Super-High Resolution Vision System "FAY-1000"

Kazuhiko Fukuda

1. Introduction

Accompanying the development of various highly technological materials, electronics and printing techniques advancing towards super-high precision and density, demands are progressively increasing for precisely automated visual inspections in their manufacturing processes. Despite these demands, inspections of printed patterns, sheet surfaces and semiconductors, in which defects on rather large surfaces should be inspected in full detail, have not been put into practice. This is, because conventional vision systems for general use could not meet them. In addition, as for uneven and rounded surface parts inspections, practical use has been restricted since conventional area-sensor CCD (charge coupled device) camera systems were not capable of handling them.

The last inspections in the manufacturing processes of these high density and high precision parts or rounded surface parts have now been automated but still partially rely on personal visual inspections. However, as their mounting density and processing precision increase in the future, the personal visual inspection of finished products will be practically impossible. Realizing a highly precise and automated visual inspection with digital image processing technology is now indispensable.

The major topics of the super-high resolution vision system encompass the following fields:

(1) Printed food vessel surface inspection

Printed external surface inspections of cans, resin cups, Styrofoam cups, etc.

(2) Sheet surface inspection

Inspections of plain or printed continuous sheets including paper, aluminum, film and steel.

(3) Semiconductor inspection

Super-fine defect inspections in the manufacturing processes of IC wafers, TAB (tape automated bonding), lead frames, etc.

(4) Flat panel display inspection

Surface defect inspections of flat panel display including liquid crystal panels, and plasma display panels.

(5) Cylindrical parts inspection

Fine surface defect inspections of cylindrical parts including drums.

In response to the above topics, Fuji Electric developed the FAY-1000 super-high resolution and high-speed vision system combining a super-high resolution line-sensor CCD camera with original gray-scale image processing technology and pattern matching technology. An overview of these technologies is described below.

2. Merits of the FAY-1000 Super-High Resolution Vision System

2.1 Super-high resolution

Although there are high resolution appearance inspection systems for FA (factory automation), an area-sensor CCD camera with 512 × 480 pixels is presently used as the image processing system. But to fulfill the needs of recent super-fine inspections, approximately 200 times the conventional pixel resolution is required.

For realizing such super-high resolution, the FAY-1000 is based on image processing with the high resolution line-sensor camera.

Line-sensor cameras of 4,096 pixels/line, 2,048 pixels/line and 6,000 to 8,000 pixels/line are respectively selected for standard, super high-speed and high sensitivity, and super-high resolution, respectively.

In addition, it is also possible to connect with area-sensor cameras of 1,024 × 1,024 pixels or 2,048 × 2,048 pixels.

2.2 Unique gray-scale image processing technology

With the 2-dimensional space image processing technology which Fuji Electric has been developing for some time, such defects as faint uneven spots, stringy scratches, dents, and stains can be inspected despite the fact that the FAY-1000 is a line-sensor image processing system.

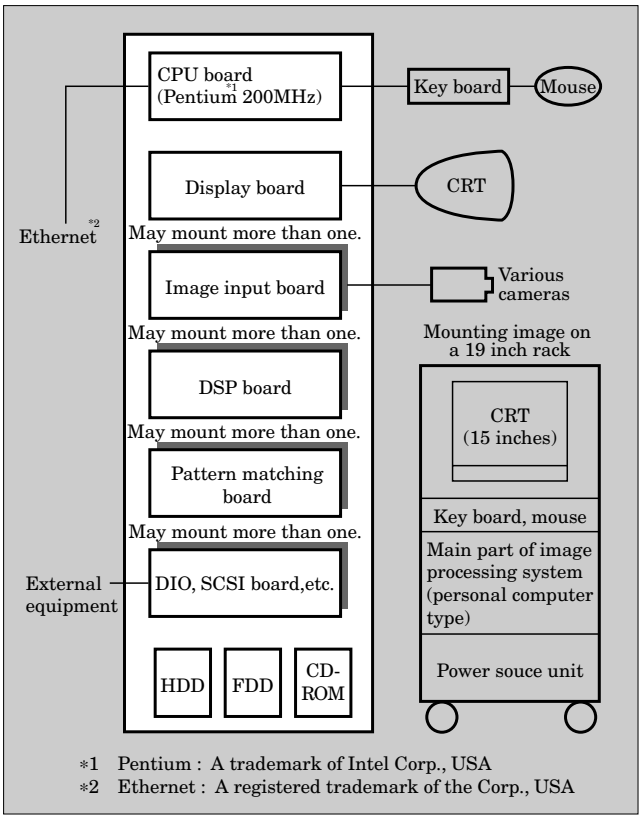
2.3 Dynamic programming based pattern matching technology

