# Advanced Functions of the Scanning Laser Range Sensor for Environment Recognition in Mobile Robots

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***Abstract*— We have developed scanning laser range sensor called "SOKUIKI" sensor which is ultra-small scanning laser range sensor adopted for various types of mobile robots as we have already published. As a sensor for environment recognition, we thought the sensor must have not only outputting distance data but also another helpful function for mobile robots. So it was considered that what kind of advanced functions should be provided to SOKUIKI sensor. As a result two most important purposes were acquired. 1. Variation on its distance data and method to get the data. 2. The function for prevention of optical interference between sensors. These rolls were installed to the sensor, and confirmed their effect. This paper describes its result and proposes Sensor Communication Interface Protocol (SCIP) which is developed as new command system just for SOKUIKI sensor.**

## I. INTRODUCTION

VISION sensors act as an eye of the mobile robots for path planning and obstacle detection while moving in the unknown environment. They also play vital role in map building and localization. Various types of optical sensors are developed for this purpose [1][2]. Among them laser range sensors are widely used in the robotic research [3]-[5]. However most of such sensors are bulky, heavy and power hungry and it causes difficulty to adapt them in the system.

Hokuyo Automatic Co., Ltd. has designed and developed various types of obstacle detection sensors with model names PB9 and PBS. These are compact, smaller and low power consuming sensors with LED as a source of light[6]. They are being widely used in UGVs(unmanned ground vehicles). There are also some examples of these sensors being used in the robotics due to their smaller size [7]. However their applications are strictly limited to detect the obstacle rather than to measure the distance to it.

Finding the need of the distance measurement, we have developed "SOKUIKI" sensor for obstacle detection as well as to measure the distance to the obstacle with high accuracy in a wide capture range [8]. Its other features include low power consumption, small size, lightweight, compact design and low cost. Our aim is to develop a sensor having specifications suitable for mobile robotic platforms of different sizes. For that purpose, we investigated the advanced functions which such sensor should have.

In this paper we describe these functions in detail and propose new command system named SCIP ver:2.0.

## II. INTEGRATION OF SENSOR

### A. SOKUIKI sensor

Fig. 1 shows first SOKUIKI sensor "URG-04LX" and TABLE 1 shows its specification.

Light source used in the sensor is infrared laser with the wave length 785nm. Laser safety is Class 1 regulated by IEC (International Electrotechnical Commission).

The motor used to rotate the mirror is brush less spindle type with extremely low noise. By making the rotational axis hollow and adopting outer-rotor structure it was possible to miniaturize the size and obtain the compact design. The rotational speed of the motor is 600rpm due to which the measured data of one scan is obtained in 100msec.

The maximum measurable distance of the sensor is 4,095mm with the accuracy of 10mm between 20 to 1,000mm and 1% of distance for more than 1,000mm (for white sheet under test conditions). The angular range is 240 degrees with the resolution of 0.36 degrees. It means that the sensor measures distance at 682 directions (steps). Its body dimension is 50×50×70mm with approximate weight 170g.

As external I/O device, RS-232C and USB are provided. Communication between host and sensor is built as receiving command and answering to it by sensor.

The algorithm to measure distance is AM-CW. It means that the phase difference between transmitted light amplitude modulated and reflected light is transformed to distance. The frequencies of the emitted light are 46.55MHz and 53.2MHz. The reason why two kinds of frequency are used is that single wave of modulated frequency was the difficulty in measuring the distance with more than $2\pi$. These two waves are transmitted alternately. To detect phase difference the

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Fig. 1. URG-04LX

received light is sampled at 50MHz by AD converter built in ASIC. The sampled data are reconstructed to wave of 3.3MHz. To select this algorithm made designing ASIC easy, one of the most important factor to realize the sensor's size decreased.

Finally URG has both compactness and high efficiency as a sensor for environment recognition by mobile robots.

## *B. Additional Function and Information*

Two methods to output measured distance data are considered. One is to output immediately each data calculated and the other is to output all data together after finishing measuring sequence of each scanning of motor. Though the former method has advantage host can get the data as soon as possible, such passive communication with sensor is difficult for robot. Consequently the latter method was chosen. Robot requests the data to sensor by transmitting command and receives appropriate reply from sensor. Although URG receives command all time with direct memory access (DMA), the processing of all requests is done one time every scanning by their receiving order. If sensor receives duplication command, only first command is accepted and the rest same command is rejected as error.

In this case one big problem exists. It means that the exact time of flight emitted each direction is not clear. Lag exists in the time each direction's distance measured because URG detects distance by rotating laser with motor in 100msec. Max time-lag of each scan is 66.6msec and the time is big problem in case that the sensor or objects or both are moving.

