

## MULTI LIGHT SOURCES RANGE FINDER SYSTEM

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### ABSTRACT

This paper describes a new range finder system which projects multi light planes. The purpose of the system is to get 3-D data of objects at high speed and with high accuracy. To realize the purpose two new techniques are introduced.

One of the techniques is its optical system: each light source is composed of a laser diode and a cylindrical lens, and projects a light plane on the object. Fifteen light sources are located on a circle around a rotating mirror so that light planes are converged on the axis of rotation. A CCD camera takes the image of the light planes projected via the mirror. For each rotation angle, the light sources are turned on and off according to a specified code so that the light sources can be identified from the image data. Then, the mirror rotates to project light planes to other parts of the object.

Another technique is the pre-processing circuit: it converts, in real time, video data from camera into reliable 2-D information of light planes appearing in the image. Due to the result that essential information is extracted with the circuit, size of output is drastically reduced. In this process, the 1/10 pixel accuracy of detected position data is achieved with a special interpolation scheme by a hard-wired computing circuit.

### INTRODUCTION

It is an important approach for computer vision to use range data. There are two types of measurement techniques for obtaining range data. One is based on trigonometry and another is on time of flight [Lewis 1977] [Jarvis 1983]. The former has two major measurement techniques, one is the passive stereo vision and another is the active range finder. The techniques measuring time of flight need high technology to measure very precise time to achieve high accuracy. The range finder, which projects special light patterns (spots, light planes, grids, etc.) on the object, has following merits compared with stereo vision. 1) No needs of matching and 2) availability for curved surface. On the other hand, this technique has a demerit that it tends to take much time in measurement. To solve this problem, a technique was proposed [Ueda 1981] in which multi light planes are projected. This technique requires coded light patterns to identify the light source causing each bright point in the image. The measurement time becomes  $(\log_2 N)/N$  times of the single light plane case, where  $N$  is the number of the light planes. Some researchers use a PLZT electrical

shutter [Ueda 1981], slide films [Minou 1981] and a liquid crystal shutter [Inokuchi 1986] to make light patterns. Because they make light patterns by means of covering a light source with filters, they have the following demerits. 1) A high power light source is required because this process necessarily wastes large amount of flux. 2) The contrast of light pattern is not clear at distance out of the focus. 3) No availability of coherent light source because of interference problem. 4) The number of grids which influences the resolution is constant and small.

In this paper, a technique which is not suffered from such demerits is proposed. We propose an optical structure with multi light sources. Each light plane emerged from each light source reaches the object directly, so the power of light source required to project light patterns bright enough is low. In this scheme, coherent light source is available and high contrast image is achieved. The resolution in the scanning direction is changeable because it is controlled with a rotating mirror with high angle resolution.

Another feature of the system is the pre-processing circuit which reduces large amount of video data to necessary 2D location data of light planes. It is able to get the horizontal locations of sub-pixel order. This circuit is necessary to realize real-time data acquisition. A similar circuit was proposed for one light plane [Oshima 1973], but it is not available for multi planes range finders.

### SYSTEM CONFIGURATION

Fig.1 shows the block diagram of the range finder system. The system is composed of 1) an optical unit and 2) a signal processing unit.

The optical unit projects coded light pattern on the object and obtains the image. It is composed of 1) light sources, 2) a rotating mirror, and 3) a camera. They are synchronized by a sync signal. They are controlled through a personal computer or through the control panel.

The signal processing unit receives the video signal and extracts the necessary data which are stored in the digital memory. This process is done in real-time. The memory is accessible from the personal computer, and the data can be stored in disks or sent to another computer.

The 3-D coordinates are obtained with this data by the computer afterwards.

### MEASURING PROCESS

The hierarchical measuring process of the system is as follows:

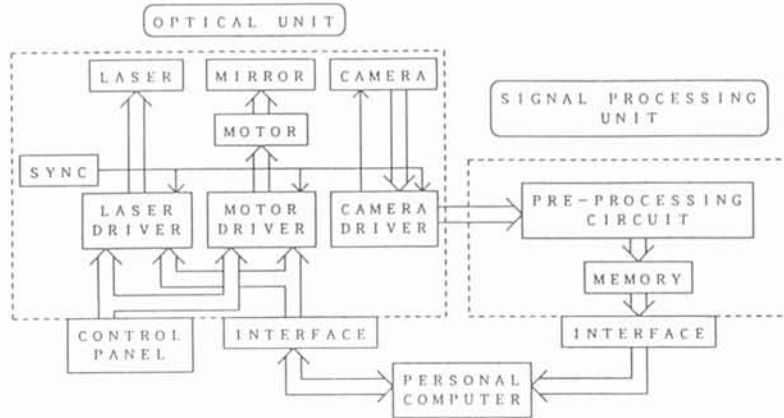


Fig. 1 System Configuration

```

for(n = 0; n < N; n++){
  rotate mirror angle  $\Delta\theta$ 
  for(m = 0; m < M; m++){
    set laser pattern m
    take one frame of camera data
  }
}