On inspection of large and flat surface patterns, there often appears significant stretching/contracting,

bending or shiting of patterns that existed originally on the parts or were generated when conveying the parts. Many of the conventional image processing systems were not capable of handling this. For the FAY-1000, the dynamic programming based pattern matching technology, which automatically calibrates the above stretching/contracting, bending or shifting of patterns, has been developed. This constitutes a first in this industry, in addition to the gray-scale judgment function with a normalized image co-relation method.

Fig.1 Appearance of the FAY-1000

Fig.2 Basic system structure of the FAY-1000



*1 Pentium : A trademark of Intel Corp., USA
*2 Ethernet : A registered trademark of the Corp., USA

2.4 Compatibility with personal computers

Recent needs for visual inspections are closely related to information processing technology. This need includes not only the inspections but also network construction of the upper and lower processes, co-operation with quality control systems, and data base systematizing of inspection results. By adopting a personal computer (Windows 95[*1], Windows NT[*2]), the

*1 Windows 95 : A trademark of Microsoft Corp., USA
*2 Windows NT : A trademark of Microsoft Corp., USA

Table 1 Basic functions of the FAY-1000

Item	Function	
Camera portion	Monochrome line-sensor camera	Super high-speed and high-sensitivity type: 2,048 pixels Standard type: 4,096 pixels Super high-resolution type: 6,000 to 8,000 pixels
	Color line-sensor camera	RGB full color type: 2,048 × 3 pixels
	Area camera	Wide monochorome area type: 2,048 × 2,048 pixels
	Number of cameras	Maximum: 2 (expandable)
Image processing controller portion	Processing image size	Horizontal direction: 2,000 to 8,000 pixels × Vertical direction: 2,000 to 6,000 pixels in standard
	Gray level	256 levels (8 bits/pixel)
	Standard image regisration	Correct sample input method (with an average of N pieces)
	Position/orientation calibration	Calibration functions of position in X, Y direction and of rotation
	Pre-processing functions	Image enhancement/smoothing/ differentiation etc.
	Timing of taking images in	With external encoder
	Speed variation calibration	Follows conveyed parts and speed variation
	Position search function	Possible to search position in specified patterns
	Gray level trans-formation function	Calibration with look-up table
	Judgment functions	Area judgment, pattern matching judgment, shape judgment, etc.
	Judgment objects	Attached foreign substans, stain, broken/attached patterns, pinhole, broken/distored character, color unevenness, color tone defect, position shifting
	Judgment area setting	Setting with rectangular, circular or polygonal shapes
	Judgment criteria setting	Possible to set judgment criteria with AND/OR
	Monitoring	Indication of taken-in images, indication of positions judged as defective
	Defects judgment processing	Possible to sum up every kind of defect and possible to save defective images
	Adjustment	Automatic adjusting functions of camera sensitivity/noise level

FAY-1000 can offer an integrated system directly linked to the production process lines.

3. Specifications of the FAY-1000

3.1 Appearance of the FAY-1000

Figure 1 shows the FAY-1000. When compared to the conventional video-sensors of the Fuji Electric's FAY series (FAY-400/600), the FAY-1000 has a rack mount construction that allows use in rack-based system applications.

3.2 Basic functions of the FAY-1000

Figure 2 shows the basic system structure of the FAY-1000, and its basic functions are listed in Table 1.

4. Specifications and Application Examples of the FAY-1000 for Every Application Field

The basic specifications of the FAY-1000 for every typical application field will be introduced below.

4.1 Inspection of the external surface of the printed food vessel

The main inspection objects of the external surface of the printed food vessel.

- ○ Type 1: Cans (beer, juice, coffee, etc.)
- ○ Type 2: Resin cups (yogurt, ice cream, etc.)
- ○ Type 3: Styrofoam cups (Chinese noodles, wheat flour noodles, etc.)

