**CHAPTER 2**

**Review of Related Literature**

**2.1 Novel Study in Copepod Automatic copepod identification and Classification**

One study about the Identification and Classification of copepods by L.K. Leow et.al in 2015 uses Image processing and neural network. The researchers used the conventional image processing using the square lattice and it was made through Matlab’s image processing software. They used eight species of copepods namely *Acartia spinicauda, Bestiolina similis, Oithona aruensis, Oithona dissimilis, Oithona simplex, Parvocalanus crassirostris, Tortanus barbatus and Tortanus forcipatus*. The researcher used 240 samples which were then divided into three sets, the training set (168 samples, or 70% of samples), validation set (36 samples, 15%) and testing set (36 samples, 15%). The data from the training set were used for network training; the validation set for measuring network generalization and terminating training before overfitting; and the testing set for independent measure of network performance during and after training. The overall approach demonstrated not only a fast and automated technique for copepod identification and classification but also an accuracy rate of 93.13%. The performance evaluation of the system was evaluated using MSE or the Mean Square Error and Confusion matrices. The other 160 independent samples (20 samples from each species) were used for system performance evaluation. The trained network was simulated using the testing data as input and the output was then compared to the predicted data and recorded in a confusion matrix.

His approach demonstrated an overall classification accuracy of 93.13% (100% for A. spinicauda, B. similis and O. aruensis, 95% for T. barbatus, 90% for O. dissimilis and P. crassirostris, 85% for O. similis and T. forcipatus).

**2.2 Advantages of Hexagonal Sampling Vs Square Sampling**

The summary of the advantages of hexagonal lattice are summarized below:

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| **Aspect** | **Advantages** |
| Isoperimetry | As per the isoperimetric theorem, a hexagon encloses more area than any other closed planar curve of equal perimeter, except a circle. This implies that the sampling density of a hexagonal lattice is higher than that of a square lattice. |
| Additional equidistant neighbours | Every hexagon in the lattice and hence a hexagonal pixel in an image has six equidistant neighbours with a shared edge. In contrast, a square pixel has only four equidistant neighbours with a shared edge or a corner. This implies that curves can be represented in a better fashion on the hexagonal lattice and following an edge will be easier. |
| Uniform Connectivity | There is only one type of neighbourhood, namely N 6 , possible in the hexagonal lattice unlike N 4 and N 8 in the square lattice. This implies that there will be less ambiguity in defining boundaries and regions. |
| Smaller Quantization Error | Quantization is compulsory for the image pro  -cessing operations because of the limited capable  Sensors to represent the real-world scenes. Quantization error is an important measure to analyze the Merits of the configurations of the different types of Sensors. Here the hexagonal sampling gives lesser Quantization error when compared to square |
| Greater Angular Resolution | For representing curved images, hexagonal Grid is efficient. Adjacent pixels in hexagonal grid are Separated by sixty degrees instead of ninety degrees in square. So, curved images can be represented in a Better way. Main reason behind this is the consistent Connectivity. Human eyes have a special visual preference of seeing the lines which are at oblique angle. So, this is another reason for representing lines also in a better way in hexagonal grid |
| Higher Symmetry | Hexagonal lattice is proven to have higher symmetry by Serra in his morphological operations. He also concluded that hexagonal lattice has more simpler operations than the square. |

**Table 1**. Summarized advantages of hexagonal lattice over square lattice.

One aspect of the sensing method used in computer vision is sampling using the square lattice. In this study, the lattice will be changed to hexagon due to various reasons above but the main ones are geometry and nature (Middleton, 2005). According to Gupta and Pahwa in their study “Comparison of Image enhancement techniques on square and hexagonal lattice structures”, hexagonal representation resembles human vision system and it was agreed by other dozens of researchers such as Tirunelveli in “Comparison of Square-pixel and Hexagonal-pixel” on 2002 where he said that hexagonal pixels have greater advantage in terms of rotational symmetry, he explained further about the packed structure that the pixel has, and a great resemblance to circular pixel. Many reasons were also proposed by He and Jia in their study the “Hexagonal Structure for intelligent Vision” these include that Hexagonal representation has more efficient Sampling Schemes, Smaller quantization Error, Equidistance, great Angular resolution, Higher symmetry, etc. Middleton also explained in his monograph in 2005 about his thought on Hexagonal lattice in image processing and said that there are three main reasons why hexagon outstands the square lattice and those are Isoperimetry, Additional equidistant neighbours, and Uniform connectivity. He also made a framework in python which programmers can use as a substitute from conventional square image processing.

