Automatic Defect Recognition on a Automatic MPI Billet Inspection System

A Paper By

Mark Willcox

Telephone
+44 (0)1981 541122

Fax
+44 (0)1981 541133

Email
Sales@InsightNDT.com

Web Site
www.InsightNDT.com

Insight NDT Equipment Ltd
The Old Cider Mill
Kings Thorn
Herefordshire
HR2 8AW

Directors
Mark Willcox BSc (Hons)
Jiang Li BSc (Hons)

VAT Registration No.
771 3060 50

Registration No.
4198815 England

Registered Office
21 St Owen Street, Hereford,
Herefordshire HR1 2JB

Table of Contents

IN-LINE FULLY AUTOMATIC MPI BILLET INSPECTION SYSTEM

1 Introduction

Different MPI techniques exist for the inspection of billets for longitudinal surface defects; usually it will be one of the following techniques:

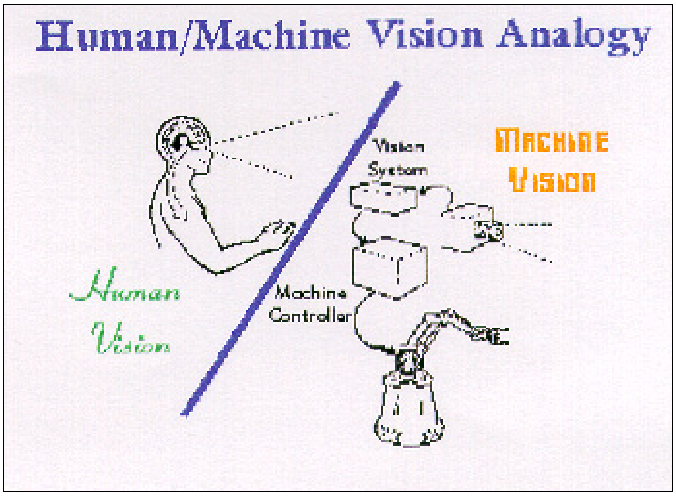
- A Contact System - using current flow contacts on the ends of the billet.
- A Non-Contact System - where the billet passes through a yoke arrangement.

The Non-Contact System lends itself most readily to an Automatic Defect Recognition System. Since the billet would be moving and the UV Illuminated Viewing area stationary, therefore the billet can pass through any viewing system.

For such a system inspection speeds of up to 30 feet/min are attainable, using two trained inspectors to view and mark the defect area on the billet. To achieve higher inspection speeds, an Automatic Defect Recognition System is necessary.

2 Human Vision vs Machine Vision

As a model we can consider the human vision system comprising the eye(s), the optic nerve, and the brain. The eye forms an optical image with its lens and senses this optical image with the retina. The optic nerve transmits the image information to part of the brain which analyses and extracts the image information. Another part of the brain uses this information to control the body's muscles.



A model of machine vision is quite similar to the simplistic model of the human vision system. A camera with a lens forms the optical image onto an image sensor, a video signal then travels through a cable to a computer that analyses the image information to extract the necessary information. This information is then sent to a controller which operates some machinery.

If machine vision were limited to only emulating human capabilities, no one would have ever tried, and succeeded, to make measurements with machine vision; the unaided human eye is an unreliable rule. Machine vision would be limited to working only with visible light, instead of also exploiting the potential of infrared, x-ray imaging and ultraviolet inspection.

3 Human Viewing of MPI Indications

The human eye only responds to visible light, that is light that falls in the visible light spectrum, from Red with a wavelength of 700 nanometres (700×10^{-9} of a metre) to Violet with a wavelength of 400 nanometres (400×10^{-9} of a metre). The eye also has the highest sensitivity to light that has a wavelength of 555 nanometres (555×10^{-9} of a metre) which is in the Yellow / Green region of the light spectrum.

When viewing an MPI indication illuminated by an ultra-violet light (blacklight), the human eye filters out any reflected ultraviolet light, and only sees the visible Violet background on the component which is emitted by the blacklight. A defect which fluoresces in the Yellow / Green region of the light spectrum will stand out in contrast to the surface of the component and the Violet glow from the blacklight.

