Image Restoration in Industrial Robotics

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ABSTRACT
Image restoration is the reconstruction of a degraded image towards the original object by the reduction or removal of the degradations. These degradations may be introduced during the formation, transmission and reception of the image. Natural images have distinct features that allow the human visual system to detect the presence of distortion, and to extract remaining information from the observation. Image restoration aims to construct an approximation sharing the relevant features still present in the corrupted image, but with the artifacts suppressed. In order to distinguish the artifacts from the signal, a good image model is essential. Most of the image restoration techniques model the degradation phenomenon, usually blur and noise, and then obtain an approximation of the image. Whereas, in realistic situation, one has to estimate both the true image and the blur from the degraded image characteristics in the absence of any a priori information about the blurring system. In this paper, an automatic system is proposed for detecting the presence of split defects in sheet-metal forming processes.

Keywords: Image Restoration, Artifacts, Degradation model, Filters, Machine Vision.

1. INTRODUCTION
Natural images have distinct features that allow the human visual system to detect the presence of distortion, and to extract remaining information from the observation. Image restoration aims to construct an approximation sharing the relevant features still present in the corrupted image, but with the artifacts suppressed. In order to distinguish the artifacts from the signal, a good image model is essential.

Image restoration refers to removal or minimization of known degradations in an image. This includes deblurring of images degraded by the limitations of a sensor or its environment, noise filtering, and correction of geometric distortion or non linearities due to sensors.

An image is often corrupted by noise in its acquisition or transmission. The goal of denoising is to remove the noise while retaining as much as possible the important signal features. Traditionally, this is achieved by linear processing such as Wiener filtering. Thus a fundamental result in filtering theory used commonly for image restoration is called the Wiener filter. This filter gives the best linear mean square estimate of the object from the observations. It can be implemented in frequency domain via the fast unitary transforms, in spatial domain by two dimensional recursive techniques similar to Kalman filtering, or by FIR non recursive filters. It can also be implemented as a semi recursive filter that employs a unitary transform in one of the dimensions and a recursive filter in the other.

Several other image restoration methods such as least squares, constraint least squares and spline interpolation methods can be shown to belong to the class of Wiener filtering algorithms. Other methods such as maximum likelihood, maximum entropy, and maximum a posteriori are non linear techniques that require iterative solutions.

2. APPLICATIONS OF RESTORATION
The first application of digital image restoration in the engineering community was in the area of astronomical imaging. Ground based imaging systems were subject to blurring due to the rapidly changing index of refraction of the atmosphere. Extraterrestrial observations of the Earth and the planets were degraded by motion blur as a result of slow camera shutter speeds relative to rapid spacecraft motion. The astronomical imaging degradation problem is often characterized by Poisson noise, Gaussian noise etc. It is necessary to restore these degraded images through digital image restoration techniques.

In the area of medical imaging, image restoration has played a very important role. Restoration has been used for filtering of Poisson distributed film-grain noise in chest X-rays, mammograms and digital angiographic images, and for the removal of additive noise in Magnetic resonance Imaging.

Another important application of restoration technique is to restore aging and deteriorated films. The idea of motion picture restoration is often associated with digital techniques used not only to eliminate scratches and dust from old movies, but also to colorize black and white films.

The expanding area of application for digital image restoration is that in the field of image and video coding. As techniques are developed to improve coding efficiency, and reduce the bit rates of coded images, artifacts such as blocking effect become a severe problem. Blocking artifacts are a result of the coarse quantization of transform coefficients used in typical image and video compression techniques. Much has been accomplished to model these types of artifacts, and develop ways of restoring coded images as a post-processing step to be performed after decompression.

Digital image restoration has also been used to restore blurry X-ray images of aircraft wings to improve federal aviation inspection procedures. It is used for restoring the motion induced effects present in still composite frames, and in general, restoring uniformly blurred television pictures. Printing applications often require the use of restoration to ensure that halftone reproductions of continuous images are of high quality. Digital restoration is also used to restore images of electronic piece parts taken in assembly – line manufacturing environments.

3. IMAGE MODELS

Developing techniques to perform the image restoration task requires the use of models not only for the degradations, but also for the image themselves. Image models express our prior knowledge about the structure of the original image. The development of a suitable model for discrete image requires a trade-off between the accuracy of representation and its utility in image identification and restoration. The image models can be distinguished into two broad categories i.e., deterministic and stochastic (statistical). In stochastic model, an image is considered to be a sample function of an array of random variables called random fields.

Distortion is almost always involved in recorded images. Distortion is mainly due to imperfections in the imaging system. Distortion may occur due to i) relative motion between the imaging system and the object ii) defocusing of camera lens iii) Uniform out of focus blur and iv) Uniform 2-D blur. The image distortion may be due to an inherent property of the imaging system. This problem can get complicated due to random noise involved in the imaging. It may originate from the imaging or recording process or due to medium or combination of all these. So what we have is a distorted blurred image with a random noise added to it. In image restoration we are supposed to obtain an image, which is as close as possible to the original image. The exact knowledge of the distortion and noise is not available at most of the times. Even if it is available, the problem of image restoration is an ill-posed problem. That means a small variation in the data (due to noise) can cause large variation in the solution. Hence prior knowledge of the nature of the original image and noise is incorporated in the restoration process. Although the blur is the most important degradation visually, the noise that is mixed with the data constitutes an important limitation in restoring blurred images.