```

where  $\Delta\theta$  is the angle of one step rotation, N is the number of mirror rotation and M is the number of projecting patterns. N is decided as the number of all light planes divided by the number of light sources. Typically,  $\Delta\theta$  is decided as the angle between two adjacent light sources divided by N so that the measurement pitch is uniform.

Actually, N is set 32 and M is 4, for 15 light sources coded with Gray code.  $\Delta\theta$  is 0.1 degree.

### OPTICAL SYSTEM

Fig.2-1 shows the top view of the optical system. The range finder has 15 light sources, a mirror with a rotating motor and a camera.

All the light sources are located on a circle centered at the rotating axis of the mirror. All the light planes are reflected on the center. The angle between two adjacent light sources are set equal (actually,  $3.21^\circ$ ) so that each light source sweeps the object uniformly. With such alignment they seem to emerge from center of the mirror and scan simultaneously. This alignment has two merits. 1) The equations relating light plane parameters with the mirror rotation angle are simple, and 2) A narrow mirror is available, which causes small moment of inertia and enables quick motion of the mirror.

The number of light sources, 15, is decided as  $2^4 - 1$ . This means that when the light sources are coded with binary or Gray code, it needs 4 patterns to identify the light source from the scene data. In general,  $2^n - 1$  is the most economical number for cases where n patterns is necessary.

Fig.2-2 shows the close-up view of the light sources. Each light source is composed of a 5[mW] infrared (wave length = 780[nm]) laser diode and a cylindrical lens. The lens narrows the laser beam only in the horizontal direction and does nothing in the vertical direction. Then, the beam going out from the lens comes to be a vertical light plane. Laser beam width is designed to be smallest in the measurement range (from 1[m] to 2[m] distance) with an ap-

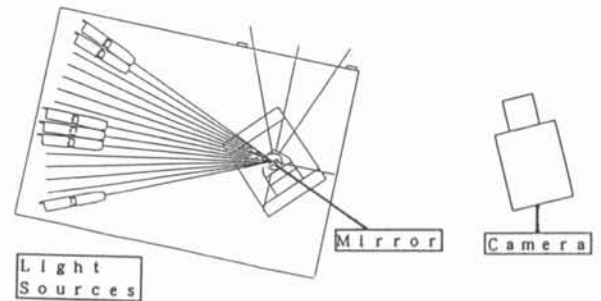


Fig. 2-1 Top View of the Optical System

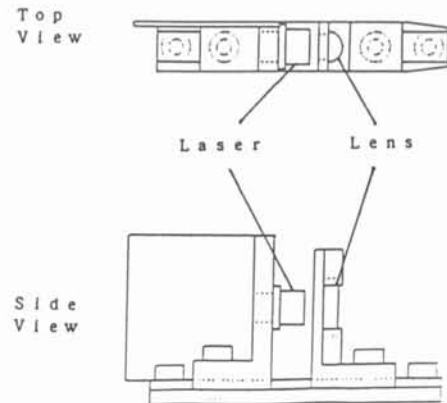


Fig. 2-2 Top and Side View of a Light Source

proximate equation [Dickson 1970]. Its value is between 1[mm] and 2[mm].

The mirror is 6[cm] height and 1[cm] width. It has a rotating axis on the mirror face. The rotor is a galvano motor which rotates quickly and precisely.

The camera is a CCD camera, which has a sensitivity in infrared wave length domain. With a infrared-pass filter set on the lens of the camera, we can get a high contrast sharp image of the light planes on the object surfaces. It allows us to run the range finder at bright environment under fluorescent lamps, because the light from them does not have infrared component. This camera is set at the mount which keeps the camera image plane vertically.