As solution for that subject, timestamp, which is time sampled at starting point of measuring distance each scan is added to the distance data and a command for adjusting the timer is prepared. The time of each direction's distance detected can be reckoned back from timestamp because it is already known that the interval of one direction to next direction is 100usec. On the other hand, robot memorizes its own position and angle for past 100 msec before receiving distance data. Then both data are matched by their time on recognizing correctly their surrounding or constructing the accurate map.

TABLE 1
Specification of the sensor URG-04LX

| | |
|---|---|
| Light source | Infrared laser (785[nm]) |
| Modulated frequency | 46.55[MHz], 53.2[MHz] |
| Motor | Spindle motor |
| Detection range | 20 ~ 4095[mm] |
| Accuracy | ±10mm (20 ~ 1,000[mm])<br>±1% of distance (1,000 ~ 4,095[mm]) |
| Angle | 240[degrees] |
| Angular resolution | 0.36[degrees] |
| Response time | 100 ~ 110[msec] |
| Dimensions | $\phi$(42~ 50) × 70[mm] |
| Weight | 170[g] |
| Environment | Indoor |

URG equips one simple output line and outputs periodical rectangular signal from the line every one round of motor. This signal can be considered synchronized signal, so it is more accurate than timestamp because of no bottle-neck of communication. As another application the timing to move URG can be determined with this signal on sensor driven system for 3D mapping.

URG often fails to measure distance at some directions and its reasons are put on various subjects. For example the calculated data is not enough to be trusted because of a lack of strength of received light, which means its low signal to noise ratio (SNR). Furthermore large difference between distance data calculated from two frequencies is one of the major reasons. Such large difference is caused by light emitted to edge of object. In such case the information why the sensor cannot detect distance is also important for environment recognition. Therefore detail error number is output as a substitute for distance data.

## *C. How to Detect Distance*

The information "When was this distance datum sampled?" is key factor for moving mobile robot processing the distance data. The timestamp mentioned above is one of the information. Furthermore two kinds of distance request command are prepared. One command is for the newest data at the time robot receives it, and the other is for future data after received. The latter command is extended to continuously outputting data.

There will be a case that the efficiency of the sensor, detecting angle and angular resolution is too high. For recognizing only half side of the sensor, the data of another side are unnecessary. For detecting big obstacle near robot, low angular resolution 0.70 degrees or more is enough for that purpose. Beside, the sensor can not send all direction's distance data, which means the size of electric text is about 1.5 kbytes within 100msec by RS-232C whose baud rate is 115.2 kbps. In that case it takes about 130 msec to complete transmitting all data. That is to say, it is impossible to get the distance data every scan. Therefore function for flexible compressing of electric letter is indispensable. As a result parameters for directing expected detecting area are added to the command text for requesting distance data. The concrete

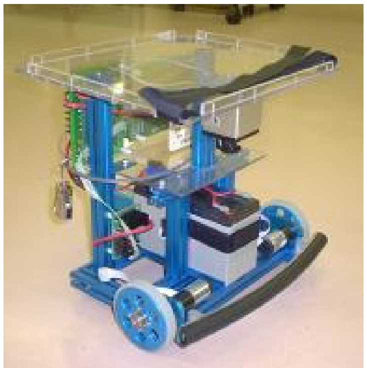
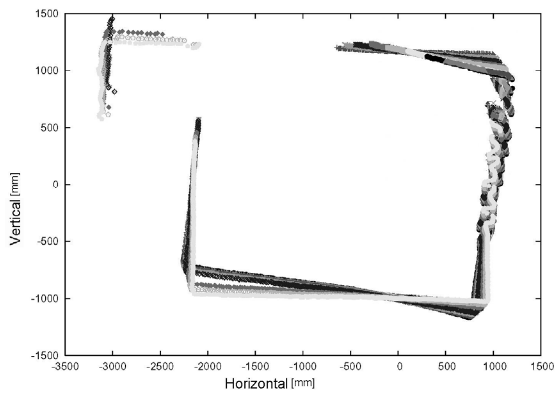
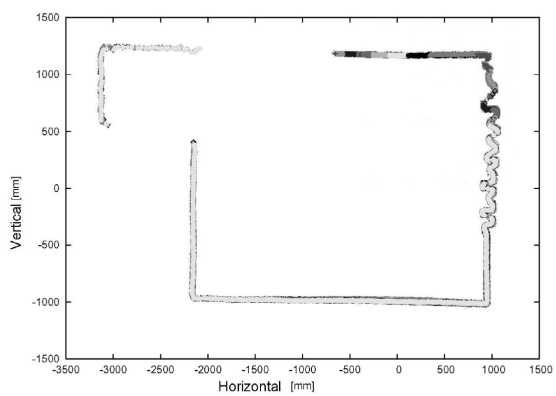


