Department of Electronic & Telecommunication Engineering

University of Moratuwa

EN 3030 – Circuits and Systems Design

<u>Interim Report</u>

<u>Instruction Set Architecture & Software Implementation</u>

<u>Group Members</u>

<u>Name</u>	***<u>Index Number</u>***
Rathnayaka R.G.H.V.	*180529E*
Udara A.W.T.	*180650P*
Thilakarathna G.D.O.L	*180642T*
Sewwandi B.L.P.N.	*180589K*

December 15, 2021

This Report is submitted as a partial fulfillment of the requirements for the module EN 3030 – Circuits and Systems Design

Department of Electronic and Telecommunication Engineering,

University of Moratuwa.

Introduction to the Task

The task is focusing on the design of a processor which suits to down sample a grayscale image of size n x n pixels to $(\frac{n}{2})\ x\ (\frac{n}{2})$ pixels. We selected to down sample a grayscale image of 256 x 256 pixels to 128 x 128 pixels. For continuing the task, we designed a Gaussian low pass filter in the aim of reducing any information loss and minimizing the changes happening because of aliasing due to high frequency components.

Algorithms Associated with the Task

Algorithm for the processing part of the task is developed based on two parts as,

I. Filtering Algorithm
II. Down Sampling Algorithm

All the testing regarding these two algorithms was done using **Python 3.9**.

I. Filtering Algorithm

As the very first part of the task, we had to remove the high pass frequency components in the image. For that, we used a Gaussian low pass filter which can remove the high pass frequency components. The Gaussian filter that was used for filtering in this implementation is given below under *Figure 01* with the weight distribution of the kernel.

1	3	1
3	16	3
1	3	1

Figure 01 – 3x3 Gaussian Kernel used in Low pass

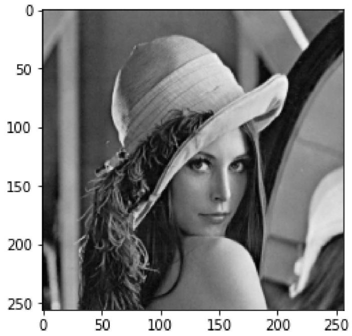
The selected image of N x N pixels was convoluted with this 3 x 3 Gaussian kernel which outputs an image where low pass component are there. In this convolution process, overlapping the center pixel of the kernel with an image pixel provides a weighted summation value. This result is divided by the total weight of the kernel (here it is 32.) to normalize. Then, this average value is stored at the top left corner pixel location in the RAM. After the initial convolution operation, the kernel is moving forward and the average value of the each set of convolutions is stored at the top left corner pixel. After finishing the forward move kernel move downwards and again the procedure is continuing until all the set of pixels are covered. Filtered image is completely stored in the RAM in this sequential order. As we neglected the effect surrounding marginal pixels' effect. So, no padding was done for the 3 x 3 kernel.

Python implementation done with **Jupyter Notebook 6.0** to filter the image to avoid high frequency components is given below.

In [1]:
```python
import cv2 as cv
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
```

In [2]:
```python
img=cv.imread('lena256.jpg',cv.IMREAD_ANYCOLOR)
[width,hight]=img.shape
print(img)
plt.imshow(img,cmap='gray')
plt.show()
```

```
[[137 135 133 ... 145 147 114]
 [137 137 133 ... 144 148 114]
 [138 133 134 ... 133 125  87]
 ...
 [ 28  29  28 ...  53  61  59]
 [ 20  24  25 ...  64  70  65]
 [ 22  30  25 ...  71  67  72]]
```



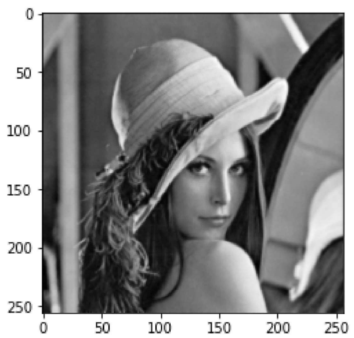
In [5]:
```python
mem = img.reshape(-1,1)
print(mem)
```

```
[[137]
 [135]
 [133]
 ...
 [ 71]
 [ 67]
 [ 72]]
```