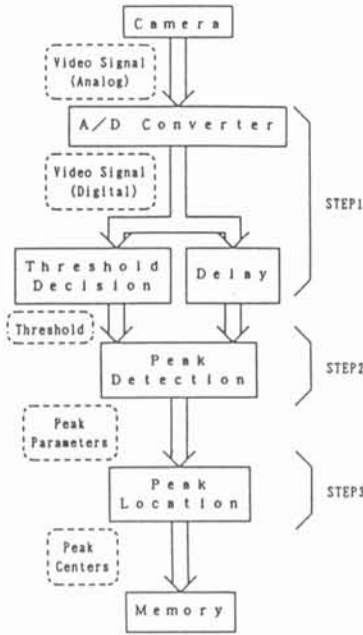


Fig. 3-1 Data flow of Pre-processing Circuit

PRE-PROCESSING CIRCUIT

The data size in one frame of video signal is very large. For example: when we digitize the data for 512 x 480 pixels of 8 bit depth, the data size is 240 [Kbyte]. Furthermore, when we project 480 light planes and code them with binary or Gray code, the total data size is 240 [Kbyte] x 4 (patterns) x 32 (mirror positions) = 30 [Mbyte]. It is not a reasonable data size to realize real-time measurement.

What we need is the locations of bright points in the image caused by light planes, so it is possible to reduce the size with an effective pre-processing circuit. The maximum number of light planes appearing in each scan line is 15. With binary or Gray code, it is 8. When we represent the location of a light image in the scan line with a 16-bit integer and assume that there are 16 bright portions on one scan line (these are supposed to be images of light planes), the data size for one frame is 15 [Kbyte] and the total data size is 1.875 [Mbyte], which are reasonable. If there are only 8 images of light planes for each scan line any time, the sizes are 7.5 [Kbyte] and 0.9375 [Mbyte]. Taking care of bright points caused by noise and the case where the code is not binary nor Gray, the maximum number of bright portions is given as 16.

The pre-processing circuit works on each scan line of the video signal. Fig.3-1 shows its flow. There are 3 paths of processes. 1)A/D conversion and threshold level decision path, 2)peak detection path and 3)peak center location path. "a peak" is a special term we use from now on to represent a group of continuous pixels in which intensities exceeds the threshold. These paths take equal time (one cycle of horizontal scanning) and they are performed concurrently. When data of line number *j* is in path 1, data of line number *j* - 1 is in path 2 and *j* - 2 in path 3.

The video signal used here is data converted by an A/D

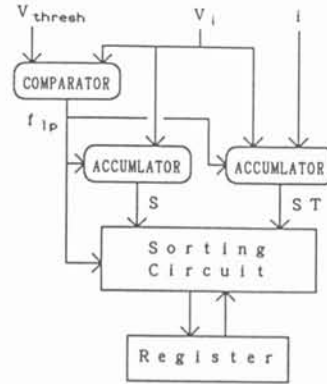


Fig. 3-2 Peak Detection Path

converter. The threshold intensity value  $v_{thresh}$  is decided as :

$$v_{thresh} = \frac{\alpha}{N_h} \sum_{i=1}^{N_h} v_i, \tag{1}$$

where  $v_i$  denotes *i*th value of digitized video signal in one scan line,  $N_h$  is the number of horizontal pixels (actually, 512) and  $\alpha$  is a constant for a good threshold value.  $\alpha$  is decided by an experiment, and  $\alpha = 2$  in our system.

Fig.3-2 shows the block diagram of the peak detection path. The intensity of video data  $v_i$  is compared with the threshold level  $v_{thresh}$ . When  $v_i$  exceeds  $v_{thresh}$ , a flag  $f_{ip}$  is turned on and two accumulators are initialized (set 0) and activated. When  $v_i$  comes smaller than  $v_{thresh}$  again ( $i = i_E$ ),  $f_{ip}$  is set off, its fall deactivates the accumulators and triggers a real-time sorting circuit. The accumulators work for two parameters as follows:

$$ST = \sum_{i=i_S}^{i_E} v_i(i - i_S) \tag{2}$$

$$S = \sum_{i=i_S}^{i_E} v_i, \tag{3}$$

where  $i_S$  and  $i_E$  are the start and end point of the peak,  $ST$  means the moment of the peak around  $i_S$  and  $S$  means the area of the peak.

