Chapter 1

Introduction

1.0 Preamble
In recent times, Pattern Recognition and Image Processing are being used to solve numerous interesting and challenging problems related to machine vision and machine intelligence (Petrou and Bosdogianni, 1999).

Few such open issues under research are target identification in defence, defect detection in manufacturing, fabric fault analysis etc. Out of these the target identification problem has been gathering lot of importance in the past decade and consequently, many methodologies have been suggested to solve it (Chetverikov and Hanbury, 2002). But it is well known that entities in defence arena are normally camouflaged. Thus, most/all of the target identification techniques may fail in such scenarios where objects are camouflaged. This is a conventional camouflaged scenario. A deeper analysis of the problems related to defect detection in manufacturing and fabric fault analysis portrays another interesting camouflaged situation called as aesthetic camouflaging. Aesthetic camouflaging is a kind of psychological blindness caused due to the observation of a huge clutter of similarly looking objects. Aesthetic camouflaging may inhibit the human visual system from discriminating objects with minor variations/defects/faults when kept among similarly looking object clutter. This thesis proposes techniques to identify such conventionally and aesthetically camouflaged objects through pattern recognition and image analysis approaches.

Camouflaging is a process to hide an object in its spatial surroundings, such that it is virtually lost or at least not easily traceable or detectable in the background of the image. In other words camouflaging is the technique of disguising an object image to blend in with its surroundings in its image representation. Camouflaging can hinder the performance of a recognition algorithm because it is not a phenomenon which can be predicted in isolation. Camouflaging is a function of an object’s relationship to the scene in which it is embedded. The relationship can be due to color, texture or shape or combination of these. When the relationship due to texture is high, even the human
visual system would find it difficult to resolve the camouflaged or defective portion. This is due to the effect of aesthetic camouflaging caused by texture similarity between the camouflaged object and the surrounding. The minor/finer/local variation in the textures of camouflaged objects may not be so easily identifiable. The camouflaged portion normally being smaller in size and its matching with the surrounding chromatically makes it difficult to be resolved. This demands a close microscopic analysis to understand the composition of the camouflaged/defective area whose texture may have minor difference in orientation or slight chromatic dissimilarity from that of the background or surrounding. Methods that can perform such microscopic analysis to resolve camouflaged/defective regions are termed as Decamouflaging Algorithms according to this thesis.

The purpose of this research work is to explore the different possibilities and the extents to which the formation of such camouflaging texture and color could be resolved through pattern recognition and image processing techniques.

1.1 Pattern Recognition(PR) and Image Processing(IP) Strategies for Decamouflaging

Pattern Recognition is a branch of Artificial Intelligence with techniques to cognize and recognize patterns present in different kinds of data. Image processing and computer vision are fields largely influenced by pattern recognition. Such an influence has led to many applications like target detection in defence, vision based robotic navigation, object recognition and identification, vision based fault/defect detection in manufacturing, surveillance, land classification, climate forecasting based on satellite pictures, aerial surveying etc. These applications are directly or indirectly related to decamouflaging. Based on the process flow intended for above applications, the overall strategy for decamouflaging through PR and IP methodologies is illustrated in the block diagram shown in Fig 1.1.
The figure 1.1 indicates the need for high resolution image capture for applications involving decamouflaging. It is because the features that discriminate the camouflaged image from the background/surrounding are highly minuscule and finer. Most times, the minute texture variations will have to be enhanced before feature extraction to detect the camouflaged regions. Once the camouflaged region is detected through suitable feature/pattern analysis, the camouflaged area is segmented. This leads us to the requirement of understanding the literature in the following disciplines.

(i) Camouflaging
(ii) Image Analysis techniques for decamouflaging
(iii) Feature/Pattern Analysis
(iv) Image and Object Segmentation

1.1.1 Camouflaging: Definitions and State of the Art

The term ‘camouflage’ originated from the French word ‘camoufler’ (Roy 1988) which means ‘to blind’ or ‘veil’. Camouflage, also called protective concealment, means to disguise an object in plain sight so as to conceal it from something or someone. An American artist Abbott Thayer (Roy 1988) made a significant remark about animals in the environment that becomes a valuable instrument in developing modern camouflage. Subsequent to studying wildlife, Thayer was able to make out that the colouring of many animals graduated from dark, on their backs, to almost white on their bellies. This property was very useful in developing modern camouflage.
Almost all animals have some kind of adaptive coloration or camouflage patterning (Web-mbl, 2006). These are mainly meant for defending against predators, communication with organisms, attracting or deceiving mates, repelling or deceiving rivals, signaling alarm to organisms, protection from environment and approaching prey.