In [6]:
```python
AC  = 0 # 16 bit
Z   = 1 # 1 bit
R   = 0 # 16 bit - store calculated data for filtering
R0  = 0 # 16 bit - read address for filtering
R1  = 0 # 16 bit - limit of loops for filtering         - read address for sampling
R2  = 0 # 16 bit - write address for sampling
R3  = 0 # 16 bit - no of rows in down sampled image
R4  = 0 # 16 bit - filtering address                    - no of columns in down sampled image
```

In [7]:

```python
#filtering
AC,Z = 0,1
R1 = 65022 # (256*(256-2))-2
AC,Z = 0,1
R4 = 257 # first pixel to be filtered
while True:
    #taking values from middle row of the kernal
    R = 0
    R0 = R4
    AC = mem[R0][0]
    R = AC*16
    R0 += 1
    AC = mem[R0][0]
    R += (AC*3)
    R0 -= 2
    AC = mem[R0][0]
    R += (AC*3)
    #taking values from lower row of the kernal
    R0 = R4 + 256
    AC = mem[R0][0]
    R += (AC*3)
    R0 += 1
    AC = mem[R0][0]
    R += AC
    R0 -= 2
    AC = mem[R0][0]
    R += AC
    #taking values from upper row of the kernal
    R0 = R4 - 256
    AC = mem[R0][0]
    R += (AC*3)
    R0 += 1
    AC = mem[R0][0]
    R += AC
    R0 -= 2
    AC = mem[R0][0]
    R += AC
    R = R/32
    mem[R4][0] = R
    R4 += 1
    R1 -= 1
    if R1 == 0:
        Z = 0
    if Z == 0:
        break
filtered_image = mem.reshape(256,256)
plt.imshow(filtered_image,cmap='gray')
plt.show()
print(filtered_image)
```




```
[[137 135 133 ... 145 147 114]
 [137 135 133 ... 139 138 118]
 [132 133 133 ... 120 110  94]
 ...
 [ 30  28  27 ...  52  58  52]
 [ 27  25  25 ...  62  66  65]
 [ 22  30  25 ...  71  67  72]]
```

II. Down Sampling Algorithm

Since, it is needed to down sample the image from both height and width with a down sampling factor of 2, a one value is taken per four pixels from the image obtained through convolution with the 3 x 3 kernel. Then, that value is kept stored in the memory for getting the output. Values taken from a 6 x 6 filtered image is shown in the *Figure 02* below.

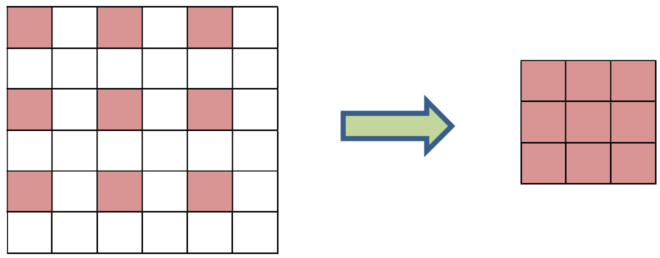
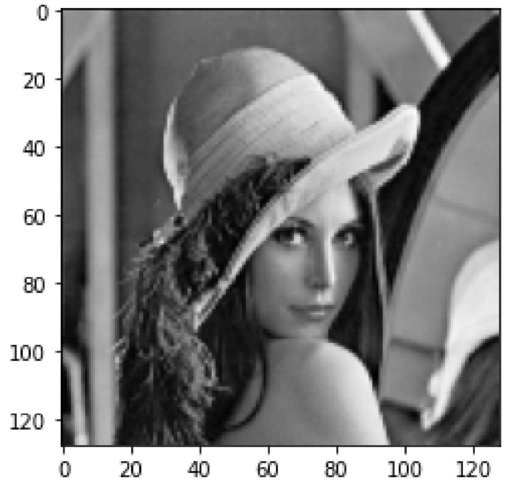


Figure 02 – Graphical Illustration of Down Sampling method

Every other pixel from the filtered image is used in constructing the output image. No interpolation is used as the image is already down sampled. The down sampling algorithm done with the use of python through **Jupyter Notebook 6.0** is given below.