Fig.3-3 shows the detailed real-time circuit. It compares the values of  $S$ 's obtained in one line and stores only the most significant  $K$  (actually 16) peaks into the registers assuming that other peaks caused by noises. Each time a fall of a peak is detected (i.e.  $f_{ip}$  is set off), this circuit compares the  $S_{new}$  value with old  $S_k$  values which have already been detected in this line. At the beginning of one line data, all the  $S_k$  are set to 0. Each comparator outputs one bit result of comparison. Second, the conclusions enter the bit sum circuit. This is a logical circuit which outputs the number of 1's in all input bits, which means the number of  $S_k$ 's greater than  $S_{new}$ . This value  $r_{new}$  is equal to the rank of  $S_{new}$  in the  $K + 1$  values of old and new  $S$ 's. Third,  $r_{new}$  is compared with all the ranks of  $S_k$ 's ( $r_k$ ). At the beginning, all  $r_k$  are set to  $k$ , and no two  $r_k$ 's have equal values at any time. Fourth, according to the conclusion of this comparison, the contents of registers are changed. There are  $4 \times K$  registers,  $S_k, ST_k, i_{Sk}, r_k$ . The logic of this part is as follows:

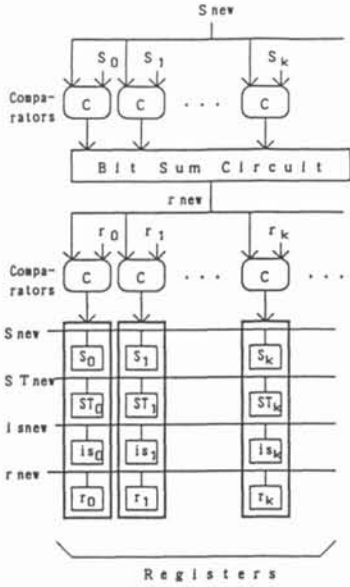


Fig. 3-3 Real-time Sorting Circuit

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if (r_new < r_k) {
    if (r_k == K - 1) {
        S_k = S_new;
        ST_k = ST_new;
        i_s_k = i_s_new;
        r_k = r_new;
    } else
        r_k++;
} else
    do nothing.
    
```

As Fig.3-3, the circuit has  $K$  sets of comparators and registers, and they work in parallel. The time necessary to reorder the data in the registers corresponds to a few pixels of video signal, which is short enough.

Due to the fact that the laser beam has a Gaussian intensity distribution, we can interpolate the beam center from intensity information for a set of pixels. The center of gravity of each peak is applied as the true location of the image of each light plane.

In the peak center location path, the center of gravity  $G_k$  is computed in one scan line time from the parameters obtained in the peak detection path.  $G_k$  is computed by the following equation:

$$\begin{aligned}
 G_k &= \frac{\sum i v_i}{\sum v_i} \\
 &= i_{S_k} + \frac{\sum (i - i_{S_k}) v_i}{\sum v_i} \\
 &= i_{S_k} + \frac{ST_k}{S_k}, \tag{4}
 \end{aligned}$$

where all summations are in the range from  $i_{S_k}$  to  $i_{E_k}$ .

This computation includes a division, which takes a lot of time although it is executed on some hardware. We applied a table of  $1/S$  values for all  $S$ 's which is possible under a condition that the value of  $S$  is reasonably small (actually,  $S$  is from 1 to 4095). Therefore, the division is realized as 1)referencing the table with  $S$  value and 2)multiplying  $ST$  by  $1/S$ . In this way, it is possible to obtain the  $K$  centers



Fig. 4 Experimental Result

of gravity in one scan line period. The process is based on the second line of the formula (4) to avoid very large  $\sum i v_i$  value when  $i$  is large (i.e. when the peak appears near the right side of the view).

EXPERIMENTAL RESULT

Fig.4 shows an experimental result of a statue. Only 64 light planes are displayed, although data for 480 light planes are actually obtained. To complete the measurement, 4 frames of video data (for Gray coding) were taken for 15 angle position. The data on smooth curved surfaces are obtained clearly, of 1/10 pixel order.

CONCLUSION

We have proposed new techniques to realize a range finder system with multi light sources. As the optical system uses coherent light sources, the power loss is smaller and the accuracy for 3-D coordinates of beams is higher than other systems which are forced to use incoherent light. The combination of lasers and a rotating mirror realized a flexible (the beams are easily controlled by a program) and high-speed system. The pre-processing circuit, which is necessary for real-time measurement, reduces the data size effectively in real-time with high precision accuracy.

Currently, the conversion from peak location data to 3-D coordinate data is performed by computers and takes a lot of time. As the conversion is homogeneous and executable simultaneously, we will be able to design a circuit for this purpose, which is our future study.

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