The simple and straightforward approach for camouflaging an object is to enclose it with a texture similar to that of the surrounding in such a way that conventional vision systems fail. Nagabhushan and Gowda (1993) define Camouflage as an art of disguising an object to blend in with its surroundings. Many animals (Huimin Lu, et.al., 1999) follow this strategy by concealing their body patterns with the background. When they keep stationary, it is very difficult for a normal visual system to discover the presence, whereas when they are moving, such visual camouflage is less effective.

Camouflage is also intelligently created by man for his survival and protection particularly during war (Everett 1988, Barbara, 1989). The essence is to obscure a target within a background in a non-distinguishable manner. In a battlefield, camouflaging provides protective concealment to soldiers and army equipments for guarding against enemy attacks (Morgan et.al 1992). Successful concealment adds the value of surprise in attack and provides security in defense. Although modern warfare employs increasingly deadly weapon systems and highly sophisticated electronic surveillance devices, the necessity and importance of deceiving the enemy always remains (Morgan et.al 1992). To much extent, the success depends upon the ability to remain undetected by the enemy. Thus camouflaging strategy is purposefully employed in military applications. Camouflage may simply be tactical deception designed to make it harder for an enemy to see where to attack resources. Thus camouflage helps organisms/entities in real life to protect themselves from the predators. It could be through the body color of the organisms or with its patterns or both.

Thus, the background of the camouflage work lies in the evolutionary arms between predator and prey. Although the prey organisms in almost all taxonomic groups have developed sophisticated natural anti-detection or camouflage mechanisms, the
predator vision system have also been extraordinarily adapted to resolve the camouflaged objects from the background/surrounding. Few ideas have been developed based on the predator vision system, their psychology and strategies for decamouflaging.

1.1.2 Vision Based techniques for Decamouflaging: State of the Art

Osorio and Srinivasan (1991) exploited the concept behind animal camouflage patterns and provided solutions based on the visual processing mechanisms of predators. In one common type of camouflaging the borders of the coloured patterns are enhanced through high contrast lines. This type of camouflage is seen in many frogs and thus is used as a basis for speculating the vision in small frog-eating snakes. It is found that a mechanism based on phase congruency detection is used by the snakes for finding preys. Osorio et al proposed a technique based on edge detectors by employing such phase-congruence strategy.

Ariel and Yehezkel (2000) presented a biological evidence for camouflage breaking using the convexity of intensity function. Animals using the apatetic coloring prevent their detection by gray level convexity. This implies that other animals might be able to break camouflage based on gray level convexity. The authors demonstrate the effectiveness of convexity based camouflage breaking using an operator ‘$D_{arg}$’ for detection of 3D convex or concave gray levels. Its high robustness and biological motivation make $D_{arg}$ suitable for camouflage breaking. It is also demonstrated that the operator is capable of breaking very strong camouflage, which might delude even human viewers. Being non-edge based, the performance of operator is juxtaposed with that of representative edge-based operator in the task of camouflage breaking.

Srinivasan (1993) made a broad survey on the methods adopted by bees for resolving the aesthetically camouflaged targets. The research observing freely flying insects revealed a number of computational ‘short cuts’ that insects use for perceiving the visual world in 3D, and navigating successfully in it. Bees segment objects from their backgrounds by sensing the apparent relative motion at the boundary between object and background. The distance to objects are gauged in terms of apparent
speeds of the motion of the object images rather than by using complex stereo mechanisms to compute range. Hoverflies 'shadow' obscures by camouflaging their motion. The shadowing insects achieve this by moving in such a way as to emulate the motion of the image of a stationery object in the eye of the moving shadowee. Bees flying through a tunnel maintain equidistance to the side walls by balancing the apparent visualization of wall image sequences. Bees landing on a horizontal surface hold constant the image velocity of the surface as they approach it, thus automatically ensuring that flight speed is close to zero at touchdown. These strategies were applied to solve many problems in robot navigation and machine vision.

Copeland et al, (1997) suggested models and metrics for signature strength evaluation of camouflaged target. It is demonstrated that the signature strength of a target in a sensed image is equivalent to distinctness of the image pattern of the target from its background. In order to measure the signature strength of a target, they have computed metrics including first and second order probability distribution and boundary strength. To compare the quantitative measure of target distinctness to human judgment of same attribute, test images were used as stimulus in paired comparison with human observer. The raw judgment of few observers' opinion was taken into account to estimate scale value for the stimuli, indicating the relative amount of perceived target distinctness in the images. They also demonstrated that the second order metrics based on a model of image texture were most strongly correlated with the scale values. The techniques were applied for resolving and designing camouflaged pattern.