4 Camera Viewing of MPI Indications

There are several variables which play a role in the Camera Viewing of an MPI indication on steel billet. The following list represents the main concerns which need to be addressed with such a viewing system:

- Magnetic Particle inking solution used
- Contrast Ratio between defect and background
- Camera type used
- Camera Shutter Speed
- Camera Spectral Sensitivity
- Twist in the billet
- Out of straightness of the billet

A CCD camera not only responds to visible light but also responds to invisible light, that is light that falls in the spectrum, from Infrared with a wavelength of 1 millimetre (1×10^{-3} of a metre) to Ultraviolet with a wavelength of 10 nanometres(10×10^{-9} of a metre). This response is a much wider range than the limited response of the human eye.

When viewing an MPI indication, which is illuminated by ultraviolet light, the camera's wide light spectrum response becomes a big problem. The camera would be sensitive to the reflected ultraviolet light energy, which actually saturates any image that the camera sees. Therefore, it would not be possible to discriminate the defect indication which is in the Yellow / Green region of the light spectrum from the ultraviolet reflection in the Ultraviolet region of the light spectrum. It is therefore necessary to use optical filters so that the human eye light spectrum response may be mimicked.

An optical filter placed in front of the camera lens would preferentially transmit light of their own wavelength and hold back light of other wavelengths. Therefore the use of both Ultraviolet and Infrared absorbing filters screen out the non-visible light of the light spectrum and only allow the visible light through to the camera lens. Using these filters, it is possible to resolve the defect indication which fluoresces Yellow / Green.

It is possible to add additional filtration which will only allow the Yellow / Green light to pass through to the camera lens, further enhancing the contrast of the defect to background.

The use of the Yellow-Green filter has the effect of increasing the apparent brightness of the MPI indication, essentially increasing the defect to background contrast ratio, making the defect more obvious.

5 Particle Selection to Enhance Defect Contrast

The experiments so far used particles which exhibit low background characteristics and fluoresces a colour closer to Yellow rather than Green. This particle was initially selected because of its low background characteristics which is essential to aid the contrast of the captured image. If a high background particle is used it would be necessary to process the captured image to remove the random spots of the background, something that would be unacceptable in a time critical application, such as billet inspection.

Semiconductor CCD cameras are generally most sensitive to light that has a wavelength of 700 nanometres (700×10^{-9} of a metre), that is visible Red light. It was therefore thought necessary to investigate the use of a particle that fluoresces Red or Orange rather than the more usual Yellow / Green.

The use of the Red particle made it necessary to use a Red filter, in place of the Yellow-Green filter previously used. It was found that this Red particle appeared to have a greater brightness to the human eye, over the Yellow / Green particle used previously, which is surprising, since the human eye is more sensitive to Yellow / Green rather than Red.

With the Red filter in place, only Red light is allowed to pass through to the camera lens, further enhancing the contrast of the defect to background.

In order to capture this image from the arrangement it was necessary to change the setting of the lens by one stop, to f4.0. This change effectively means that the image captured is at least twice the brightness of the images captured using the Yellow / Green particle.

When the resulting image is examined closely it is possible to see that the image brightness is higher than the previous images. Therefore, from these experiments the only conclusion can be, that it is advisable that a Red or Red / Orange particles used when trying to view the defect indications by a CCD camera, rather that the more conventional Yellow / Green particles.

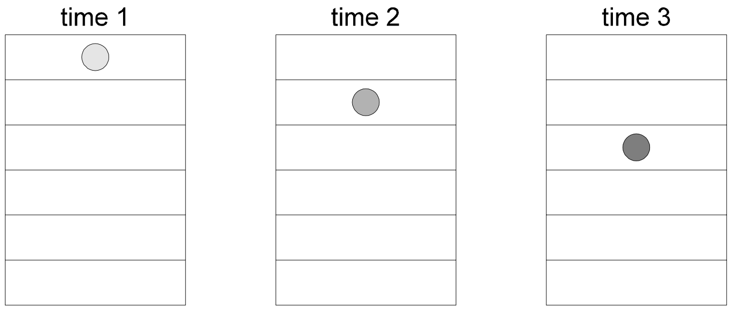
6 Camera Selection to Enhance Sensitivity

All the discussed experiments used a CCD Imaging Camera, with a resolution of 768 by 512 Pixels and a 25mm lens. This type of camera is ideally suited to capturing images from static components. However, when inspecting steel billets the billet is moving at speeds of up to 100 feet/minute. It would therefore be necessary to use a shutter on the camera. Even so, the system would be limited to an update rate of 30 frames per second, which is the same rate as used in conventional video cameras. At these rates an imaging camera would be sampling every 0.67” of billet movement.

