Embedded System for Onboard Object Detection in Hyperspectral Images

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MEEC

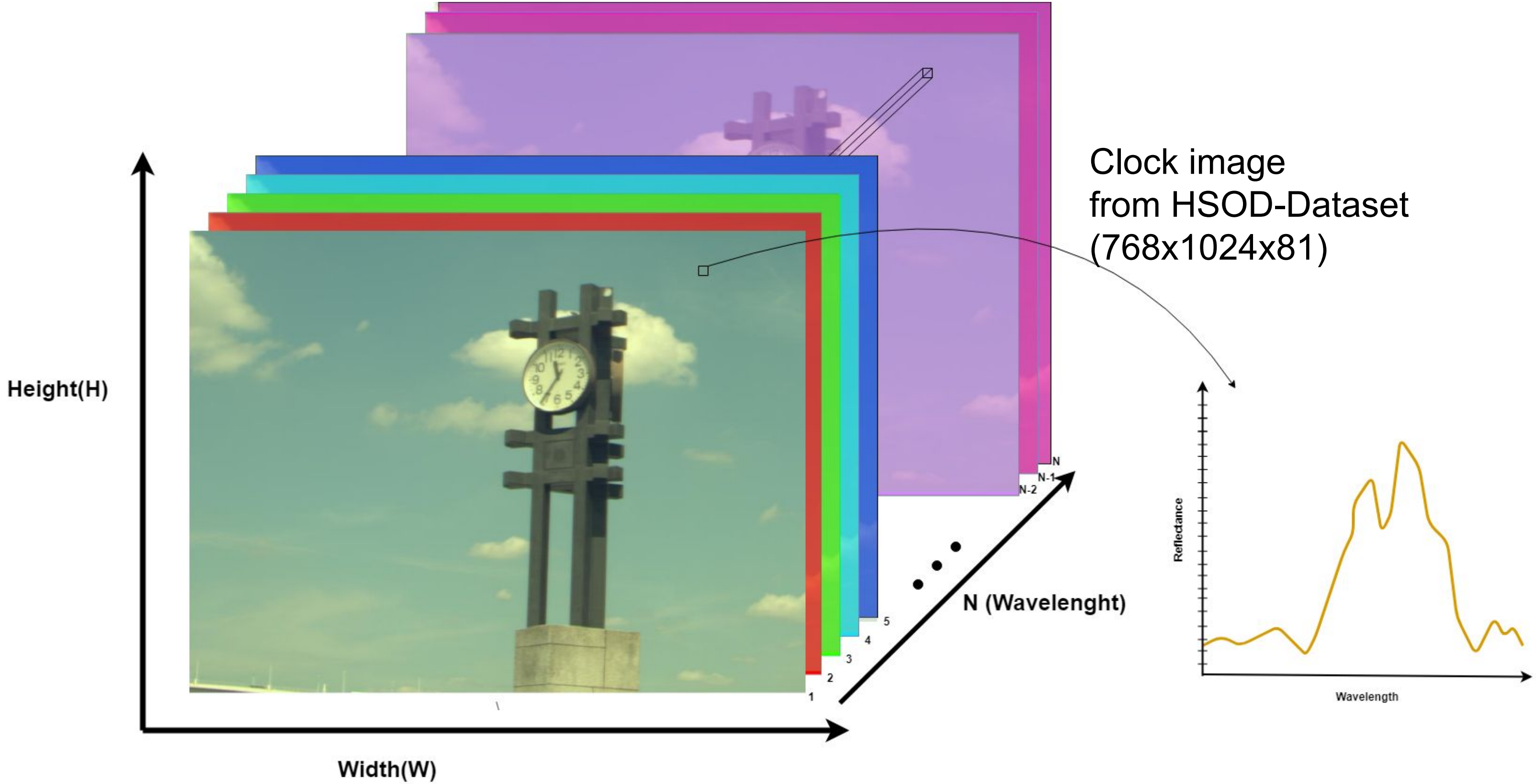
2nd Cycle Integrated Project in Electrical and Computer Engineering

Objectives/Motivation

Develop a hardware/software system for target detection on hyperspectral images(HSI), executing on a Soc-Fpga