The restoration techniques are oriented towards modelling the degradation and applying the inverse process in order to recover the original image. The modelling of the degradation is explained in the next section.

4. DEGRADATION MODELS

Image degradation involves both linear and non linear process. A general model for image degradation that represents these processes is:

$$d(x, y) = \sum_{i,j}^{X} h(x - i, y - j) f(x, y) + \eta(x, y) \qquad 1$$

where h(x-j, y-j) is the two dimensional impulse response of the blurring system at pixel (x,y), represent a point-wise operation, and $\eta(x,y)$ is the corruptive noise process. It is usually assumed that the blurring function is space-invariant and the noise $\eta(x,y)$ is the additive white Gaussian process. As the blur function is assumed space-invariant so the non linear degradation process becomes linear degradation process. However, in some applications, it is necessary to take the sensor non linearity into account.

The noise term is important because in practical imaging situations, additive noise is not negligible. The additive noise term can be realized in different ways depending upon the situation and the same is explained in the paragraphs to follow.

Common types of noise are i) Electronic noise, resulting from thermal motion of electrons in the electronic components of the imaging system ii) Photoelectric noise, due to statistical nature of light and photoelectric conversion process in the imaging sensor iii) Film grain noise, from the randomness of silver halide grains in the film used for recording and iv) quantization noise which occurs during image digitization.

5. IMAGE RESTORATION TECHNIQUES

Usually all blur-degraded images exhibit similar characteristics, namely a low pass smoothing of the original image, attenuating the edge information which is very important for human visual perception. We review some of the common approaches for image restoration.

The goal of this article is to introduce digital image restoration to the reader who is just beginning in this field, and to provide an overview of digital mage restoration.

Some of the important image restoration techniques, that can be classified into spatial and transform domain approaches are reviewed in this section. Both of these classes can be further grouped into deterministic and stochastic, recursive, iterative, adaptive and non adaptive approaches.

Based on the image degradation model of equation (1), there have been a number of approaches developed to restore the original image, given the observed image 'd', 'h' represents the linear distortion which may be space-invariant or variant, and some knowledge about the noise η. These include the Miller's regularization approach and the constrained least square approach (CLS).

Total least-squares (TLS) is a technique for solving the noise perturbed set of linear equations. The constrained total least-squares (CTLS) technique handles effectively the case when the noise elements in both 'h' and'd' are linearly related and have equal variance. The problem of restoring an image by a linear space-invariant point spread function (PSF) that is not known is formulated as the solution of a perturbed set of linear equations. The Regularized constrained total least-squares (RCTLS) method is used to solve the equations. This method is superior to CTLS method and reduces the ringing artifacts around the edges as compared to other approaches.

Another algorithm for image restoration which is based on CTLS estimation is adaptively regularized CTLS (ARCTLS). It is well known that in the regularized CTLS (RCTLS) method, selecting a proper regularization parameter is very difficult. For solving this problem, one has to take the first-order partial derivative of the classic equation of RCTLS image restoration and do some simplification with it. Then, an approximate formula is deduced, which can be used to adaptively calculate the best regularization parameter along with the degraded image to be restored. It is also proved that the convergence and the stability of the solution could be well satisfied. The results of the experiments indicate that using this method can make an arbitrary initial parameter be an optimal one, which results in a good restored image of high quality.

Maximum a posteriori estimation (MAP), stochastic technique has been applied to the problem of restoring images distorted by noisy spread functions and additive noise. Although the deblurring results are slightly inferior to those obtained through Wiener filter, the advantage of the MAP estimator lies in the significant suppression of noise. Whereas the Wiener filter isolates lines in a noisy image by finding, an optimal trade-off between inverse filtering and noise smoothing. It removes the additive noise and inverts the blurring simultaneously so as to emphasis any lines which are hidden in the image. This filter operates in the Fourier domain, making the elimination of noise easier as the high and low frequencies are removed from the noise to leave a sharp image. The wiener filter approach helps to find an "optimal" estimate of the original image by enforcing a minimum mean-square-error constraint between estimate and original image. Under the minimum mean-square-error constraint, the filter assumes a functional form that involves essentially the blur matrix and the original. To be able to apply the Wiener Filter, some knowledge of the original image must be known in order to perform the restoration effectively.

The primary advantage of iterative techniques is that the progress may be monitored as it progresses. Iterative algorithms are very well suited to restoring images suffering from a variety of degradations such as linear, non linear, spatially invariant blurs and signal-dependent noise, because of the flexible framework provided by each approach.