This inspection field lags behind in practical use because of a requirement for high-speed processing and a variety of complicated printed patterns. For performing various kinds of external surface inspection of food vessels, the FAY-1000 is installed with a high-speed scanning function of printed rounded surfaces by the line-sensor CCD camera and a DP (dynamic programming) based pattern matching function for inspection, regardless of stretching/contracting, shifting or bending of the printed patterns.

(1) System structure

Figure 3 illustrates the structure of the inspection system of the printed food vessel's external surface.

(2) Inspection items

The inspection items differ depending on the inspected parts but are roughly summarized in Table 2.

(3) Conditions of conveyed parts

The parts conveyer is driven in tact, and the maximum speed allowed is 450 pieces/min. Rotation speed of the parts up to a maximum of 2,000r/min is allowed.

Rotation speed within ±1% and inclination within 1mm are desirable as conditions of the conveyed parts but they may differ according to the required detection precision.

(4) Indication of detection results

Many options are provided for the user. The basic functions are as follows:

(a) Indication of judgment results
The results of quality judgment are relayed externally through the programmable controllers.

(b) Indication of the total number and defects number
For every inspection item, the numbers are relayed externally with time information (day, hour, minute and second).

(c) Saving defective images
Image data judged as defective are automatically stored in an inside image memory. In the standard type, the memory can save up to 30 images and is optionally expandable. Furthermore, after the inspection, it is possible to transfer the image data to MO (magneto-optical) disks for off-line preservation and analysis.

Figure 4 shows a displayed screen in an application example of the inspection of the food vessel's external surface.

Fig.3 System structure of the inspection system for the printed food vessel's external surface

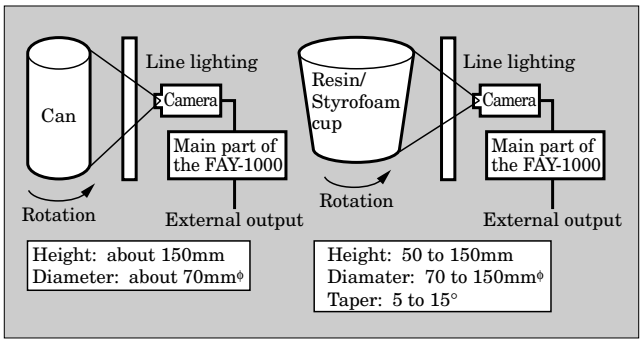


Table 2 Typical inspection items of the printed food vessel's external surface inspection

Inspection item	Inspection precision/specification
No print	None of the printed articles exist (refer to the limit sample)
Ink stain	0.5 to 2.0mm□
Ink splash	0.5 to 2.0mm□
Broken/blurred defect	0.5 to 2.0mm□
Distorted/blotted defect	0.5 to 2.0mm□
Stringy scratch	0.5 to 2.0mm□
Misdirected shifting	Gap or overlap owing to misalignment of printing plates
Color tone defect	Deepness or faintness of color tone (refer to the limit sample)
Ink shading defect	Deepness or faintness of ink (refer to the limit sample)
Printed position shifting	Within ±0.5mm of printed position in vertical direction

4.2 Inspection of the sheet surface

This is the inspection for surface defects of continuously conveyed parts in sheet form, such as rolled paper, film and copper plate.

The inspection objects are as follows:

- ○ Type 1: Rolled paper (plain or with printed patterns)
- ○ Type 2: Film (transparent or with printed patterns)
- ○ Type 3: Rolled metal sheets (copper, brass, steel aluminum, etc.)

There are already many examples of sheet surface inspections in use but until now, they have been mostly for judging spot defects on one line.

For detecting faint gray level uneven spots, stringy scratches or line-shaped defects, the FAY-1000 first extends the image taken in through the line-sensor CCD camera to 2-dimensional image data [for example, 4,096 × 4,096 pixels]. Then, they are processed with Fuji Electric's original 2-dimensional gray-scale processing algorithm. Thus, the above-mentioned defects can be inspected.