Fig.2 Mobile Robot "Beego" with the first URG



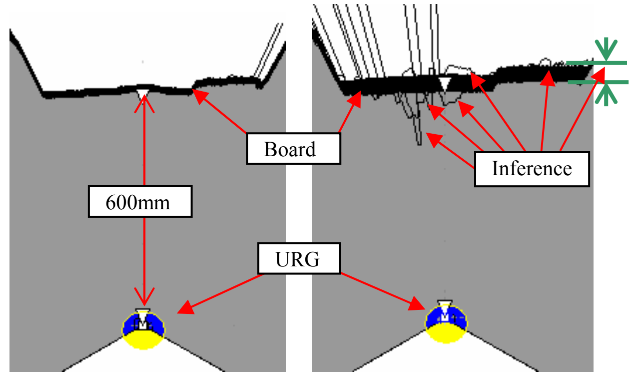

(a) Map constructed without timestamp




(b) Map constructed with timestamp

Fig.3 Constructed 2D Map
(Each mark indicates difference of scan timing)

parameters are start and end direction number for aimed area, the number of curtailed direction and scan. These parameters make the sensor send proper data without loss and moreover the host is able to process the data easily. As another effect laser can be emitted at ordered direction or scan if these parameters are known before measuring distance. Such laser control increases working span of laser device and decreases power consumption. Furthermore the effect for prevention of optical interference among sensors is expected.




(a) No interference (b) Interference

Fig.4 Comparison of distance data 'no interference' with 'interference'

### *D. Prevention of Optical Interference*

Fig.4 shows normal distance data and abnormal one by interference. Black plot indicate the position of object which the sensor detects. There are two kinds of phenomena: one is that distance data in some direction are abnormal and the other that all distance data is dropped at same value.

Optical interference between a sensor and another sensor is an essential matter. It is very difficult to separate the amplitude modulated wave from the sensor itself and the one from another sensor after they mixed once.

The simplest method for prevention of such interference is that each sensor is installed with tilting them forward 2-3 degrees, however that is not enough.

Another measure is to emit laser as few as possible. Laser should be off while sensor data is unnecessary. A command for laser on/off control and automatic laser on/off control are added to realize that. That automatic control is done as blow. Laser is off till received laser on command after the sensor starts up. When the sensor receives the future distance request command, measurement area and timing are analyzed. Laser is automatically off at unnecessary area and curtailed scan in accordance with the analyzed result. These functions contribute to not only prevention of interference but also extension of laser device and reduction of power consumption as mentioned above.

Moreover one more step is prepared, which is a function that motor speed is slightly changed by command. It is expected that continuous interference at same direction is avoided shortly by change of rotation timing among the sensors for difference of their motor speed.

## III. Experiment and Results

### *A. Effect of Time Stamp*

The experimental setup for confirming the effect of timestamp is as follows. A mobile robot "Beego" which was designed to be attached URG (See Fig. 2) is at center of a room. The size of the room is about 3m around. Beego turns at same position with storing distance data from URG and his

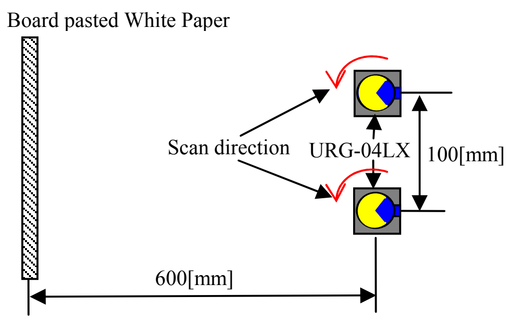



Fig.5 Experiment Environment

own odometry and time every 1msec. Rotating speed of Beego is 30 degree/sec. Then we construct two maps: one map is constructed as a precondition that all the distance data in one scan are sampled at same time and another one is constructed after exact sample time of each distance data is calculated with timestamp. Fig.3 shows the maps. The map constructed without timestamp has a lot of point gap among each scan. This gap indicates the difference of sampling time. On the other hand, the gap was revised on the map constructed with timestamp and the map successes to present exactly the environment of the room. This result suggests that timestamp is very useful for environment recognition because exact data can be obtained while robot is moving.

### *B. Prevention of Optical Interference between sensors*

We confirmed the effect of function to change motor speed for prevention of interference. The experimental setup for this purpose is shown in Fig.5 (named "location 1"). A board pasted white paper stands in front of two URG at interval of 600mm. This arrangement is very suitable to raise interference.