Although the world uses the conventional image processing, there are researches which take more effort to apply a new approach (Hexagonal Image Processing) such as Sharif et.al in 2012 where they used the new technology in Facial Detection and Recognition and proved the superiority of the said technology. The technology was also used in Local Binary Pattern in codes which was designed for texture classification, human detection and other fields (He et.al,2007). Another paper by Jiang in 2008 sighted that Hexagonal lattice has greater symmetry then it is applicable in filter banks which is designed for multiresolution. The latter also investigated the construction of orthogonal and PR FIR (Prefect Reconstruction, Filtering and Image Processing) hexagonal filter banks with 6-fold symmetry. Other Image processing steps such as edge detection, shape extraction and feature extraction, were also applied using hexagonal lattice. Researches include the “Multi-scale Feature Extraction in a sub-pixel Virtual hexagonal Environment” by Bryan Gardiner et.al in 2008. A study “Shape extraction in a hexagonal-image processing framework” was also made by Lee middleton in 2000. Edge detection using hexagonal lattices were also made by many researchers such as Vidyapeetham in 2011 where they made a Hardware implementation of edge detection on hexagonal sampled image grids, Mostafa et.al in 2015 where they studied “Fuzzy noise removal and edge detection on hexagonal image”.

**2.3 Hexagonal structure for pattern/object recognition**

Local Binary Pattern is a type of visual descriptor used for classification in computer vision. It was designed for efficient and accurate texture classification. Uniform LBPs play an important role for LBP-based pattern /object recognition as they include majority of LBPs. He at.al in 2007 presented LBPs on hexagonal structure for pattern/object recognition. They concluded that LBPs defined on square structure have less potential for more accurate description of texture than the hexagonal structure. They further explained that the number of LBP types and their uniform subset have been greatly reduced on hexagonal structure than on square which means that object recognition is far greater in hexagonal lattice than in square.

**2.4 Hexagonal lattice in shape extraction**

Lee Middleton proposed a framework in hexagonal-image processing for this particular field. His work proposes a convenient and efficient way in query of images in a database. Generally, these queries will be based upon a number of broad classes which can be extracted from the image. This can be done by looking at a class of image, shape and extracting the shape from the image. The approach is based upon the use of window to extract local information to generate description of the object’s shape. They concluded that the proposed scheme produced promising beginnings and that future works could include wider class of recognition problems. They also explain that The manipulation aspect gives it a significant advantage over representations based on primitives (such as geons or generalised cones) which can be computationally expensive.

**2.5 Hexagonal lattice in Edge detection**

Edge detection in image processing is an image processing technique for finding the boundaries of objects within images. It works by detecting discontinuities in brightness. Edge detection is used for image segmentation and data extraction in areas such as image processing, computer vision, and machine vision. Although there are many studies about edge detection, few have applied hexagonal lattice in their work and one example is “Hardware implementation of Edge Detection on Hexagonal Sampled Image Grids” by S. Veni in 2011. Their paper describes Edge detection operation on hexagonally sampled images and its hardware implementation based on cellular Logic Array Processing algorithm. Their architecture decreases the computational complexity by building up a virtual hexagonal grid system on the memory space of computer and processing algorithms can be implemented on such virtual spiral space. They compared their result to rectangular sampled grid and found less hardware utilization compared to the latter and concluded that the addressing scheme used which is half pixel shift method does not introduce distortions to the image.

**2.6 Artificial Neural Networks**

There are many types of neural networks such as Hopfiled Neural Network,Radial Basis Function Neural Network, Probabilistic Neural Network, Convolution Neural Network,Fuzzy Neural Network but one of the most famous used for image segmentation is the Feed Forward Neural Network (Z. Shi and L. He, 2010). Shi and He also noted in their study (“Application of Neural Networks in Medical Image Processing”) that the said network is less sensitive to the selection of the training sets than the Maximum Likelihood classifier.

Neural networks have been utilized in many fields of science especially in image or samples of species’ detection, recognition and classification. It is used in Insect classification by J. Wang et.al in their study “A new automatic identification system of insect images at the order level”. It was also utilized in other species or groups organisms such as Macroinvertebrates by S. Kiranyaz et.al in their study “Classification and retrieval on macroinvertebrate image databases using evolutionary RBF neural networks”; Algae by P. Coltelli et.al in their study “Water monitoring: automated and real time identification and classification of algae using digital microscopy” in 2014; Fishes in the study “Fish recognition based on robust features extraction from size and shape measurements using

neural network” by MK Alsmadi et.al in 2010 and other groups of organisms such as protozoa and metazoa (Y.P. Ginoris et.al, 2007), dinaflagellates (PF Culverhouse et.al, 1996), etc. However only Leow and his colleagues have use neural network for copepod classification.

In Leow’s study, A two-layer (hidden and output layer) feed-forward network was trained using a back-propagation algorithm which is based on ten neurons at the hidden later and eight neurons at the output layer. They used a total of 240 sample images for training set with 30 for each class. They obtained seven selected features of each species which is used as input data presented to the input nodes of the network from the training set, whereas eight desired output classes were defined by the target data. The results showed 97.90% correct classification from the confusion matrix of all 240 samples in the training, validation, and testing sets.