Fig.4 Displayed screen in application example of food vessel's external surface inspection

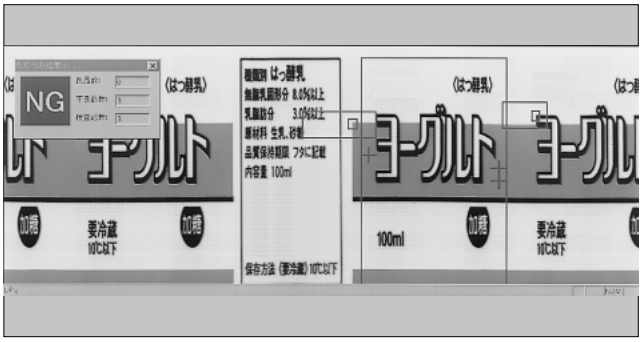


Fig.5 System structure of the sheet surface inspection system

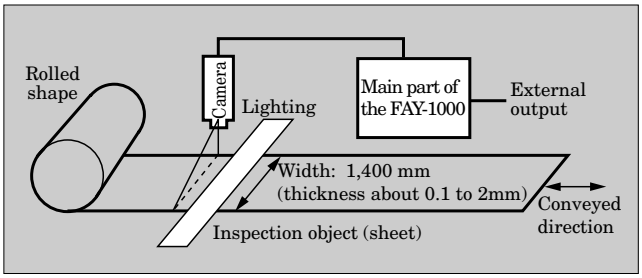


Table 3 Typical inspection items of the sheet surface inspection system

Inspection item	Inspection precision/specification
Spot defect	Black spot: 0.3 to 0.5mm□ White spot: 0.3 to 0.5mm□
Hole defect	0.3 to 0.5mm□
Line-shaped defect	Blackish: over 0.3 × 3 (mm) Whitish: over 0.3 × 3 (mm)
Stringy scratch defect	Over 0.3 × 3 (mm) of stringy scratch defects owing to twisted paper in both conveyed and cross-wise directions
Gray level spot defect	Faint stain: 3.0 to 30mmϕ (Yellow color on white ground: over 30mmϕ) Blurred defects: 3.0 to 30mmϕ
Shading defect	Deep or faint overall
Torn defect on sheet edge	About 3 to 30mm of torn part with 3mm width (on both edges)

(1) System structure

Figure 5 illustrates the sheet surface inspection system.

(2) Inspection items

The inspection items of the sheet surface inspection system differ depending on the inspected parts. They are roughly summarized in Table 3.

(3) Conditions of conveyed parts

The parts conveyer is driven continuously and a maximum speed of up to 400 to 700m/min is allowed.

Winding motion within ±10mm and up-and-down motion within ±1 mm are desirable as conditions of the conveyed parts but they differ according to the re-

Fig.6 Displayed screen in an application example of the sheet surface inspection

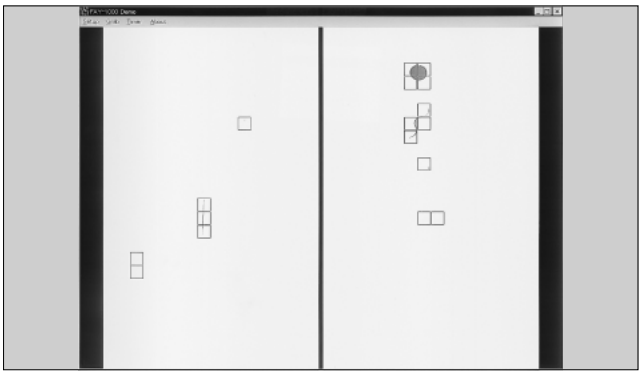
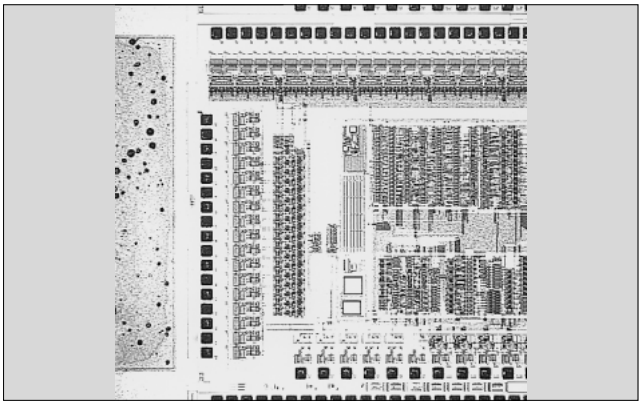


Table 4 Typical inspection items of the semiconductor inspection

Inspection item	Inspection precision
Attached foreign substance	5 to 10μm, respectively
Pattern defect	
Pattern width defect	
Electrode shape defect	
Defective distance between pins	
Defective gap between patterns	

Fig.7 Example of the IC wafer appearance inspection



quired detection precision.