There are other deterministic techniques which can be used to perform iterative restoration. The deterministic set- based approach can be generalized to form an iterative method called projections onto convex sets (POCS), in which any number of prior constraints on a solution can be imposed as long as the constraint sets are closed convex. Many techniques have used POCS based approach to perform iterative restoration with success.

Recursive restoration of blurred and noisy images using Kalman algorithms is slowed down by the correlated nature of the two-dimensional data and the excessive computing requirements of the very long state vectors. An extended Kalman filter procedure is useful for restoring representative images with significant simulated variations of the blur parameter.

Spatially adaptive image restoration techniques frequently incorporate the characteristics of human visual system (HVS). One of the properties is less sensitivity to noise in high spatial activity regions in an image e.g. edges. Since the HVS is sensitive to sharp changes in an image, therefore performing restoration, it is not pleasing to smooth over the edges. Due to this at each spatial location, different restoration filters are needed. These filters should vary between the filters applied at sharp edges and in the flat regions. Adaptive Wiener filter is one of such techniques that take care of both conflicting properties; smoothness versus edge enhancement.

6. PROPOSED APPLICATION

Image restoration techniques find its applications in the area of space imaging, medical imaging, electronic media and paper, image compression and industry. In this paper, an automatic system is proposed for detecting the presence of split defects in sheet-metal forming processes.

In a forming process, an automated visual inspection system contributes significantly to guarantee 100 percent of quality parts, reducing costs, and increased the competitiveness, but the visual inspection of complex shaped metallic surfaces is extremely difficult. Sheet-metal parts produced in forming processes are a challenge to any vision system where their non-lambertian surfaces can produce saturations, shadows, inter-reflections, and other quick variations that are extremely difficult to predict. Another difficulty is that they tend to have edges, corners, moldings, creases, etc., which may produce signals which are similar to that of a defect.

Several solutions have been presented for sheet metal part inspection (3D measuring systems, systems that project a white light or fringe pattern and analyze their projection in a retro reflective screen, etc.),but have not hitherto been applicable to on-line inspection.

The proposed machine vision system is used to locate on-line tearing defects than appear in sheet metal forming processes. The system inspects the parts proceeding from the sheet metal forming line as they are moving on a conveyor belt. An inspection-robot positioned in front of the inspection areas forms the image acquisition system.

Image acquisition system consists of light sources and sensing device for capturing images (camera). Illumination is always a crucial aspect regarding image quality and reproducibility of image acquisition conditions but in this case, where highly reflective metals are being inspected, is especially critical.

The vision control will determine whether the part will continue in the production flow or be excluded from it. By detecting defects as soon as they occur, quick action can be taken to remedy the source. Detection avoids furthermore that the manufacturer fall into a very costly product return if defective parts slips past quality procedures and arrives at the assembling line.

If the defect detection algorithm, takes the acquired image as input data, an enormous quantity of hypothetical false defects will be determined. Thus, the acquired images are firstly restored using wavelet transform in order to eliminate the spurious features without modifying the delicate characteristics of the small splits.

To obtain the best results of the inspection it is necessary to know the precise position of the parts on the conveyor belt in order that the inspection-robot can go to the programmed inspection points. But for the proper characteristics of the process, of the pieces and of the conveyor belt, they can produce variations in the positions of the pieces on the conveyor belt that they can affect the inspection. To solve this problem, recognition of parts and precise positioning of the inspection-robot is crucial.

The system performs two tasks off-line: Learning the correspondence among images and pieces positions (visual learning) and memorizing the robot positions to acquire the images over each inspection zone. The tasks performed on-line are: Acquiring an image, obtaining the part position (recognition and positioning), inspection-robot positioning over each predetermined conflictive area and defect detection.

6.1 Industrial Requirements

Metal forming is a manufacturing process where the sheet metal is bent and stretched using presses and dies. The shape and dimensions of the obtained parts correspond exactly to those of the active elements of the pressing device. In the forming processes the thickness of the stamped part can decrease dramatically from those of the original metal. In the areas where high demands are placed on (double curvatures, sharp corners, deep recesses, etc.) the metal often tears under the tensile forces when is stamped into shape. It is clear the immediate detection of splits at the output of the sheet metal forming line is important. However the on-line inspection is not an easy task due to the subtle characteristics of the defects and high reflective nature of the metallic surfaces.

Considering the properties of the sheet metal forming line, the key objectives for the system are as follows:

- the system has to be able to operate automatically under the supervision of the line controller.
- the products manufactured include a large variety of sizes and shapes.
- in the output of the line, products are placed on a conveyor belt.
- the system has to be able to detect breaks and significant stretching in inspection areas.
- the environmental parameters are far from optimum (limited available space, vibrations, variable ambient luminosity, etc.)

7. CONCLUSION

The automatic visual inspection of complex shaped metallic surfaces is extremely difficult: To obtain the best results of the inspection it is necessary to know the precise position of the pieces on the conveyor belt in order that the inspection-robot can go to the programmed inspection points. Although many approaches for solving the problem have been proposed for different applications, there is still a need for developing techniques that exhibit a more appropriate comprises among computational properties, portability and reliability for a given application.

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