Machine vision for automated inspection of surgical instruments

Shuyi Wang, Xunchao Yin, Bin Ge, Yanhua Gao, Haiming Xie, Lu Han
School of Medical Instrument and Food Engineering
University of Shanghai for Science and Technology
Shanghai, China

Abstract—**In order to improve the measuring speed and accuracy of the surgical instruments inspection, a computer-aided measuring and analysis method was highly needed. The purpose of this study was provide surgical instruments manufactures with a surgical and microsurgical instruments inspection system, so as to ensure that surgical instruments came from assembly lines were manufactured correctly. Software and hardware components were designed and developed into a machine vision inspection system. Different surgical instruments such as scissors, forceps, clamps, microsurgical instruments were inspected; the system accuracy could be 0.001mm. The result showed that the detection system had significant effects. The detection system could measure the vast amount of measurements of surgical instruments required for mass-produced devices.**

Keywords-surgical instruments; machine vision; automated inspection; digital image processing

I. INTRODUCTION

In order to performing a surgical procedure, it is necessary to assure that the surgical instruments used are safe and reliable. A large number of surgical instruments are manufactured in the developing world and many of these instruments are manufactured by manual laborers. From raw material to product, the production process of a surgical instrument may require as many as 80 different steps. Surgical instruments are inspected by human vision. In an assessment of 4800 instruments examined, 730(15%) had potential problem [1]. It is very important to control the quality of surgical instruments so as to meet appropriate standards and decrease potential hazard that may result, such as failure of cutting action, failure of correct meshing of ratchets, cracks machining burrs in teeth etc. So quality control is important in its lifetime especially in final inspection which checks the functionality, critical dimensions and surface conditions of the instrument. Manual inspection neither guarantees consistent measuring accuracy nor decreases working time. In order to improve the measuring speed and accuracy of the inspection, a computer-aided measuring and analysis method is highly needed.

Along the last 30 years the research field called "machine vision" has been evolving and developing to play an important role on either side of production processes (using robotics) and quality control of manufacturing operations [2]. Instead of human inspectors, machine vision technique promises a great economic return and good levels of accuracy without human presence; it is therefore quite obvious to suppose that in the next years most of quality inspection tasks for industrial applications will be performed by means of machine vision systems.

In this study the system proposed is based upon machine vision, to be developed using new technologies available, to perform activities within the process of inspecting surgical instruments. Then, its main function would be to measure the key dimension of various surgical instruments such as scissors, forceps, clamps and microsurgical instruments, looking for increasings on quality standards. All surgical instruments will be examined prior to entering service so as to ensure that surgical instruments came from assembly lines were manufactured correctly.

In this paper, the system principle and methodology is described in Section 2 and the result for various surgical instruments in Section 3; in Section 4 we discuss some of the ramification of the present work.

II. EXPERIMENTAL AND METHODS

Traditionally, tip details and other important dimensions of surgical instrument are measured with calipers, micrometers or other specially built gauges so as to ensure surgical instruments meet predetermined tolerances. Different person may have different inspection result for one instrument and efficiency without consistent measuring accuracy is low and unfit for mass production.

A. Structure of Inspection System

As Figure 1 shows software and hardware components are designed and developed into automated inspection system, which includes a computer, frame grabber, a 2/3" charged couple device (CCD) camera, telecentric lens, LED backlight board, and instrument holder.

The images captured by the CCD camera are transformed into an eight-bit monochrome format by the frame grabber and then stored on the memory of the computer. Each digital image of the surgical instrument consists of a 2048×1536 array of pixels with a grayscale values ranging from 0 to 255. The main advantage of using a telecentric lens is that it ensures constant images of substantial variations in object-to-view distance. LED backlight enhances the contrast of the vision system and distinguishes the object to be inspected from the whole image.

Different surgical instruments may have different size and shape, a special holder is designed to locate inspection region. Figure 2 shows the vision unit of automated inspection system.

B. Camera Calibration Process

A relative calibration for system based on gauge blocks is presented. The First Grade gauge block sized 50mm is used as calibration reference, it is necessary to ensure the image of the gauge block occupy a larger region in the image, the metric size K represented by a single pixel can be calculated by the pixel value of the gauge block L:

$$K=50/L \tag{1}$$

After calibration, any metric size M can be computed as:

$$M= K\cdot N \tag{2}$$

Where N is the relative pixel value.