(4) Defect detection and classifying system

The defective parts are classified into large, medium or small sizes and into a deep or a faint gray level, if necessary.

(5) Indication of detection results

Many options are provided for the user. The basic functions are as follows:

(a) Indication of judgment results

① Lengthwise direction (conveyed direction)
The defective positions are output with the value in mm. This is calculated from the encoder's counted value after onset (maximum 256mm).

② Crosswise direction (width direction)
The 2 to 4 defective positions per camera are output with the value in mm.

(b) Indication of the total number and defects number
For every inspection item, the numbers are relayed externally with time information (day, hour, minute and second).

(c) Saving defective images
Image data judged as defective are automatically stored in the inside image memory. In the standard type, the memory can save up to 100 images and is optionally expandable. Furthermore, after the inspection, it is possible to transfer the image data to MO disks for off line preservation and analysis.

Figure 6 shows a display screen in an application example of the sheet surface inspection.

Table 5 Typical inspection items of the panel display inspection system

Inspection item	Inspection precision/specification
Spot defect	Black spot: 0.3 to 0.5mm□ White spot: 0.3 to 0.5mm□
Hole defect	0.3 to 0.5mm□
Line-shaped defect	Blackish: over 0.3 × 3 (mm) Whitish: over 0.3 × 3 (mm)
Gray level spot defect	Faint stain: 3.0 to 30mmϕ Blurred defects: 3.0 to 30mmϕ
Shading defect	Deep or faint overall

Fig.8 Appearance of the organic photoconductor drum Inspection system

4.3 Inspection of semiconductors

The inspection objects in the semiconductor field are as follows:

- ○ Type 1: IC wafer (plain or with printed patterns)
- ○ Type 2: BGA/PGA (ball grid array/pin grid array) patterns
- ○ Type 3: Lead frame

The typical inspection items are listed in Table 4, and Fig. 7 shows an example of the IC wafer visual inspection.

4.4 Inspection of flat panel displays

The inspection objects of the flat panel displays are as follows:

- ○ Type 1: Glass plate for liquid crystal panel
- ○ Type 2: Complete liquid crystal panel (back lighting inspection)

Table 6 Inspection items of the organic photoconductor drum inspection system

Defect items in appearance			Shapes in appearance	Standard	Image defect	
					PPC	Printer
Internal defect	Black defect	Black spot	Deeply painted part in spot shape (surrounding part becomes faint)	None or $a \leqq \phi$	White spot	Black spot or faint relief in white
		Black stringy scratch	Deeply painted part in line shape	None or $b \leqq 1$	White stringy scratch	Black stringy scratch
	White defect	White spot	Faintly painted part in circular shape	None or $c \leqq \phi$	Black spot	White spot
		White stringy scratch	Faintly printed part in line shape	None or $d \leqq 1$	Black stringy scratch	White stringy scratch
	Uneven painting	Uneven color defect	Deeply painted part in irregular shape	Refer to limit sample	Irregular-shaped part relieved in white	Irregular-shaped part with faint density
		Stain	Faintly painted part in irregular shape	Refer to limit sample	Irregular-shaped part relieved in white	Irregular-shaped part faintly relieved in white
Surface defect	Attached foreign substance		Appears as uneven surface or color shade	None	Black spot or relief in white (irregular shape)	Black spot or relief in white (irregular shape)
	Scratch		Appears as uneven surface	None or $e \leqq \phi$		

○ Type 3: Colored filter
○ Type 4: Plasma display panel

The inspection items of the flat panel display inspection system differ depending on the inspected parts but are roughly summarized in Table 5.

4.5 Inspection of cylindrical parts

The inspection objects of the cylindrical parts are as follows:

○ Type 1: Drum (organic photoconductor drum, etc.)
○ Type 2: Metal rod (copper, brass, steel, etc.)
○ Type 3: Cylindrical vessel (packing vessel, etc.)

The organic photoconductor drum inspection system mentioned here is an application example of the cylindrical parts inspection. Figure 8 shows the organic photoconductor drum inspection system. The inspection items of the system are listed in Table 6. Furthermore, some examples of processed results of the organic photoconductor drum inspection are shown in Figs. 9, 10 and 11.