Barbara(1989) proposed the work which demonstrated a synthetic imagery approach for designing and evaluating camouflage, concealment, deception and obscuration effectiveness. The synthetic video and static scene imagery have been created using the views obtained by aircrafts. In this approach the authors have attempted to simulate the impact of smoke and obscurants. Effects of smoke screen were modeled using the large area smoke screen (LASS) software.

Morgan et.al,( 1992) have proposed the method to detect color camouflaged objects by Dichromats which are not detected by trichromats. In this work, the authors attempted to make use of the advantage of dichromate in breaking certain kind of camouflage. The texture elements in a target area differed in either orientation or size
from the background elements. In some situation, the texture elements are quite similar in colour, where as in camouflage condition they are randomly coloured when observed from finer perspectives. The authors demonstrate that dichromates can be at an advantage in penetrating color camouflage. A slight compensating advantage to dichromacy will merely reduce the size of the advantage of trichromacy when the trichromates color vision had an overall selective advantage. Therefore, for trichromates it is more difficult to detect the target region in the camouflaged condition, even though color was completely irrelevant to task. Dichromats did not show this effect, and indeed performed better than the trichromates in camouflaged condition. This work concluded that color can interfere with the segregation based texture, and also that dichromates are less susceptible to such interference.

Guilan and Shunqing (1997) proposed spectral pattern recognition techniques to distinguish color camouflage from green vegetation background. Here, the spectral feature is taken as the basic characteristics for recognizing the target. They have measured many reflected spectra of green camouflage material and green vegetation, before analyzing the spectral pattern regularities, and extracted the optimum features for resolving camouflage.

In this thesis we attempt to break camouflaging based on the finer texture discrimination that normally exists between the camouflaged object and the background. We also target the problem of aesthetic camouflaging for defect detection application. Defect detection becomes a tough problem when the defective objects are placed among a clutter of non-defective objects. This disability is a result of aesthetic camouflaging. The proposed decamouflaging techniques in both conventional and aesthetic situation are based on the texture properties of the objects/background. The following subsections present a broad variety of texture analysis and defect detection literatures used in various scenarios.

1.1.3 Texture Feature/Pattern Analysis: State of the Art

Image texture is function of spatial variation in pixel intensities. Texture is that innate property of all surfaces that describes visual patterns, each having properties of homogeneity. It contains important information about the structural arrangement of
the surface, such as; clouds, leaves, bricks, fabric, etc. It also describes the relationship of the surface to the surrounding environment (Sharmin, 2002). In simple term, it is a feature that describes the distinctive physical composition of a surface. Texture properties include: coarseness, contrast, directionality, regularity, roughness etc.

Zhongyang, et.al., (2000) addressed the generic issue of texture image analysis using local spectra features that are based on spatial or spatio-frequency methods. He proposes a set of local spectral features derived from the 2D Pseudo Wigner Distribution (PWD) for textures analysis. The pragmatic image textures are successfully discriminated and boundary between them is detected.

Texture analysis is proposed by many researchers for the inspection of textures in textiles (Newman et.al., 1995; Ozdemir et al., 1998).

George(2000) attempted to classify color textures. CIE xy chromaticity diagram of an image and corresponding set of two-dimensional and three-dimensional moments were employed to characterize color textures. Chromaticity is, thus, described by its two dimensional shape, i.e., chromaticity diagram, along with the two dimensional distribution of chromaticity values. A higher hit rate with small number of moments has been achieved in this work. This method has been extended to classification of granite and marble images.

Richard (1989) presented an article which focuses on the texture discrimination to perform segmentation. It concentrates on texture-discrimination tests at densely spaced image positions, and then interprets the results to localize edges. It attempts to distinguish between perceptual and physical texture differences. Physical texture discrimination requires computing image texture measures that allow the inference of physical differences in texture processes, which in turn requires modeling texture in the scene. They employed texture model that describes textures by distributions of shape, position, and color of substructures.

From this model, a set of image texture measures were derived that allows reliable texture discrimination. These measures were distributions of overall substructure length, width, and orientation; edge length and orientation; and differences in averaged color. Distributions were estimated without explicitly isolating image substructures. Tests of statistical significance were used to compare texture measures.
In conclusion, the measures could distinguish textures differing in second-order statistics, although those statistics were not explicitly measured.