It is possible, however, to have a CCD camera system that runs at much higher update rates, and this type of camera is a line scan camera. As its name suggests it is a camera that rather than having a rectangular array of light sensing elements (such as 768 by 512, as in the imaging camera used in the previous experiments) it has a single line of sensing elements (typically 512 by 1 pixels or 1024 by 1 pixels).

The main advantage of this type of camera is that the image capture is synchronised to the speed of movement of the billet under test and at much higher update rates when compared to the imaging camera. However, there is one significant draw back with this type of camera; the sensitivity of the camera is less than that of an imaging camera, typically a factor of 20 less sensitive. This essentially means that this type of camera is not suitable for viewing MPI defect indications because of the limited light intensity emitted from the indication.

To overcome the limitation of the conventional line scan camera, a new architecture called Time Delay and Integration (TDI) was developed. A typical TDI line scan camera has an 80 times increase in sensitivity over the conventional line scan camera and four times sensitivity over a standard imaging camera.

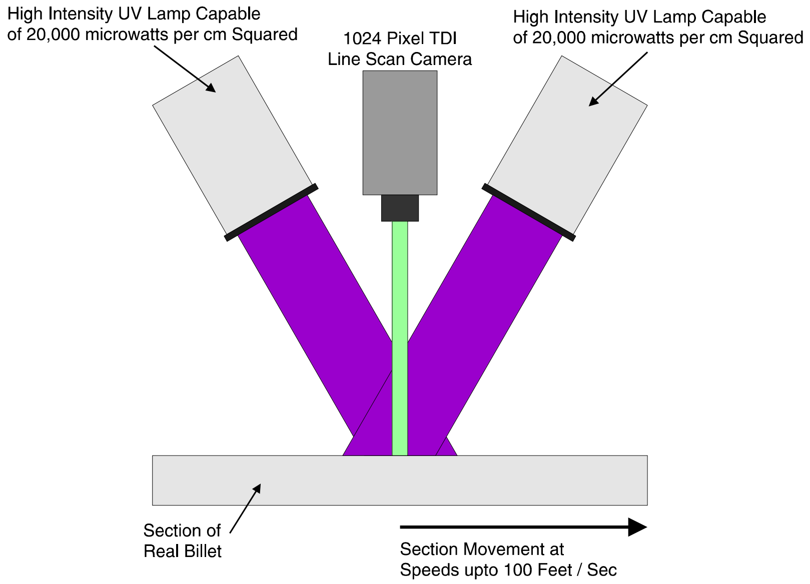


Signal strength of the circular defect
increases as it passes through each stage

A TDI line scan camera is based on the concept of taking multiple exposures of the same object. The object must be in motion since the exposures are taken at differing points in time, corresponding to different spatial locations, as illustrated in the above diagram. This illustration shows a small circular defect on a component that is moving through different exposures (stages) of the TDI array. As the defect passes through more and more stages, the signal registered by the sensor is increasing in direct proportion to the number of stages. In effect, the integration time available to collect photons has been increased by using the TDI method.