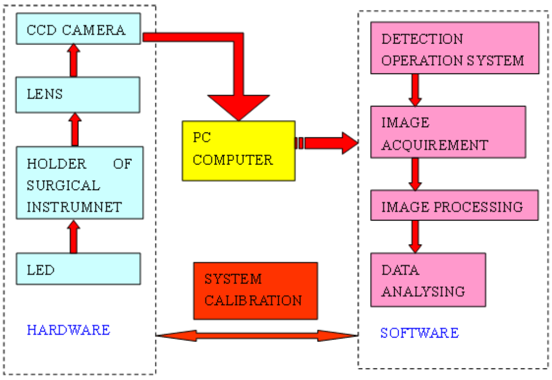

Figure 1. Block diagram of automated inspection system

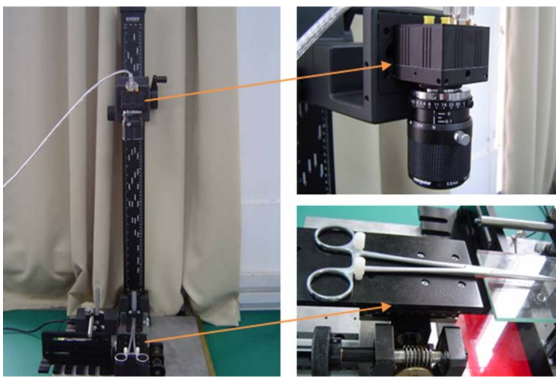

Figure 2. Vision unit of automated inspection system

C. Image Acquirement and Processing

Inspection of surgical instrument is one of typical applications of machine vision and digital image processing technology in industry production. After acquirement of initial image, erosion and dilation is necessary to make the edge of the image clearer and smoother, and eliminate illumination and noise effects.

The method of image preprocessing is mathematical morphological opening operation, which erodes and dilutes the image. There are two goals of opening operation used in image preprocessing; one goal is to filtrate the spike noise effectively, and to remove such noise's interference on the edge; the other goal is to achieve the stepwise reduction of the gray value of objective borders, and to smooth the objective border which to be extracted.

The filter mask with the same width and height is used on the erosion and dilation, so as to ensure the position of objective border consistent before and after image preprocessing. Most of small gray spots are wiped off obviously in the preprocessed image, simultaneity the change of border gray value presents more stepwise, which is good for edge extraction.

D. Sub-pixel Edge Extraction

For the purpose of high precision detection, a method of sub-pixel edge extraction based on canny operator is presented. In the method, canny operator locates the objective border in pixel level, and then cubic polynomial interpolation locates the edge in sub-pixel level.

Canny operator is the optimal detector that has a simple approximate implementation in which edges are marked at maxima in gradient magnitude of a Gaussian-smoothed image. Then the detector uses operators of several widths to cope with varying image signal-to-noise ratios. Finally the operator outputs a single pixel edge [3].

The sub-pixel edge is extracted by the method of cubic polynomial interpolation, which interpolates the sampling points of edge pixel with function $s(x)=\sin(\pi x)/(\pi x)$. The function $s(x)=\sin(\pi x)/(\pi x)$ approximately equals to the cubic polynomial below:

$$s(x)=\begin{cases} 1-2|x|^2+|x|^3 & |x|<1 \\ 4-8|x|+5|x|^2-|x|^3 & 2>|x|\ge 1 \\ 0 & |x|\ge 2 \end{cases} \tag{3}$$

Where x is the distance between mapping point and adjacent points of image inputted.

Coordinates of adjacent points showed in figure 3, center point coordinates is (i,j), the target point coordinates $f(i+\mu\ ,j+v)$ is computed:

$$f(i+\mu,j+v)=[A][B][C] \tag{4}$$

where, $[A]=\begin{pmatrix} S(1+\mu) & S(\mu) & S(1-\mu) & S(2-\mu)\end{pmatrix}$,

$$[B]=\begin{bmatrix} f(i-1,j-1) & f(i-1,j) & f(i-1,j+1) & f(i-1,j+2) \\ f(i,j-1) & f(i,j) & f(i,j+1) & f(i,j+2) \\ f(i+1,j-1) & f(i+1,j) & f(i+1,j+1) & f(i+1,j+2) \\ f(i+2,j-1) & f(i+2,j) & f(i+2,j+1) & f(i+2,j+2) \end{bmatrix}$$