In the proposed work of Monadjemi et.al (1992), the authors examine the high frequency features in high resolution images. They try to increase texture classification accuracy with the combination of lower frequency features. In view of this, they were use eight features, four low frequencies and four high frequencies derived from patches of images. Furthermore, they experiment with both single and multiple classifiers to illustrate the effectiveness of such a combination.

Xianghua et.al(2004) presented a multidimensional histogram method to inspect tonality on colour textured surfaces, such as ceramic tiles. Comparisons in the noise dominated chromatic channels are normally error prone. Xianghua et.al demonstrate the vector ordered color smoothing and generate a PCA-based reconstruction of a query tile based on a reference tile eigenspace. Histograms of local feature vectors were then compared for tonality defect detection.

In work of Mari et.al (2002), authors have demonstrated an application of gray level co-occurrence matrix (GLCM) to texture based similarity evaluation of rock images. Retrieval results are evaluated for whole images and also with blocks obtained by splitting the original images. To retrieve the images they calculate the distance between the feature vector of the query image and other feature vectors in the database. Performance of the co-occurrence matrices was compared to that of Gabor wavelet features and co-occurrence matrices exhibited better for the given rock image dataset.

Camouflage may occur due to several natural reasons such as defects in the products during the manufacturing process itself. These are situations in which objects would have undergone unnoticeable finer damages. At operation level such defects remain camouflaged mostly in cases where arrays of arranged elements pass through conveyers. The only way practiced by and large even today to detect defects is by human visual inspection. But human inspection in such situation would fail leading to many quality related problems. Automation of surface defect detection would offer several advantages like reduced labor cost and elimination of wrong subjective judgments (Smith et al.,1997).
Ibrahim and Graham (2006) have developed techniques based on hash functions to detect small changes and defect in repeating definite pattern of textures. These hash functions were used at the pre-processing stage of defect detection algorithm. Chetverikov and Hanbury (2002) have addressed the basic aspects of detection of structural defects in regular and flow-like patterns (textures). The fundamental properties like regularities and local orientations are considered to find the defects in industrial texture. Kim and Koivo (1993) proposed a hierarchical approach to classify the sample boards of red oak into nine classes with eight types of surface defects. Since the boards in a wood processing plant are usually covered by dust, the problems investigated were interesting.

Various machine vision and image processing techniques use features derived from histograms, Gray level co-occurrence matrices, morphological operators, Fourier coefficients, Markov random fields and Discrete cosine transform coefficients etc for solving many problems.

Livarinen and Visa (1998) have extracted the co-occurrence matrix and the gray level histogram features to represent the internal structure of texture for defect analysis in paper production. Kruizinga et al. (2002) presented an automated visual inspection system for detection and classification of defects encountered in production of moulded plastic products. Methods based on Fourier descriptors were employed which were invariant to translation, rotation and scaling.

Song et al., (1992, 1996) presented a Wigner filter based approach to detect synthetic cracks in random and regular patterns. The defect detection of random color texture is addressed in (Smith et al., 1997). A survey on defect detection of texture is given in (Song et al., 1992). The central moments are used in numerous texture analysis based defect detection applications and have been studied for image recognition and computer vision since 1960s (Mukundan et al 1988; Song et al., 1992; Teh et al., 1993). Hu (1962) introduced the concept of moment invariants and the use of moments in digital imaging.

Xianghua et al. (2004) presented a novel method to detect defects in random color textures which requires only a few normal samples for unsupervised training. We decorrelate the color image by generating three eigenchannels in each of which the surface texture image is divided into overlapping patches of various sizes. Then a
mixture model and Expectation Maximization (EM) is applied to reduce groupings of patches to a small number of textural exemplars, to texems. Localised defect detection is achieved by comparing the learned texems to patches in the unseen image eigenchannels.

There are many potential areas of application for texture analysis in industry (Newman and Jain(1995), Song et al. (1992)) but only a limited number of examples of successful exploitation of texture in inspection exists. A major problem is that textures in the real world are often nonuniform, due to changes in orientation, scale or other visual appearance. In addition, the degree of computational complexity of many of the proposed texture measures is very high. Before committing effort into selecting, developing and using texture techniques in an application, it is necessary to thoroughly understand its requirements and characteristics.

Textured materials may have defects that should be detected and identified as in crack inspection of concrete or stone slabs, or the quality characteristics of the surface should be measured as in granulometry. In many applications both objectives must be pursued simultaneously, as is regularly the case with wood, steel and textile inspection. Because these and most natural and manufactured surfaces are textured, one would expect this characteristic to be reflected by the methodological solutions used in practical automatic visual inspection systems.