- Hyperspectral
  - contain much more data, when comparing to RGB
  - required for high level analysis
- Deep Learning
  - allow for better and more advanced HSIs Target detection
  - Efficient capture of details in the data but computing intensive
- Embedded systems
  - Real-time local computation
  - allow reduction in latency and more secure systems

Hyperspectral image



Clock image
from HSOD-Dataset
(768x1024x81)

Hyperspectral Imaging Target Detection

- SAM (Spectral Angle Mapper) -> Conventional Method
  - Computes SAD between reference spectral signature and all the pixels in an image.
  - Smallest angle indicates high resemblance in spectral signatures

SAD (Spectral Angle Difference):

$$\theta = \cos^{-1}\left(\frac{\mathbf{x}_1 \cdot \mathbf{x}_2}{\|\mathbf{x}_1\|\|\mathbf{x}_2\|}\right)$$

x1: Spectral signature reference, x2: Spectral signature from image

Hyperspectral Imaging Target Detection

Deep Learning Methods

- CNNs
  - 1D,2D,3D
- Attention based
  - More recent, better accuracy than CNNs,
  - S2adet (Object Detection in Hyperspectral Image via Unified Spectral-Spatial Feature Aggregation)
  - SMN (Spectrum-Driven Mixed-Frequency Network)

Attention

$$\text{Attention}(Q,K,V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V,$$

*dk=2

$$X_1 = \begin{bmatrix} 0.93 & 0.423 & 0.33 \\ 0.12 & 0.03 & 0.56 \\ 0.27 & 0.7 & 0.09 \end{bmatrix}$$

Hyperspectral Image 3 by 3 by 4

Flatten

$$X_1 = \begin{bmatrix} 0.93 & 0.90 & 0.25 & 0.90 \\ 0.423 & 0.20 & 0.46 & 0.20 \\ 0.33 & 0.69 & 0.03 & 0.69 \\ 0.12 & 0.73 & 0.56 & 0.73 \\ 0.03 & 0.42 & 0.27 & 0.42 \\ 0.56 & 0.94 & 0.96 & 0.94 \\ 0.27 & 0.58 & 0.66 & 0.58 \\ 0.7 & 0.05 & 0.64 & 0.05 \\ 0.09 & 0.66 & 0.21 & 0.66 \end{bmatrix}$$

Flatten Hyperspectral Image 9 by 4

$$Q = X_1 W^Q, \quad K = X_1 W^K, \quad V = X_1 W^V,$$

$$Q = \begin{bmatrix} -0.25 & 0.90 \\ 0.46 & 0.20 \\ -0.69 & -0.69 \\ -0.88 & 0.73 \\ 0.20 & 0.42 \\ -0.96 & -0.94 \\ 0.66 & -0.58 \\ -0.64 & 0.05 \\ -0.21 & -0.66 \end{bmatrix}$$

Q Matrix 9 by 2

$$V = \begin{bmatrix} -0.25 & 0.90 \\ 0.46 & 0.20 \\ -0.69 & -0.69 \\ -0.88 & 0.73 \\ 0.20 & 0.42 \\ -0.96 & -0.94 \\ 0.66 & -0.58 \\ -0.64 & 0.05 \\ -0.21 & -0.66 \end{bmatrix}$$

V Matrix 9 by 2

$$K^T = \begin{bmatrix} -0.92 & 0.73 & -0.31 & -0.73 & -0.57 & -0.90 & -0.58 & 0.33 & -0.90 \\ 0.71 & -0.32 & 0.93 & -0.54 & -0.97 & -0.69 & -0.32 & 0.45 & -0.49 \end{bmatrix}$$

K^T Matrix 2 by 9

Attention

$$\text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right) = \begin{bmatrix} 0.19 & 0.07 & 0.20 & 0.08 & 0.06 & 0.08 & 0.09 & 0.13 & 0.09 \\ 0.10 & 0.15 & 0.13 & 0.09 & 0.09 & 0.09 & 0.10 & 0.15 & 0.09 \\ 0.09 & 0.06 & 0.06 & 0.14 & 0.16 & 0.17 & 0.12 & 0.05 & 0.15 \\ 0.21 & 0.04 & 0.16 & 0.10 & 0.07 & 0.10 & 0.10 & 0.09 & 0.11 \\ 0.13 & 0.12 & 0.15 & 0.09 & 0.08 & 0.09 & 0.10 & 0.14 & 0.09 \\ 0.07 & 0.05 & 0.04 & 0.15 & 0.18 & 0.19 & 0.12 & 0.04 & 0.16 \\ 0.06 & 0.20 & 0.07 & 0.11 & 0.14 & 0.11 & 0.11 & 0.12 & 0.10 \\ 0.14 & 0.06 & 0.11 & 0.12 & 0.11 & 0.13 & 0.11 & 0.08 & 0.13 \\ 0.08 & 0.10 & 0.06 & 0.13 & 0.16 & 0.15 & 0.12 & 0.07 & 0.13 \end{bmatrix}$$