In this circumstances we counted up the number of scans in which at least one distance data was abnormal (see Fig.4) with changing slightly one sensor's motor speed. One sensor's motor speed was kept at default 600rpm and the other's one was to be 0%, 1%, 3%, 5% and 10% down to default speed. At each experiment, number of all scans was 1,000. Then same experiment was done on setup one sensor was on same position and the other was on behind the former

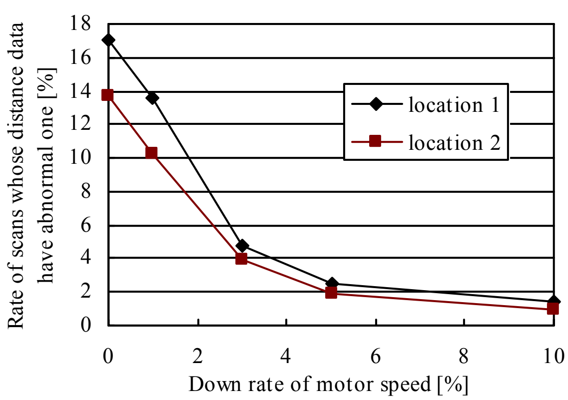



Fig.6 Rate of abnormal scans to total [1,000scans].

(HOST > SENSOR)

| | | |
|---|---|---|
| Command(2byte) | parameter | LF(0ah) or CR(0dh) |

(SENSOR > HOST)

| | | | | |
|---|---|---|---|---|
| Command | parameter | LF | status(2byte) | sum (1byte) |
| LF | data | sum | LF | LF |

Fig.7 Basic Communication Format of SCIP ver:2.0

sensor at intervals of 1m. In this case light causing interference is not incident on another sensor directly (named "location 2").

Fig.6 shows the result. This result testifies that expected effect exists to a certain extent. In the case of same motor speed and 1% down, their probability was more than 10%. Light aimed directly from another sensor increase the value on location 1. While speed difference of 1% does not have any effect, that of more than 3% display their effect. The direct light's interference is completely prevented.

This experiment was done under static environment and suitable condition for interference, so it is can be thought that this result indicates limitable rate. It means probability of interference will be lower under real environment. Finally we consider these measures we prepared for prevention of interference are enough for the purpose.

## IV. IMPLEMENT (SCIP VER:2.0)

### *A. Basic Sentence Pattern*

We propose "SCIP ver:2.0" which is communication protocol for SOKUIKI sensor and realized the functions argued above. Its features are 1. very simple structure, 2. multiplex function for detecting communication error , 3. efficient compress algorithm for electric data and 4. many useful commands for robotics. Basic format of SCIP is shown in Fig.7.

A unit of communication with SCIP is a pair of one command from host to sensor and more than one answer from sensor. Sensor certainly answers to received command and does not send any text without command from host. Each letter is expressed by ASCII. The command sentence is formed a command symbol, parameter if necessary and LF(0xa) or CR(0xd) as terminator. The answer sentence is constituted echo back of command sentence, LF as pause symbol, "status" and its sum data processed specially, LF as pause symbol and "data" and its sum data processed same as status if necessary and two LF as terminator. The "status" indicates success or failure reason of processing the command. If the size of the "data" is more than 65 bytes, sum data and LF are inserted every 64 bytes.

When received command text does not collate with all exact format, the sensor returns echo back and status code which expresses what wrong happens with the command text.

*B. 6 bits Symbolization Algorithm*

When 682 direction's distance data is transformed to hexadecimal ASCII text, its size is 2,048 bytes in case that detection rang is up to 4,095mm and 2,728 bytes in another case. Too long text is inefficient for communication. Then we contrived 6 bits symbolization algorithm for compressing electric text. Basic idea is that a value which is sum of a 6 bits value and 0x30 can be expressed ASCII: '0' (0x30) – 'o' (0x6f).

The max value of distance data which URG-04LX outputs is 4,095(0x3ff), so all data can be expressed by 12 bits. To symbolize the distance data, the data is divided to 6 bits and 6 bits and each 6 bits data is added 0x30. Then two symbolized letters are obtained from 12 bits data. In this case compression ratio is 2/3. As a result 682 direction's distance data is symbolized to 1,364 bytes data. We call this type 2 bytes encode.

Now we developing next generation of URG, and its detection area will be extended, max range is 10m or more. In such case, the distance data is split to 4 bits, 6 bits and 6 bits and each data is added 0x30. It means that compression ratio is 3/4. We call this type 3 bytes encode.