The inspection of textured surfaces is regularly treated more as a classification and less as a segmentation task, simply because the focus is on measuring the characteristics of regions and comparing them to prior trained samples. Actual working texture based industrial inspection solutions are available mostly for homogeneous periodic textures, such as on wallpaper and fabric, where the patterns normally exhibit only minimal variation, making defect detection a two category classification problem. Natural textures are more or less random with large non-anomalous deviations, as anyone can testify by taking a look at a wood surface, resulting in the need to add features just to capture the range of normal variation, not to mention of the detection and identification of defects. Defect detection may require continuous adaptation or adjustment of features and methods based on the background characteristics, possibly resulting in a complex multicategory classification task already at the first step of inspection. Solutions providing
adaptability have been proposed, among others by Chetverikov (1987). Proprietary adaptation schemes are regularly used in commercial inspection systems. Kelly and Toshiro, (1994) proposed a unique texture oriented wavelet image compression scheme which uses autoregressive texture segmentation and synthesis. It first estimates the information that would be lost at the desired compression ratio. Estimation-minimization multi-resolution segmentation is performed on the residual estimate to identify distinct texture regions and to compute the model parameters necessary for texture synthesis. The model parameters are saved and the lost texture is synthesized and added back to the image during the reconstruction process. Several variations of autoregressive texture models are demonstrated.

Abbot (2001) compares two methods of unsupervised image texture segmentation. The first technique, wavelet-based segmentation, uses Daubechies-9 and Biorthogonal-6/8 discrete wavelet transforms to describe and cluster texture elements. The second approach, color frequency analysis, uses color histogram information as a measure of color texture to perform segmentation. Both methods were applied to a set of test images both synthetic images and images of natural scenes to measure system performance and provide technique comparisons.

Cristina et.al (2002) proposed the work to perform the texture based segmentation of aerial images and characterization of landscapes. Portrayal was achieved by means of a histogram of micro texture analysis techniques Local binary pattern (LBP)/contrast(c) vectors. Segmentations were hierarchically performed in a top down way by comparing the textures of potentially similar regions with metric Graph.

1.1.4 Few other literature that influenced this Thesis

In this thesis, we address the problem of detecting the camouflaged regions in static images, in contrast to motion camouflage problem (Anderson and McOwan 2002; Juliana et al., 2002) in motion pictures. Perhaps, this is a more difficult problem if the decamouflaging has to be carried out totally in an unsupervised manner. The unsupervised approach does not require knowledge about either the normal background or the camouflage. In this research, we work on both semi-supervised and unsupervised approaches. In semi-supervised environment the properties of the
region or surface under normal conditions are known prior whereas in unsupervised the region under analysis is priory unknown.

Usually the percentage of the region that suffers from camouflage or defect is very small and also the discriminatory textures demarcating the background from the camouflaged regions are very finer and minute. So analyzing a image at coarser level may inhibit us from resolving the camouflage, thus forcing the approaches towards finer analysis of pixels or small blocks.

Lalitha and Nagabhushan (2003) have proposed method to divide an image into uniform non overlapping windows/blocks. In a typical image not too many classes are present in a block. The concept of decomposing a region into smaller regions is not a new one, but it shall be noticed that this concept is emphasized on different applications. The authors have argued that recognizing and locating the minor classes in a satellite image which have relatively very low spatial occupancy compared to other classes is almost impossible. It is because such classes would get absorbed amongst the major classes. Therefore it is disadvantageous to go for global cluster analysis. Hence the image frame is split into many adjacently placed disjoint small blocks, and cluster analysis or classification is performed at the block level. This procedure being able to capture the local information at block level has effectively recognized the presence of even highly minute classes.

In a similar manner, Joseph et al. (2001) proposed to use block-wise feature extraction method for analyzing texture segments. With the local features of smaller blocks being projected, it would be useful in computing the local texture parameters that would enable the discrimination of the camouflaged defects.

Nagabhushan and Pradeep Kumar (2005) proposed continuous wavelet transform based multi-resolution approach for knowledge mining through wavelet histograms. In this paper they discuss on techniques for analyzing data at multiple resolutions from coarser to finer levels. A histogram distance measure based on cumulative histogram and regression lines have also been introduced for low complexity distance calculation. In this thesis, a modified regression distance measure based on piecewise regression lines has been introduced for dealing with finer camouflages.