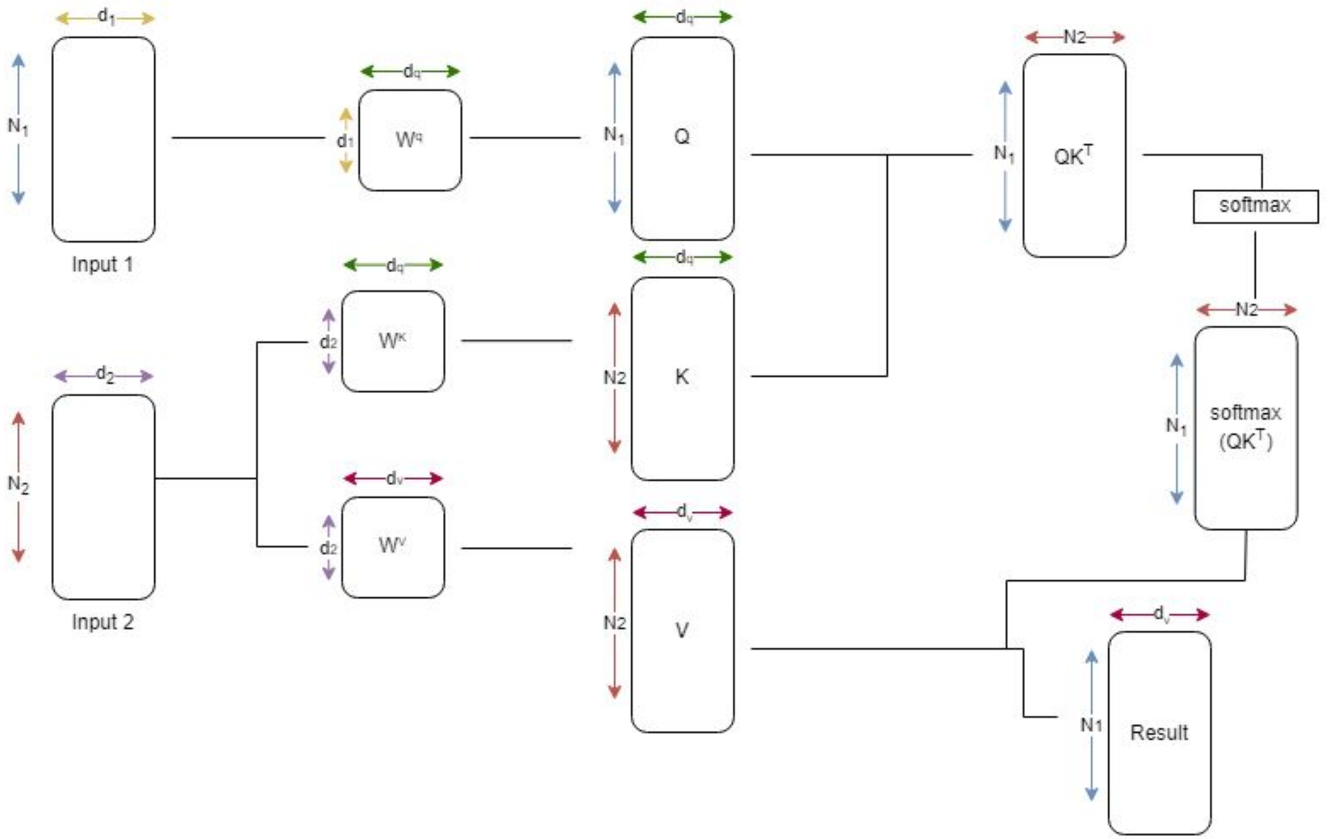
QK Matrix 9 by 9

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V,$$

*softmax applied row wise
*dk=2

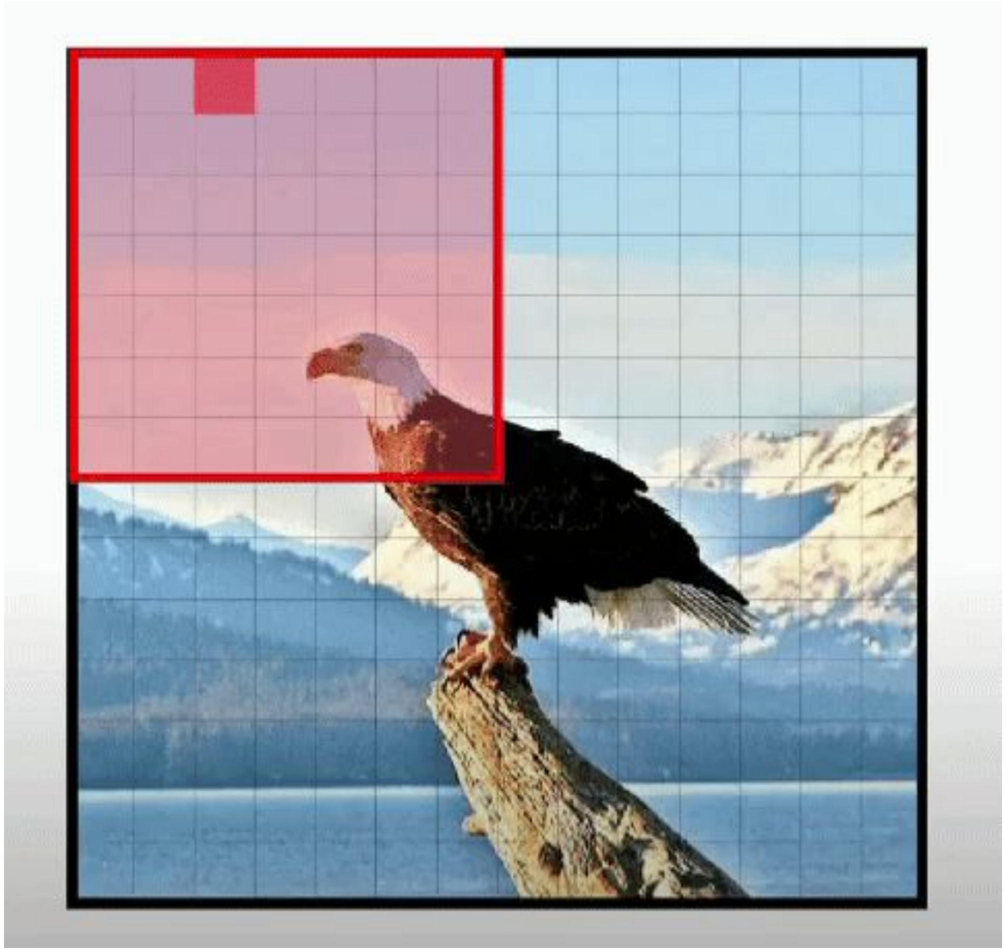
Attention

Cross Attention



Attention

Neighborhood Attention



Hyperspectral Imaging Target Detection

Attention methods:

SMN:

Metrics	FLOPs (G)	#Params (M)
SMN-R (Ours)	**14.58**	7.27

dataset: HSOD, input 224x224x50

S2aDet:

Metrics	FLOPs (G)	#Params (M)
S2ADet	169.20	48.64

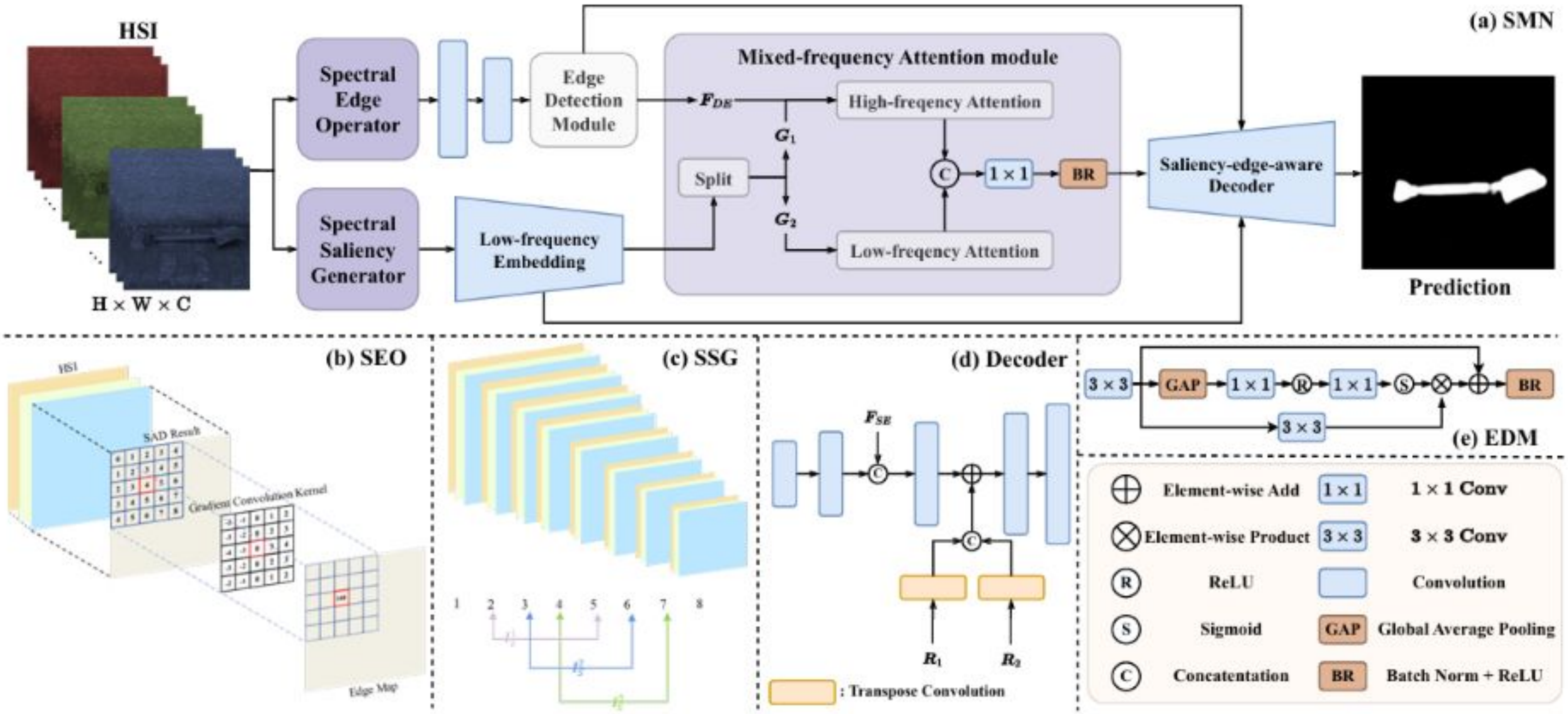
dataset:HOD3K, input 512x256x16

Vantagens:

- Menos parâmetros
- Dataset open source, imagens 768x1024x81

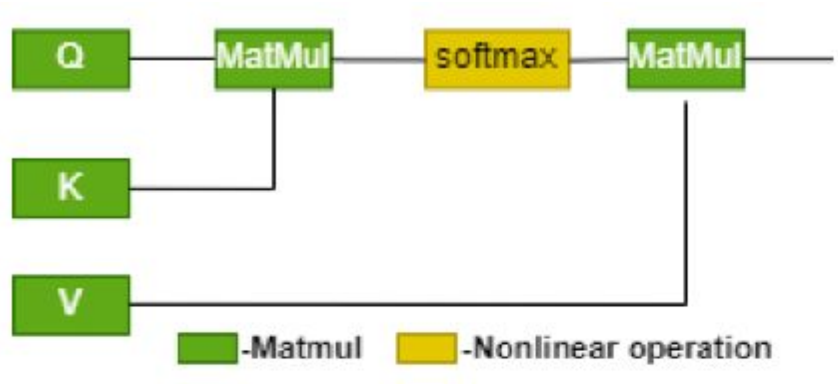
reduzidas para 224x224x50

SMN- Spectrum-driven Mixed-frequency Network

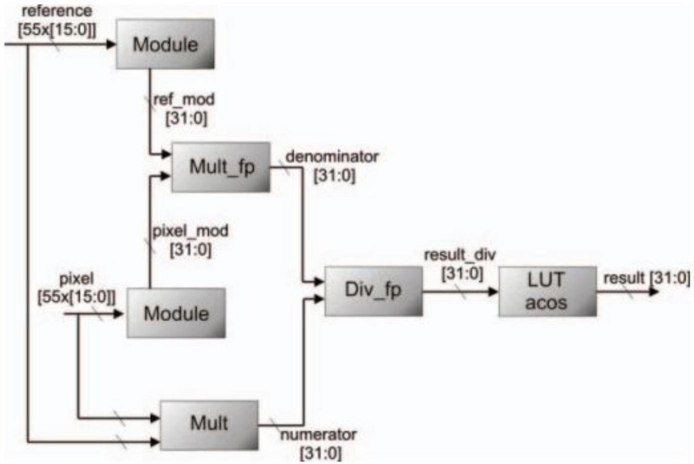


Hardware acceleration opportunities

Attention:



SAD:



CNN:

- MatMul operations
- Layer parallelism

Model Optimization opportunities

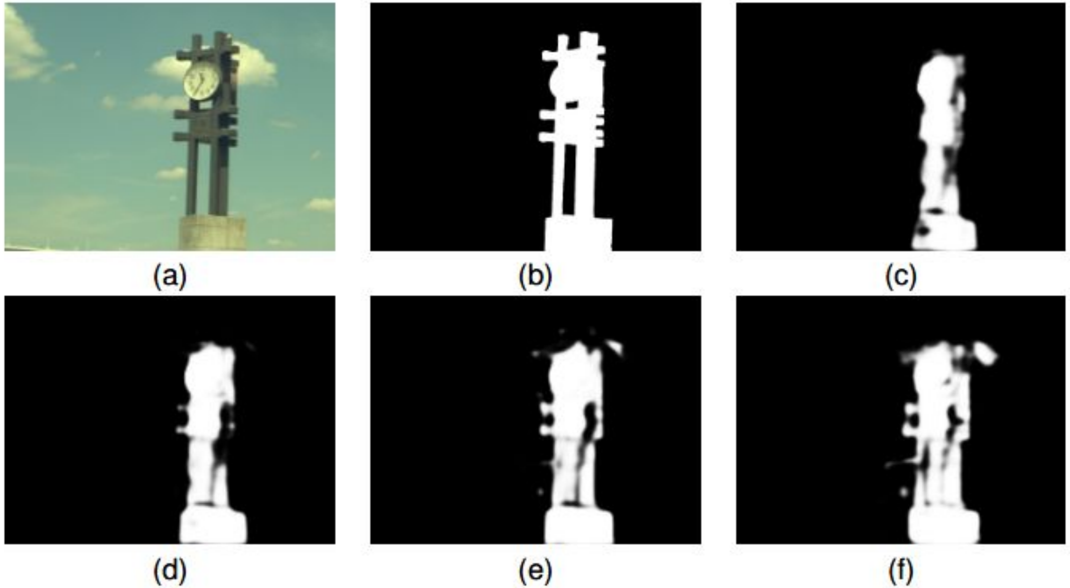
Image Pre-Processing
- SEO neighborhood size

Attention
- Neighborhood size
- Weights Quantization

CNNs
- Number of filters
- Weights Quantization

Preliminary Work

Method	MAE	S-measure	Max F-measure	AUC	CC
SMN	0.072	0.778	0.680	0.906	0.693



	SEO Input	MAE	S-measure	Max-Fmeasure	AUC	CC	GFLOP Count
(c)	3,5,7	0.079	0.733	0.622	0.875	0.636	0.5
(d)	5,9,13	0.075	0.761	0.666	0.891	0.672	1.6
(e)	5,15,25	0.072	0.778	0.680	0.906	0.693	6.2
(f)	25,35,45	0.076	0.749	0.643	0.902	0.643	20.3

Work Proposal

- Model exploration and tuning in phyton. (1.5 months)
- Embedded C/C++ implementation of the model. (2.5 months)
- Hardware/Software Profiling of the C/C++. (2 weeks)
- Implement the hardware accelerators. (2.5 months)
- Integrate the accelerator components with Software components. (1 month)
- Test and Validation. (3 weeks)
- Thesis writing. (8 months)

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