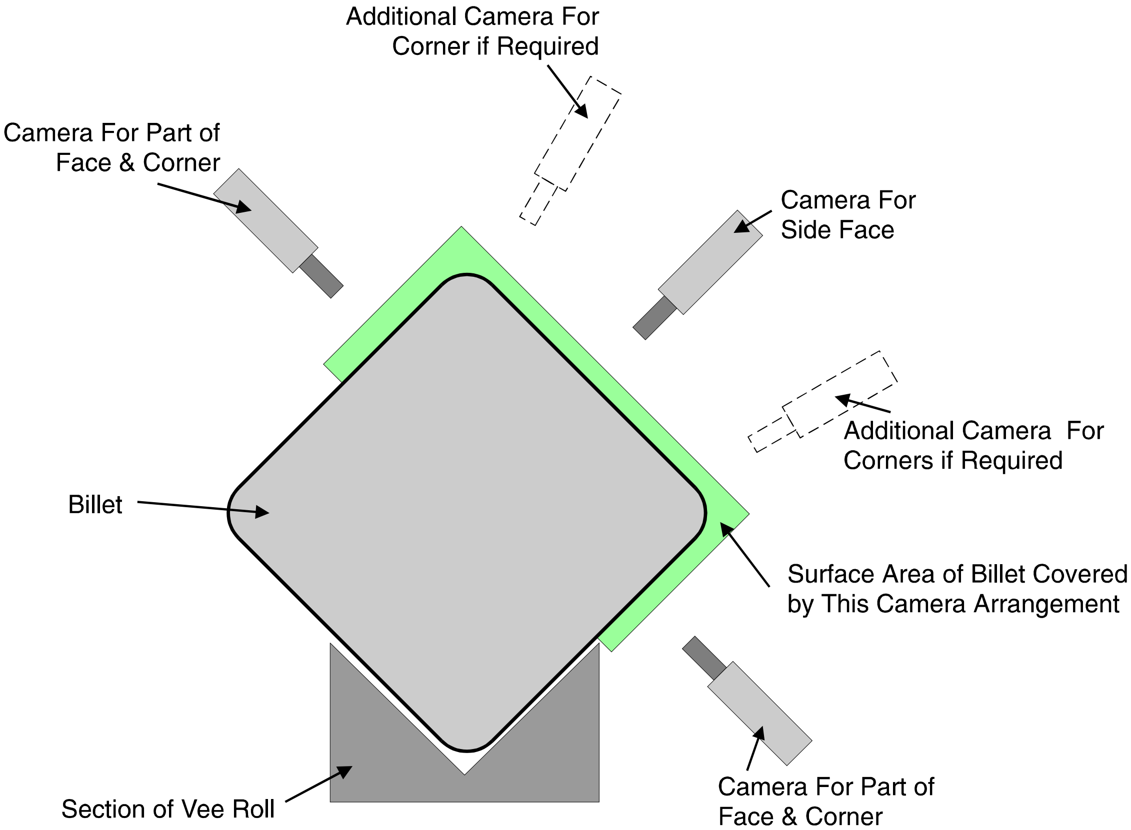
7 A Prototype Automatic Billet Inspection System

This prototype system is designed to detect linear agglomerations of magnetic particles such that the dimensions of the agglomeration is not less than 0.008” in width and 0.25” in length. Also the ratio of the minimum single pixel brightness, measured within the agglomeration, to the maximum local background brightness, measured in the vicinity of the agglomeration should be not less than 10.1.



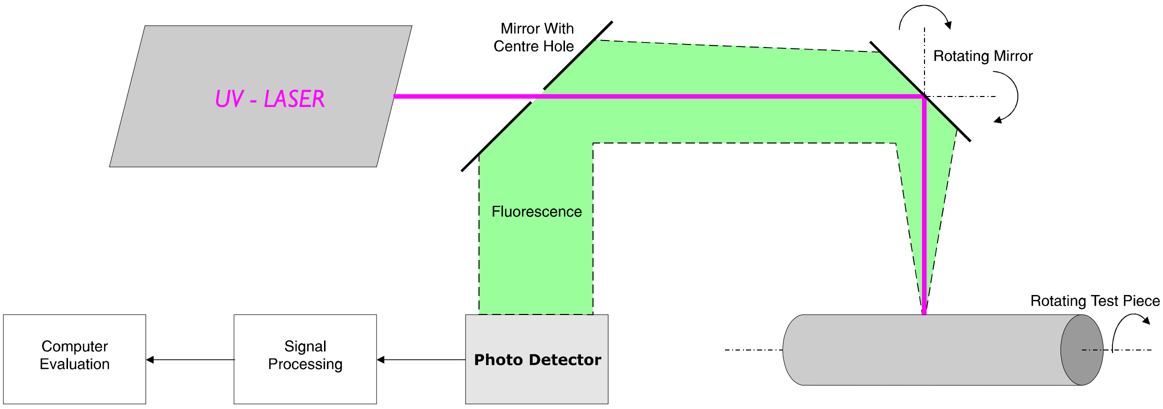
The system uses a single TDI line scan camera, with 1024 pixels per line. The line scan rate will be automatically adjusted based on the speed of the test sample so that the projected pixels are approximately square. At a speed of two feet per second the line rate will be approximately 3000 line per second. This rate implies that the effective exposure time is about 1/3000 of a second. This short exposure is required to minimise blurring of the image. By using a TDI camera it is possible to increase the effective sensitivity by about a factor of 80 which compensates for the very short exposure. Also it allows the use of a sufficiently small aperture so that the depth of field can be maintained for various billet sizes, approximately 5” to 8”.