It is clear from the discussion that all the aforementioned methods appear to be relevant in one or other sense. Some of the literature which drew our attention to
develop decamouflaging models are the works of Lalitha and Nagabhushan 2003, Smith et al. 1997, Nagabhushan and Pradeepkumar 2005, Copeland et al 2000, Brady 1998. The above exploration of survey is more or less oriented towards individual aspects. In order to build complete decamouflaging model, combination of concepts from texture analysis, classification and segmentation are required. But there is dearth of sufficient literature combining aforementioned aspects. In other words, outsized amount of research work has not been reported on decamouflaging concepts, basically because of the intrinsic difficulties encountered in such research work. There could be meager amount of research conducted in this direction perhaps in the defence laboratories, but the results of such attempts are not available openly. Nevertheless the vast amount of literature survey and critical analysis of various related research material portrayed many challenges and challenging applications prevailing with decamouflaging problems.

1.2 Decamouflaging Challenges and Challenging Applications

The applications pertaining to low contrast or camouflage targets in complex clutters significantly restrict conventional target detection techniques from being applied due to the following challenges (Terrance et.al., 2001):

- Out door lightning is naturally or continually varying. The system must be robust enough for false detections caused by sunlight filtered through trees and intermittent cloud cover.

- Targets need to detected quickly, when they are still very small and distinct, for example about 10-20 pixels on target or less than one hundredth of a percent of the image.

- In most of the occasion targets use camouflage to blend in or hide. So the system must be very sensitive to finer discriminatory information. Since parts of the target will often match the background, fragmentation is expected.

- Occlusion, especially in wooded areas is very significant; an average visibility distance in moderate woods is less than 50 meters. The directions of
targets’ motion are only slightly constrained and entire area must be watched. Combined, these suggest need for very wide field of view.

- Trees, bushes and clouds all move. While maintaining sensitivity, the system must include algorithms to help distinguish these insignificant motions from real target motions.
- Many targets move slowly, Image velocities of under 0.1 pixels per frame are typical with some targets an order of magnitude slower. Some targets will try very hard to blend into the motion of the tree or bush. Therefore, frame to frame differencing is of limited value. Furthermore, one must ensure that temporal adaption scheme do not cause the blending of slow targets into the background.
- Targets consist primarily of humans and occasionally vehicles. Targets will be partially occluded and, in general, will not be ‘upright’ or isolated. Thus, labeling of targets based on simple shape, scale, or orientation models is not likely to be successful.
- The algorithms need to be real-time and suitable for use on low-cost, low-power, embedded common-off the shelf systems.

The above remarks emphasize that, although motion decamouflaging techniques could be easier to detect the camouflaged target or the objects, the disturbances caused by the objects in the background region makes it a non-attractive technique. On the other hand a successful still image decamouflaging technique can also resolve the camouflaging in the motion video. Thus this thesis concentrates on resolving camouflaging in a still image scenario by characterizing the texture property of the image. Accordingly this work is focused on identification and recognition of patterns which are camouflaged in similarly patterned background.

### 1.3 Problem and Datasets

The objective of this research work is to detect the camouflaged targets or objects. The investigations probe the presence of obscured objects in an environment and the outcome techniques are collectively put under the title 'decamouflaging'. In this work Pattern Recognition and Image processing methods are employed to carry out
Decamouflaging of naturally or aesthetically obscured objects. The thesis attempts to resolve camouflaging through texture analysis. The perception of whole objects is governed by Gestalt laws (Moore and Fitz 1993). Psychologist Gestalt proposed few laws that act as a guide to the art of camouflaging and decamouflaging. The laws are as follows:

**Law of proximity:** Objects that are positioned close to one another are often seen not as separate parts, but rather as one coherent whole shown in Fig. 1.2. It is also demonstrated through the perception of a Dalmatian dog sniffing the ground in the shade of overhanging trees (Fig. 1.3). The dog cannot be recognized by first identifying its parts (feet, ears, nose, tail, etc.), and then inferring the dog from those component parts. Instead, the dog is perceived as a whole all at once.

**Law of similarity:** When objects look similar to one another they are often perceived to be part of a pattern as shown in Fig. 1.4.

**Law of continuity:** Items that continue a pattern or direction tend to be grouped together as part of the same pattern. This law states that learners tend to continue shapes beyond their ending points (Moore, Fitz 1993). The lines identifying switch parts on Moore and Fitz's example simply continued onto the graphic itself. The improved version stopped the lines before reaching the graphic and used arrowheads to identify specifically to which part of the graphic the label belonged, it is shown in Fig 1.5.
Law of closure: Humans tend to perceive an enclosed space by completing a contour and ignoring gaps. For instance, the human eye will see a triangle in picture shown in Fig. 1.6, although no triangle has actually been drawn. Gestalt theory seeks completeness; with shapes that are not closed, they seem incomplete and leads the learner to discover something missing, rather than concentrating on the given instruction. Moore and Fitz draw boxes around the illustrations in their instruction, to separate it from other illustrations and group the elements of one illustration together. Otherwise, the user is not sure which parts belong to what illustration (Moore, Fitz 1993). The mind must work harder to fill in the gap.