In [8]:

```
#downsampling
R3 = 128
R1 = 0
R2 = 0
while True:
    R4 = 128
    while True:
        AC,Z = 0,1
        AC = mem[R1][0]
        mem[R2][0] = AC
        R2 += 1
        R1 += 2
        R4 -= 1
        if R4 == 0:
            Z = 0
        if Z == 0:
            break
    AC,Z = 0,1
    R1 += 256
    R4 = 128
    R3 -= 1
    if R3 == 0:
        Z = 0
    if Z == 0:
        break
dwn_smpld_image = mem[0:16384].reshape(128,128)   #16384 = 128*128
plt.imshow(dwn_smpld_image,cmap='gray')
plt.show()
print(dwn_smpld_image)
```




```
[[137 133 138 ...  85 123 147]
 [132 133 134 ...  90 111 110]
 [117 130 132 ...  89  49  28]
 ...
 [ 26  31  38 ...  31  27  27]
 [ 28  29  33 ...  31  33  47]
 [ 27  25  30 ...  33  51  66]]
```

Hardware Requirements

I. Registers

Implementation of the processor design was done with the use of 5 special purpose registers.

Name	Size	Used to store	
		When Filtering	When Sampling
Z	1 bit	Control the flow	Control the flow
AC	16 bits	Inputs to ALU	Inputs to ALU
R	16 bits	Calculated data	
R0	16 bits	Addresses to read memory	
R1	16 bits	Limit of no of loops	Addresses to read memory
R2	16 bits		Addresses to write memory
R3	16 bits		No of rows in down sampled image
R4	16 bits	Addresses to write memory	No of columns in down sampled image

Table 01 – Information on Registers

II. Memory

Two types of memory are associated with this design as,

1. Instruction Memory – keeping the instruction in the program.
2. Data Memory – Storing data on intensity values of the pixels of input and output image. Here, size of a memory location is 8 bits while the address length comprises of 16 bits.

Instructions are in frame size of 8 bits (1 byte). 32 types of instructions are used in ISA. The minimum size expected from the data memory can be evaluated as,

- Total number of pixels in the input image--------------------------256 x 256
- Intensity value width per pixel-- 8 bits
- Memory size needed to store input image----------------------256 x 256 x 8 bits

Instruction Set Architecture (ISA)

INSTRUCTION	INSTRUCTION CODE	INSTRUCTION OPERATION
NOP	0000 0000	No operation
CLAC	0000 0001	$AC \leftarrow 0$ $Z \leftarrow 1$
LDAC $\mathcal{T}$	0000 0010 $\mathcal{T}$	$AC \leftarrow M[\mathcal{T}]$

STAC $\mathcal{T}$	0000 0011 $\mathcal{T}$	M[$\mathcal{T}$]←AC
ADDM α	0000 0100 α	AC←AC+α
SUBM α	0000 0101 α	AC← AC-α
DIV 32	0000 0110	AC←AC/32
ADD	0000 0111	AC←AC+R
MUL	0000 1000	AC←AC*R
MULM α	0000 1001 α	AC ← AC*α
INCR0	0000 1010	R0←R0+1
INCR1	0000 1011	R1←R1+1
INCR2	0000 1100	R2←R2+1
INCR4	0000 1101	R4←R4+1
DECR0	0000 1110	R0←R0-2
DECR	0000 1111	R←R-1 if (R-1 =0) Z←0 else Z←1
DECR1	0001 0000	R1←R1-1 if (R1-1 =0) Z←0 else Z←1
DECR3	0001 0001	R3←R3-1 if (R3-1 =0) Z←0 else Z←1
DECR4	0001 0010	R4←R4-1 if (R4-1 =0) Z←0 else Z←1
MVACR	0001 0011	R←AC
MVACR0	0001 0100	R0←AC
MVACR1	0001 0101	R1←AC
MVACR2	0001 0111	R2←AC
MVACR3	0001 1000	R3←AC
MVACR4	0001 1001	R4←AC
MVRAC	0001 1010	AC←R
MVR1AC	0001 1011	AC←R1
MVR2AC	0001 1100	AC←R2
MVR3AC	0001 1101	AC←R3
MVR4AC	0001 1110	AC←R4
JPNZ $\mathcal{T}$	0001 1111 $\mathcal{T}$	IF (Z==0) GOTO $\mathcal{T}$
JPPZ $\mathcal{T}$	0010 0000 $\mathcal{T}$	IF (Z==1) GOTO $\mathcal{T}$

Table 02 – Instruction Set

Assembly Code

Implementation of the aforementioned Python code was done with the use of some assembly level codes. The code segment used in implementation using multiple instructions from ISA is given below.

