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The evaluation of a multi-sensor robotic visual inspection system

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Abstract
In this paper, the performance of a multi-sensor, robot-mounted, inspection system has been investigated. A robot-arm was used to enable large-scale, flexible inspection using a 2D laser scanner. The laser scanner can be used to quickly scan the inspection surface, and using the scan data the location of possible faults or special features is determined. A high resolution optical sensor, co-located with the laser scanner, can then be used to obtaining high resolution scans of selected features. The combination of the two sensors provides a relatively fast, but also, high resolution inspection system. The performance of the inspection system is investigated by considering the impact of scanning paths on the quality of data recovered from the laser scanner. This demonstrates the need for optimised sensor scan paths, which are necessary to inspect and reconstruct complex surface structures in a robust way. A methodology to identify the location of possible features of interest on the scanned surface is developed; allowing automatic positioning of the high resolution optical sensor for subsequent detailed inspection.

Keywords: robot, surface inspection, laser scanning, high resolution local inspection, feature detection, surface following.

1. Introduction

Accurate 3D measurements, inspection and feature detection over large-scale free-form surfaces represent a significant challenge, and are essential for product improvement and quality control [1-3]. The need to combine high measurement speed and large inspection volume with high resolution is especially challenging. The most promising solutions are generally provided by multi-sensor systems [1, 3, and 4]. While the majority of these systems require the transfer of selected samples to a dedicated instrument, production-line integrated inspection offers substantial savings and benefits [5, 6].

For production-line integrated, on machine applications, laser scanners are robust devices that combine fast acquisition speed with relatively high resolution, flexibility and mobility [2]. However, laser scanners also have limitations, and high data quality can only be obtained under a restricted set of operating conditions [7-9].

In this work, the need to optimise the operating conditions for laser scanners is highlighted. A custom built laser scanner is mounted on a robot to form a multi-scale inspection system. The raw image data from the laser scanner is analysed to determine optimum robot scanning paths. Then, a defect detection system is used to locate areas of interest suitable for high resolution inspection. Using a multi-sensor approach, this system combines relatively fast laser scanning, optimised by robot-guided path following, with feature detection capabilities, allowing subsequent automated feature inspection using a high resolution inspection capability.

2. Methods

2.1. Scanning of large freeform surfaces and point cloud reconstruction

A custom made laser scanner was assembled using a Flexpoint MVnano, 450nm, 1mW, 30° fan angle, focusable laser and a Basler acA1600-20gm GigE camera. These were mounted on a Fanuc LR Mate 200 iC industrial robot arm, driven by a R-30+A Mate controller, as shown on Figure 1A. A standard USB microscope providing high resolution local inspection capability was co-located with the laser scanner (Figure 1A).

A piece of aluminium, formed into a highly curved surface was created for testing the inspection system; the sample contained distinct features, such as holes, bumps, and scratches. The test sample was scanned, moving the laser scanner with the robot, on a custom, pre-programmed path. Subsequent laser scanner point cloud extraction and object reconstruction was performed using the Halcon image processing software library. As each laser scanner image was taken, it was transformed into a common coordinate system, based on robot position and pose, to create a full point cloud representing the scanned object.

2.2. Feature detection and high resolution local inspection

An unsupervised learning algorithm was developed and used to detect features in the obtained point cloud. The location of the feature was extracted and the robot was instructed to automatically visit each feature, placing the high resolution sensor (USB microscope) on top of it and acquiring detailed structural information (Figure 1 A, E inset).