Fig.9 Processed results example of the organic photoconductor drum inspection (in detection of spot defects)

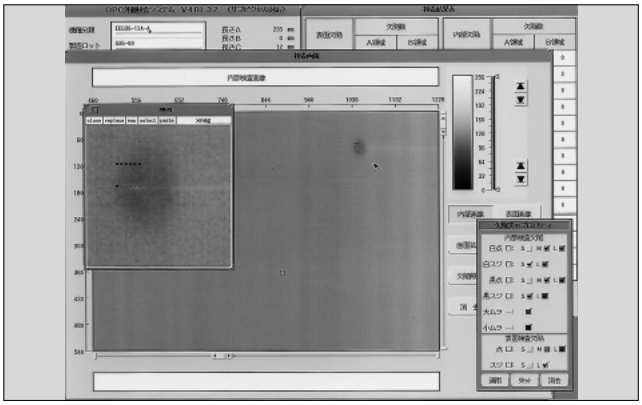


Fig.10 Processed results example of the organic photoconductor drum inspection (in detection of gray level non-uniformity defects)

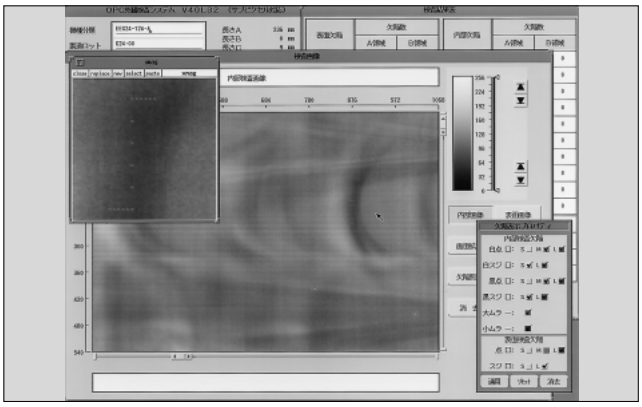
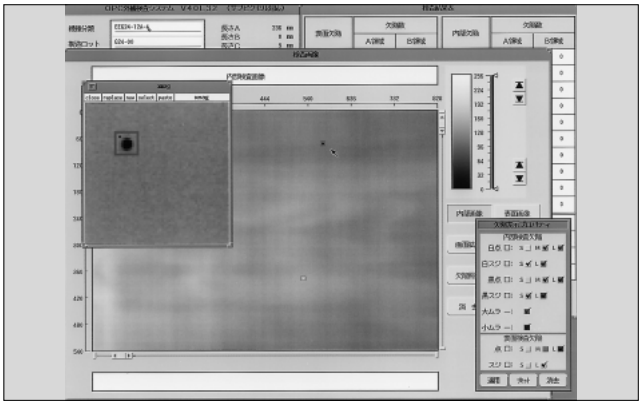


Fig.11 Processed results example of the organic photoconductor drum inspection (in detection of spot defects in uneven painting)



5. Application Form of the FAY-1000

(1) Application software

The FAY-1000 is an engine for offering a dedicated system specified for every kind of use. The system is supplied to the user in the form of the FAY-1000, and supplemented with application software. For the typical applications described in Chapter 4, a sufficient number of packaged programs is planned so that the software will be developed more quickly.

(2) Parts conveyer mechanism

Similar to the application software, the FAY-1000 requires the most suitable conveyer mechanism for every application. For typical applications, like software, standardization of the mechanism is planned to shorten the development terms of the respective conveyer mechanism. However, engineering must be based on arrangements with the user since the mechanism must be well-matched to the user's process line.

6. Conclusion

The FAY-1000 super-high resolution vision system is used for precise visual inspections of parts of higher density. These include the external surfaces of printed food vessels, sheets, semiconductors, flat panel displays, and cylindrical parts. Several application examples and a technical overview are described.

For performing those highly precise visual inspections, development of image recognition technology which allows flexible judgment adapted to the surface characteristics, and visual inspection technology which holds a resolution of sub-micron level are required as future developments. Fuji Electric will promote further development of the precise visual inspection technology and make efforts for further expansion of this technology. This includes the progress to a 3-dimensional surface inspection and development of a sensing technique having an active relationship between sensor and lighting and a sensing technique in a laser beam area.