When the final system is fitted to the Billet Inspection Line the TDI camera arrangement will generally be as the illustration below.



8 Recent Developments in MPI Defect Detection

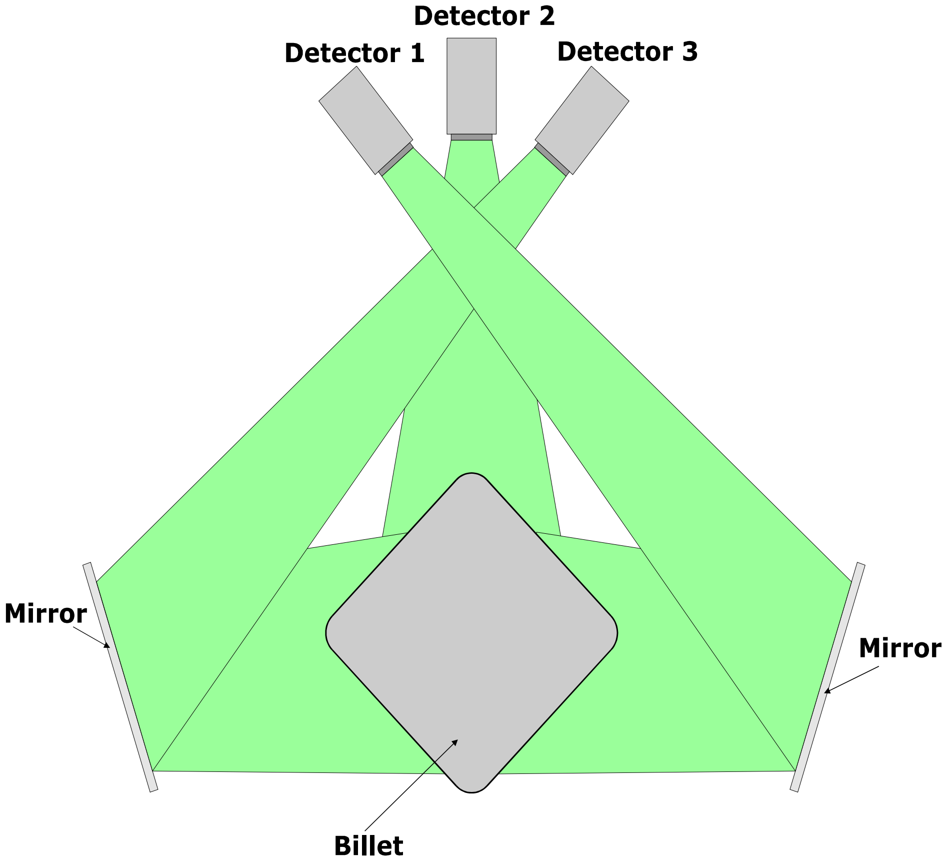
An emerging technology in the field of Machine Vision and automated gauging is that which uses lasers and particularly UV lasers.



A UV laser beam is directed towards the test piece during testing. The laser beam path passes a number of mirrors that can be moved allowing the test component to be scanned. Please refer to the illustration opposite.

The great intensity of the laser beam results in a high fluorescence from the magnetic particles. Also the fact that the light is in the form of a tiny spot greatly reduces the complexity of the processing required on the signal, since there will be no illumination of the background as a whole.

A typical system is illustrated below. When directed towards the test piece the laser beam passes through a centre hole in a 45^{o} fixed mirror between this mirror and the test piece the laser beam and the fluorescence from the MPI indication follows a common path.



There is no imaging required since the photo detection is only interested in the return fluorescence and the fact that the laser beam is an almost parallel light beam. The only light received is that from the MPI indication, illuminated by the laser spot.