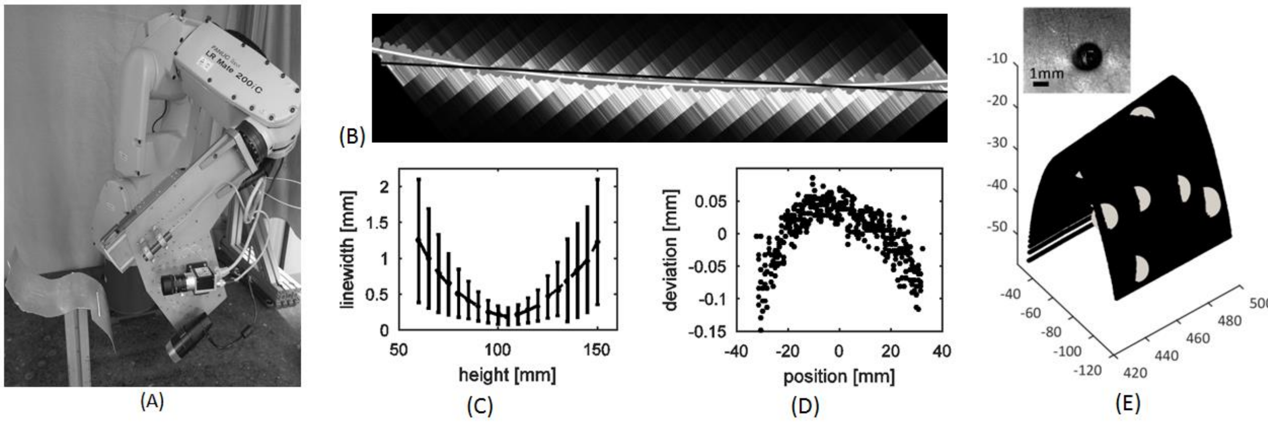

Figure 1. (A) Custom robot-mounted inspection setup. (B) Laser line image. Note: for the purpose of visualization, the image has been zoomed asymmetrically. Pixel data as recorded by the camera (white/grey stripes) has been overlapped with the (Gaussian) peak intensity of each pixel column (grey dots). The later has been fitted with a linear (black line) and a polynomial (white curve) function. (C) Laser line quality in function of height. Data points represent the mean of laser light deviation from its centre line (see panel B), while error-bars show its scattering as the standard deviation of each point to the centre line. (D) Laser line deviation from linearity: the difference between the linear fit (panel B, black line) and the second order polynomial fit (panel B, white curve) along the laser line. (E) Reconstructed point cloud (PC) of a scanned large aluminium plate, containing introduced features (dents, holes). Only a part of the object is shown. Detected features are marked grey. Inset: high resolution image of an example feature. All units are in mm.

2.3. Laser scanner evaluation

The laser scanner was evaluated by placing a flat surface at a range of heights, *h,* from the laser*;* the value of *h* was varied between 60 and 150, in 5 mm increments. A grayscale image of the laser line was acquired for height value.

Each image was processed to extract a set of maximum intensity pixels that represent the centre of the laser line. Using least squared regression modelling, the maximum intensity pixels were then used to create a first and second order polynomial (Figure 1 B).

The distance of each bright pixel to the first order fitted line was then used to compute the laser line width (mean distance) and its scattering (standard deviation) for each height, *h;* this is shown in Figure 1C.

To investigate the effect of camera lens distortion, the distance between the first order fitted line and the second order fitted line was extracted at regular intervals. This provided the deviation from linearity of the laser line image, as observed using the camera (Figure 1D).

3. Results

3.1. Laser scanner evaluation

The quality of the laser scanner was evaluated within ($h=f_{laser}\pm10mm$) and outside the normal depth of field of the laser scanner, as described in section 2.3. We found that the laser line becomes wide and highly scattered once the limits of its working volume are approached (Figure 1 B). This leads inevitably to loss of feature detail and position. Additionally, the laser line image was found to deviate from the expected linearity due to lens distortion error (Figure 1 D). These deviations are approximately 0.1 mm at ideal height ($h=f_{laser}=105mm$), becoming even more severe as $h\neq f_{laser}$, and thus represent a serious source of error. Consequently, the laser scanner only provides accurate data when used at the ideal distance from a surface.

3.2. Scanning of large freeform surfaces and detecting features

For the above reasons, the robot was programmed with a path that follows the surface of the object, keeping the scanner at the ideal distance to, and normal to, the surface at all times. This allowed for the collection high quality topography data, which could be used to detect selected features with high confidence (Figure 1E, 8 out of 9 defects were detected with no false positives, and one false negative.

Having obtained the location of targeted features, the robot is capable of automatically inspecting these locations with a high resolution, but small area imaging sensor, obtaining detailed information from this region (Figure 1 E inset).

4. Conclusion

We have demonstrated that a custom, multi-sensor, robot mounted inspection system, based on an optimally employed laser scanner and high resolution inspection sensors has the ability to quickly scan large, free-form surfaces, extract possible features and collect detailed information from the latter. Such a system provides reduced inspection time, while providing high details on targeted features only. Additional work is currently underway to extend feature detection and classification.

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