Thus, Camouflage can happen under various circumstances. Natural camouflage might be possible biologically, ecologically and also psychologically. On the contrary, in military applications the camouflage is synthetic or man made. Animals express/represent information about the image in the form of variables like contrast, border, shape, color texture etc, which are easily perceivable. Among these, this thesis concentrates on the texture features for decamouflaging.

The techniques that have been developed for decamouflaging could find its applicability in defence, agriculture, horticulture, medical and other biological fields as well. The techniques have been tested on many datasets including both natural and synthetic images. Few of the benchmark datasets are shown below:
Sample Image set I – Completely Synthetic Image

A set of synthetic camouflage images were generated for experimentation by hiding segments of ‘V’ in an array of U’s, 1’s obscured in an array of lower case L’s, Q masked in an array of O and ‘|’ hidden in an array of ‘!’ . The images are portrayed in figures 1.7 (a) - 1.7(d) respectively.

Sample Image Set II – Semi Synthetic Images

A set of camouflage images were synthesized by creating minor unobservable defects in images consisting of an array of similarly looking natural objects arranged in a particular order. Fig 1.8(a) to 1.8(d) reveal these images.
Sample Image Set III – Aesthetically Camouflaging Images

When minute changes are made in images with various levels of gray shades or flaring colors, it is an impossible task for human eyes to detect the part/region consisting of these changes. Fig 1.9(a) to 1.9(c) show these pictures.
Sample Image Set IV – Natural Images

The natural image set consists of brown lizards obscured in sand, green lizard hiding in grass, paddy mixed in wheat, defective stone image and a tile consisting of mild dirt. These images are portrayed in Fig 1.10(a) to 1.10(d).
The thesis attempts to demonstrate the strength of the proposed algorithms and techniques with the help of the above datasets. The subsequent sections outline the contributions and the organization of the thesis.

1.4 Proposed Strategies /Approaches and Motivations

Decamouflaging is an interesting research area in the broader area of Pattern recognition and Image processing. If new techniques could be developed for decamouflaging, they have relevance not only to the defence requirements but also to agriculture, horticulture, medical and other biological fields as well. Autonomous image surveillance and monitoring of objects in video has a rich history. The various
systems deployed are able to reliably track human/object motion in indoor and controlled outdoor environments, such as parking lots and university campuses etc.

A challenging domain of vital military importance is the surveillance of non-cooperative and camouflaged targets. These situations require sensitivity and a very closer field of view for detecting the presence of targets. Thus the detection of camouflaged target needs modern technological touch through the application of concepts drawn from the areas such as Image Processing, Pattern recognition and related fields.

This research works aims at developing indigenous tools and techniques for detecting the obscured segment in similarly textured background. Hence, the thesis is very much a relevant context in defense and agriculture services and the outcome is expected to contribute a lot in these fields.

The purpose of this work is also to explore the different possibilities and the extent to which the formation of high-level object models depend on texture as target identification and segmentation clues. Since we strongly feel that the rigorous analysis of deviation in the texture should be able to detect the camouflaged object, texture analyzing and contrasting algorithms were developed in this thesis for decamouflaging. At the macro level, texture based approaches are expected to generate an alarm indicating the presence of camouflage and at the micro level texture contrasting algorithms should be able to perform decamouflaging. We adopt a Quad tree based approach and a coarser to finer strategy for accomplishing the same. The texture based strategies for decamouflaging are proposed to detect an ‘unexpected’ texture in the spatial composition of the camouflaged scene, in contrast to an ‘expected’ texture in an otherwise noncamouflaged scene.

The given image requires several image preprocessing stages such as an image enhancement to enable better texture analysis. The applications of relevant convolution masks are also investigated.

A severely camouflaged image may not respond to the texture based method suggested above. Then it is necessary to study the relevance of transforming the test image. Both spatial domain transformations and frequency domain transformations
were elaborately studied to make it possible for generating clues and tools to achieve decamouflaging.

Initially basic approaches based on statistical features like mean, variance and histogram were used for decamouflaging. Subsequently, the performance of higher order central moments and zernike moments were investigated extensively. In this research work, we also applied spatial transformations based on Principal Component Analysis to develop strategies for decamouflaging. The conventional pattern recognition and image processing applications accept first one or two principal components for pattern/image analysis, in view of maximum variance being present in these components.

