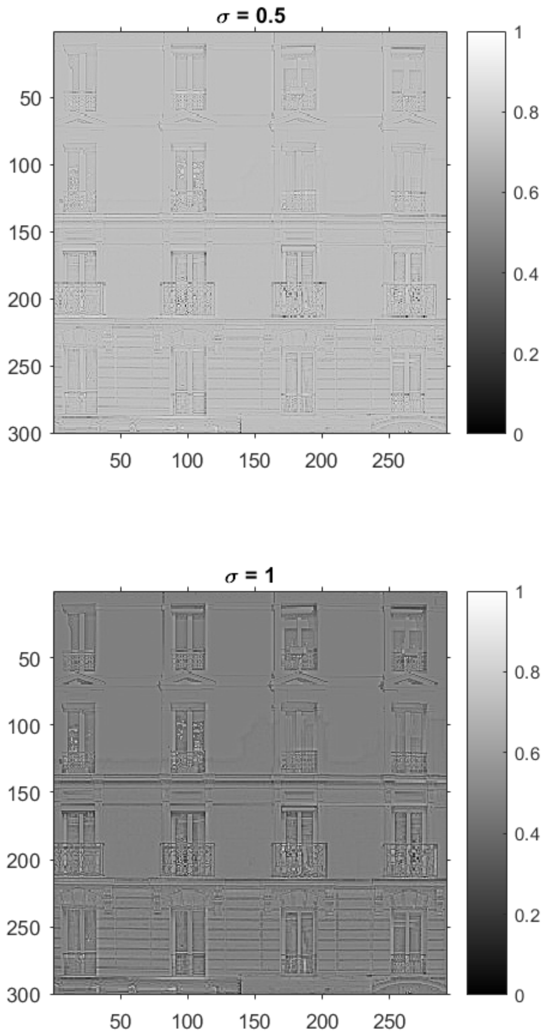




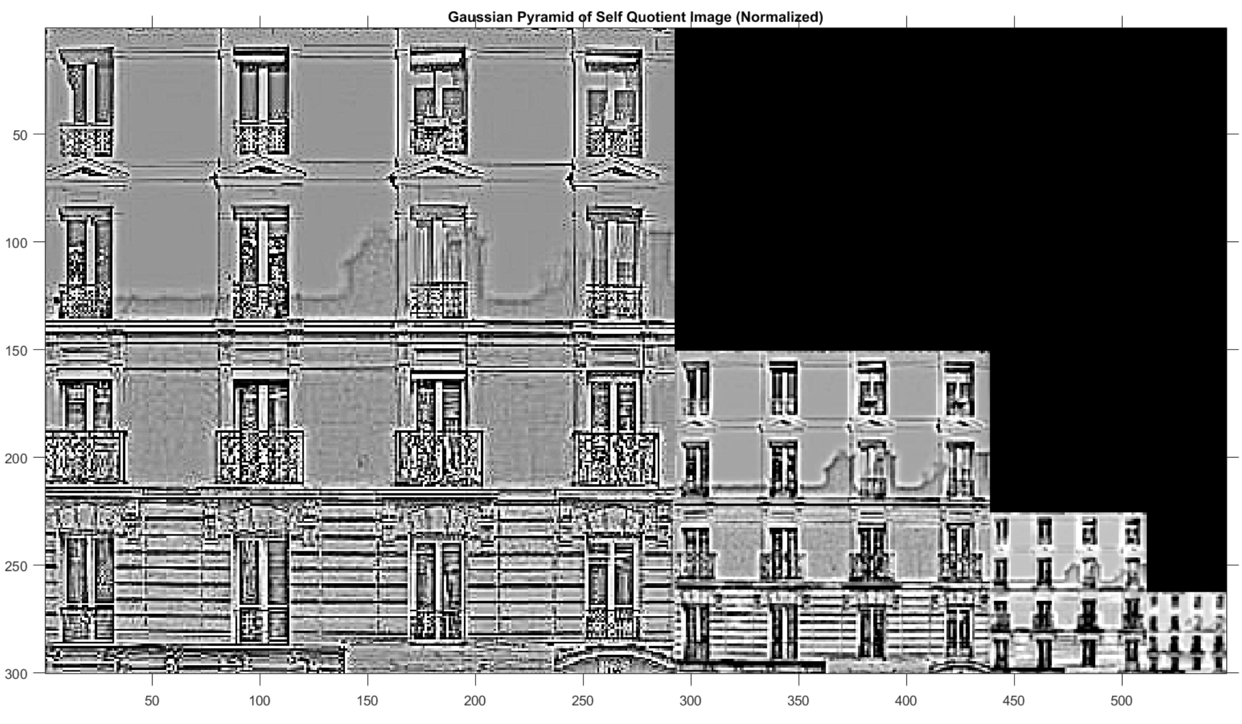


3) Algorithm Stages in Test Case

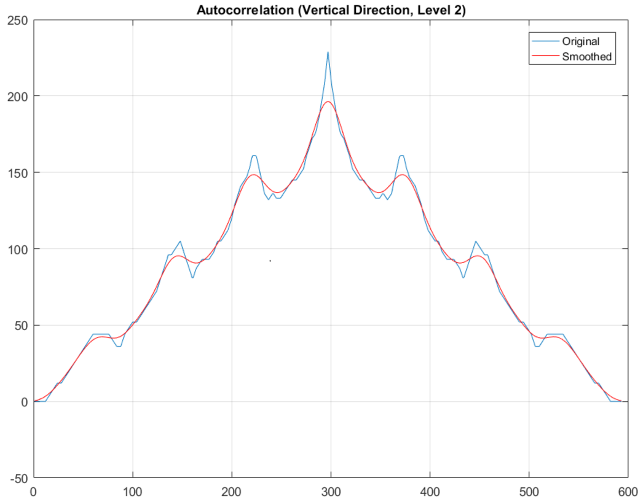
1. Calculation of Self Quotient Images with different Gaussian kernel variance:

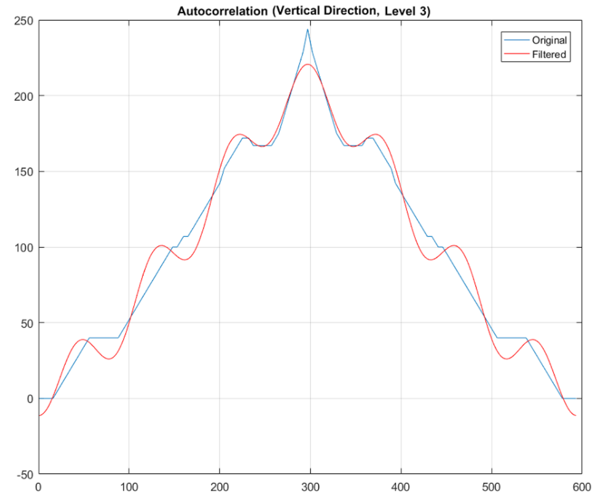


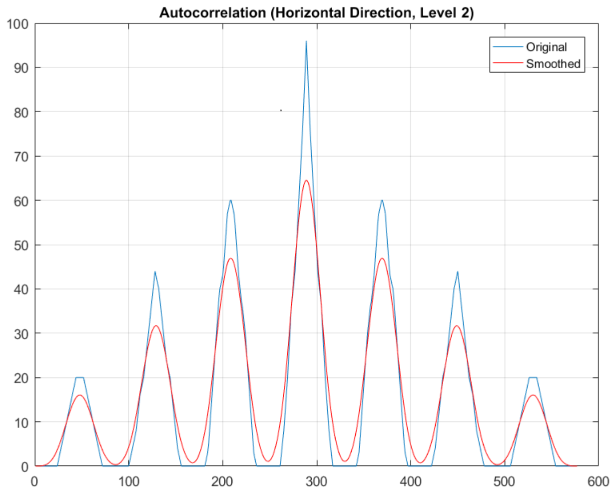
2. Gaussian Pyramid Construction (after combining SQIs and passing through sigmoid function)

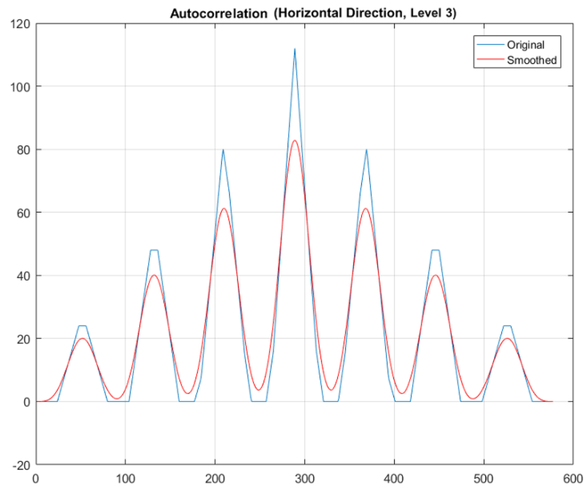


3. Cluster autocorrelation sequence estimation & smoothing / filtering:

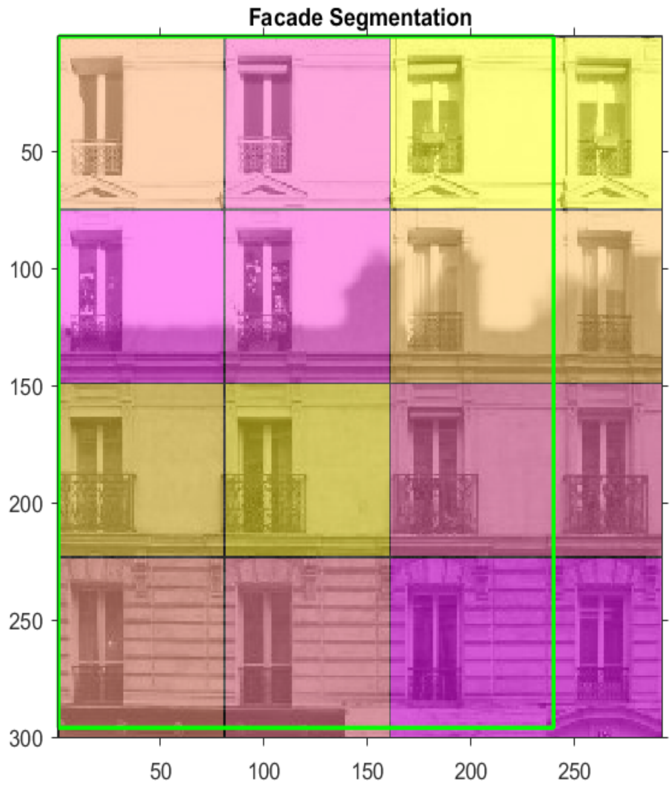








4. **Facade segmentation** (last column of windows is ignored because the algorithm requires consistent block size):



5. **Low-rank modelling** (Partitioning are visualized as array of class numbers)