$$[C]=\begin{bmatrix} S(1+v) \\ S(v) \\ S(1-v) \\ S(2-v) \end{bmatrix}$$

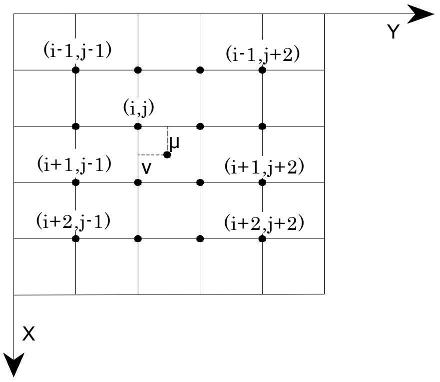

Figure 3. Cubic polynomial interpolation

III. EXPERIMENTAL RESULTS

A software system is build based on VC++. With the direction of drop-down menu and dialog box, click mouse and put surgical instrument is enough for operator. Location and Acquirement of image are automated. All the inspection data could be saved in a database. Measurements are performed by the machine vision system. The initial image and sub-pixel edge points detected by the method proposed upon are showed in Fig. 4 and 5. Different dimension could be inspected. One important dimension is the width of surgical instrument, at a key point 0.5mm from the tip towards the joint and in the midline of the blade a line perpendicular to the edges of the blade is drawn, the blade with along this perpendicular line is the width of the surgical instruments. The execution time of different surgical instrument is less than 800ms, the quite satisfying results of inspection is shown in Table I.

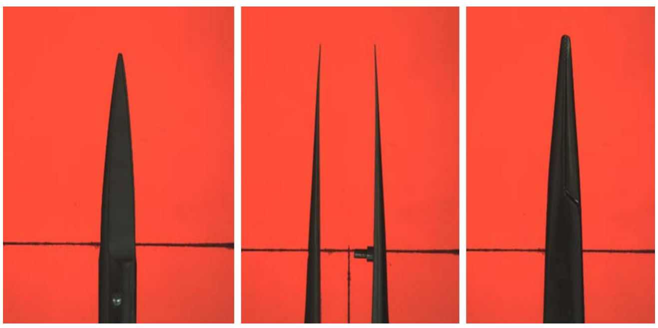

Figure 4. Initial images of surgical instruments

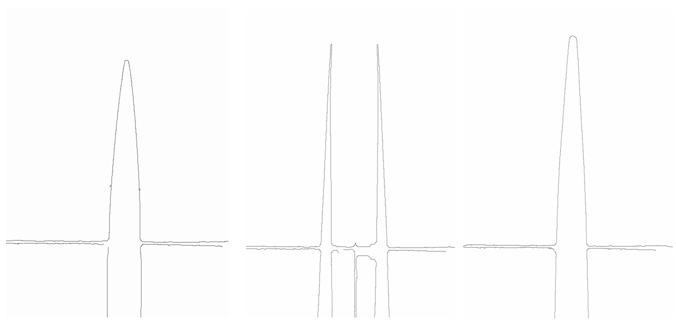

Figure 5. Sub-pixel edges of surgical instrument

TABLE I. THE RESULET OF INSPECTION OF THE WIDTH OF SURGICAL INSTRUMENTS

Measurement Times	**Different surgical instruments (unit: mm)**		
	scissors (0.5mm from the tip)	*forceps (0.5mm from the tip)*	*clamp (0.5mm from the tip)*
1	0.757	0.148	1.430
2	0.757	0.148	1.430
3	0.756	0.148	1.430
4	0.756	0.147	1.430
5	0.756	0.148	1.427
6	0.756	0.148	1.430
7	0.757	0.148	1.430
8	0.757	0.148	1.432
9	0.756	0.148	1.430
10	0.755	0.148	1.427
mean	0.756	0.148	1.430
Standard Deviation	0.0007	0.0003	0.0015
Average inspection time	706.22ms	509.09ms	512.6ms

IV. CONCLUSIONS AND FUTURE WORK

In this paper, a successful system is developed for computer-assisted machine vision automated inspection of surgical instruments. Three types of surgical instrument with different sizes could be inspected by the system. The overall system accuracy could be 0.001mm so as to ensure the quality of surgical instruments by the ideal specification given by surgeons. The result showed that the inspection system had significant effects. The system is proved to be very convenient for users. The inspection system could measure the vast amount of measurements of surgical instruments required for mass-produced devices.

Advancements in zoom optics and high-resolution cameras have made machine vision technology well suited for the tiny devices and features that many manufacturers in the medical industry make, a tenth of a micron is almost common in encoding devices. Different optical components could be used for different need.

Surface quality inspection and neural work aided inspection will be investigated for convenience application. Automatically converting surgical instruments image into features is future work. With the development of algorithm, machine vision inspection system could be used to inspect surgical instruments through the whole life-time.

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