However with camouflaged scene this convention may fail, since that is the purpose behind camouflaging. Hence an extensive investigation on the possibility of extracting useful subset of Principal Components for discrimination of camouflaged objects from uncamouflaged objects were explored. An intensive research was conducted in the direction of hybridizing the use of both spatial transforms and frequency transforms to achieve decamouflaging. This has been broadly explored by first passing the image through Gabor filter banks and then accumulating the gathered image information from these bands in few principal component features for decamouflaging. Also a methodology to extract eigen features through principal component analysis has been explored.

The problem taken up is an open research issue. In this research work, we could identify few Pattern Recognition and Image Processing approaches to build new strategies, which are expected to detect the camouflaged scene and further could decamouflage, such a scene.

Decamouflaging is the identification and recognition of that object which is camouflaged. In fact, to the best of our knowledge no concrete research is reported in this direction. There is some research in this direction in the defense laboratories, but the results of such attempts are not available as publications.

This thesis brings out interesting aspects of decamouflaging and projects it as a broader area of pattern recognition and image processing application research. The contributions made in this thesis provide a foundational framework and avenues for
focused future work in fields like defense, agriculture, horticulture, medical and other biological fields.

1.5 Contributions

The focus on decamouflaging research resulted in numerous interesting contributions. The contributions have opened up many interesting issues and avenues that could result in several research outcomes. The major outcomes based on this thesis are listed below:

- A mean-variance based model for camouflaged target identification through Doyle's distance.
- Texture characterization through histogram features for decamouflaging.
- Analysis of coarser to finer strategy for decamouflaging.
- Central moment and zernike based approaches for decamouflaging and camouflage segmentation.
- Gray level co-occurrence matrix (GLCM) based features extraction for texture analysis and decamouflaging.
- A gray level co-occurrence matrix based model for decamouflaging using non-overlapped and overlapped image blocks.
- Discriminatory feature enhancement mechanism through line masks.
- Designing of line masks for extracting various orientational edge information from images and decamouflaging using line mask coefficients.
- A Texture analysis model using Gabor filter banks and principal component histograms for decamouflaging.
- Eigen feature extraction through principal component analysis for decamouflaging.

1.6 Organization of the thesis

The above contributions towards decamouflaging are organized as listed below to provide an incremental flow of ideas from trivial techniques using mean-variance to advanced techniques based on gabor filters, eigen features etc.
Chapter 2 proposes techniques based on mean-variance features for characterizing the textures of image blocks. The mean-variance features are analyzed through Doyle's distance and is further improved to introduce a histogram based mechanism for decamouflaging. As the Euclidean based distance measure for histograms are highly complex, a piecewise regression fit based distance measure is introduced for low complexity camouflage analysis.

Chapter 3 presents central and Zernike moment based models for decamouflaging. In this approach, we propose to split the entire region into smaller blocks. Each of these blocks are subjected to advanced texture analysis model through invariant central and Zernike moments. A complete performance analysis and inferences derived by using lower order moments to higher order moments for decamouflaging is illustrated.

In chapter 4, we propose a model based on gray level co-occurrence matrix to detect camouflaged objects/regions obscured in background texture. GLCM is used for intensive texture analysis to detect such camouflaged portions. This chapter proposes a pair of models with slight variations to detect the camouflage through second order texture parameters extracted from the GLC matrices.

Chapter 5 introduces the concept of line mask for texture analysis. This chapter proposes a model for designing the line mask kernels for capturing the different edge information. Such edge information obtained with line masks are used for enhancing the discriminatory features of the camouflaged object from that of its background.

Chapter 6 employs Gabor filter banks to gather the finer discriminatory feature at different orientations and image resolutions. Characterizing huge amount of Gabor band coefficients without much information loss has been a great challenge all these days. This chapter proposes a model to make use of histogram principal component analysis technique for holding the entire set of information in few principal component histograms. The finer discriminatory features that are required for decamouflaging can be captured by analyzing these principal component histograms.

Chapter 7 elaborates on the appearance based decamouflaging model through 2D-Principal Component Analysis. The properties of the texture characteristics in an image are best represented through their variance parameters. We model the variance of the image through eigen features and subsequently use them for decamouflaging.
Chapter 8 compares the performance of the various decamouflaging approaches proposed in this thesis through a cluster effectiveness parameter.

Chapter 9 summarizes the findings and lists out the broad future scope/challenges in decamouflaging for further research.