[This code is to down sample a grayscale image of size 256 x 256 pixel to an image of 128 x 128 pixels]

1. *CLAC ; AC←0, Z←1*
2. *ADDM 256 ; AC←AC+256*
3. *MVACR ; R←AC*
4. *DECR ; R← R-1*
5. *DECR ; R ← R-1*
6. *MUL ; AC←AC*R*
7. *MVACR1 ; R1←AC // limit for filtering*
8. *DECR1 ; R1← R1-1*
9. *DECR1 ; R1← R1-1*
10. *CLAC; AC←0, Z←1*
11. *MVACR0 ; R0←AC // read address*
12. *MVACR3 ; R3 ← AC*
13. *MVACR4 ; R4 ← AC // middle pixel address*
14. *INCR4 ; R4 ← R4+1*
15. *MVR4AC ; AC← R4*
16. *ADDM 256 ; AC← AC+256 // initial pixel address*
17. *MVACR4 ; R4← AC*
18. *LOOP:CLAC ; AC ←0, Z←1*
19. *MVACR ; R←AC*
20. *MVR4AC ; AC← R4*
21. *MVACR0 ; R0← AC*
22. *LDAC R0 ; AC ← M[R0]*
23. *MULM 16 ; AC← AC*16*
24. *MVACR ; R← AC*
25. *INCR0 ; R0← R0+1*
26. *LDAC R0 ; AC← M[R0]*
27. *MULM 3 ; AC← AC*3*
28. *ADD ; AC← AC+R*
29. *MVACR ; R← AC*
30. *DECR0 ; R0← R0-2*
31. *LDAC R0; AC← M[R0]*
32. *MULM 3 ; AC← AC*3*
33. *ADD ; AC← AC+R*
34. *MVACR ; R← AC*
35. *MVR4AC ; AC← R4*
36. *ADDM 256 ; AC← AC+256*
37. *MVACR0 ; R0← AC*
38. *LDAC R0 ;AC← M[R0]*
39. *MULM 3 ;AC← AC*3*

40. ADD ; AC← AC+R
41. MVACR ; R← AC
42. INCR0; R0← R0+1
43. LDAC R0; AC← M[R0]
44. ADD ; AC← AC+R
45. MVACR ; R ← AC
46. DECR0 ; R0← R0-2
47. LDAC R0 ; AC← M[R0]
48. ADD ; AC← AC+R
49. MVACR ; R← AC
50. MVR4AC ; AC← R4
51. SUBM 256 ; AC← AC-256
52. MVACR0 ; R0← AC
53. LDAC R0 ;AC← M[R0]
*54. MULM 3 ;AC← AC*3*
55. ADD ; AC← AC+R
56. MVACR ; R← AC
57. INCRO; R0← R0+1
58. LDAC R0; AC← M[R0]
59. ADD ; AC← AC+R
60. MVACR ; R ← AC
61. DECR0 ; R0← R0-2
62. LDAC R0 ; AC← M[R0]
63. ADD ; AC← AC+R
64. DIV 32; AC← AC/32
65. STAC R4 ;M[R4] ← AC
66. INCR4 ; R4 ← R4+1
67. DECR1 ;R1←R1-1, if (R1-1 =0) Z←0 else Z←1
68. JPPZ LOOP(18)

Filtering of image is over. After filtering down sampling of image by 2 is as below as following assembly code.

69. CLAC ; AC←0, Z←1
70. ADDM 128; AC←AC+128
71. MVACR3 ;R3 ← AC // No of rows in down sampled image
72. MCAVR4 ; R4←AC // No of columns in down sampled image
73. CLAC ; AC←0, Z←1
74. MVACR1 ; R1←AC // READ ADDRESS
75. MVACR2 ; R2 ← AC // WRITE ADDRESS
76. LOOP:LDAC R1 ;AC←M[R1]
77. STAC R2 ; M[R2]←AC
78. INCR2 ; R2←R2+1
79. INCR1 ; R1←R1+1
80. INCR1 ; R1←R1+1
81. DECR4 ; R4←R4-1 if (R4-1 =0) Z←0 else Z←1
82. JPPZ 76
83. MVR1AC ; AC←R1
84. ADDM 256 ; AC←AC+256
85. MVACR1 ; AC←R1
86. CLAC; AC←0

87. ADDM 128 ; AC←AC+128
88. MVACR4; R4←AC
89. DECR3 ; R3←R3-1 if(R3-1=0) Z←0 else Z←1
90. JPPZ 76