Timestamp is also symbolized by this algorithm. The timestamp begins to be counted up at starting up of the sensor. Counting it up is done every 1msec and the value is initialized when it reaches to max value (0xffffff : 24 bits). So timestamp is split to four 6 bits data and symbolized to 4 bytes ASCII. In electric text timestamp is expressed them.

The sum data is calculated as follows: 1. adding up value of target letters, 2. masking the sum data by 0x3f (6 bits) and 3. summing up 0x30 to the value.

*C. Prepared Command*

Following nine kinds of command are prepared in SCIP ver:2.0.

1. Version request command
2. Baud rate setting command
3. Turning laser on/off command
4. Pre-sampled distance data request command
5. Continuous distance data request command
6. Suspending continuous output command
7. Timer for timestamp matching command
8. Motor speed setting command
9. Internal status request command

In these commands, we explain the two kinds of distance request command and timer matching command in following sections.

*D. Distance Data Request Command*

With the command No.4, host can get the newest distance data at the time when the sensor starts processing the command. Three parameters are added to the command text, which are "start step number", "end step number" and "number of curtailed steps" where step means direction of emitted laser. The step number was defined 0-768 based on 270 degrees for future extension. In case of 240 degrees of URG-04LX, active step number is 44-725. This step parameter is expressed 4 bytes decimal ASCII. The reason why we adopt 4 bytes is to prepare for increase of number of step by future extension of angular resolution. To curtail steps is done as follows: ordered number of steps is regarded as one step and minimum distance data is returned as the data of the step. For example, if the directed number is 0 or 1, the sensor returns distance data of all steps. As another example, ordered number is 4, the sensor searches minimum distance data every 4 steps and returns the data as distance data of one step. In this case the size of electric text becomes 1/4 shorter than the case of no step curtailed. This parameter is expressed 2 bytes decimal ASCII. While this command is accepted normally and laser is turned on by command, laser is always emitted within 240 degrees. Its reason is that the parameter necessary for automatic laser control is obtained after measuring distance.

With the command No.5, host can get the future distance data after the time when the sensor starts processing the command. Furthermore host can get data continuously by ordering desired number of scans. Five parameters are added to this command text, which are three parameters same as the command No.5, "number of curtailed scans" and "number of scans outputted their distance data". To curtail scans is done as follows: after receiving this command, first scan's distance data is outputted and after skipping ordered number of scans next scan's data is outputted. If the ordered number is 0, the sensor does not skip any scans. While skipping scans, echo back and status which means "This scan is curtailed." are returned to host every one scan. These process repeats for the times of ordered number in another parameter. This parameter is expressed 1 byte decimal ASCII. The parameter for indicating number of scan is expressed 2 bytes decimal ASCII. When this parameter is 0, the sensor continues to output distance data till suspend command is received. Moreover while this command is active, other commands except suspend command are not accept regularly and echo back and error status which means "There is not such command." are returned to host and automatic laser control function is also active.

Each these two distance data request command has two types: one requests distance data less than 4,095mm what is 2 bytes encoded data and the other requests longer data what is 3 bytes encoded data.

The structure of answer text for each command is same. It is formed by echo back, 2 bytes status, 4 bytes timestamp and distance data if necessary. The value of timestamp added to this answer text is sampled at 44step of same scan, which means the timestamp is the time when measuring distance began. The distance data is enumerated along the order from start step to end step. In these data value which is more than 0 and less than 19 is error code. This error code presents the result or cause of failure of measuring distance at the step.

The sensor returns echo bask and error status if laser is turned off by laser control command or the sensor has any trouble.

### *E. Timer Matching Command*

To use timestamp for matching the time when each distance data is measured with the time when odometry data is sampled, it is necessary to synchronize the sensor's timer and host's timer. This command is prepared for that purpose. The command text has one parameter. This parameter is control code expressed 1 byte decimal ASCII. When it is 0, the sensor turns off laser and suspends all sequence and then enters timer matching mode. While the sensor in on this mode, other command is not accepted regularly and echo back and error status which means "There is not such command." Then this command with its parameter 1 is sent to the sensor, it returns timer value of timestamp at that moment immediately. Actually, it is impossible to synchronize internal timer of host and timer of the sensor by the returned time value because of communication delay. But such delay time can be guessed with comparing the time of sending command with the time of receiving answer or plural request of timer to the sensor. Then it is possible to synchronize them not completely but fairly well. Then this command with its parameter 2 is sent to the sensor, its mode returns to normal mode.

## V. CONCLUSIONS

In this paper we discussed advanced function which SOKUIKI sensor as environment recognition sensor for mobile robots should have. As a result, the following functions should be prepared: 1. additional information such as timestamp, synchronized signal and detail error status, 2. the various methods to provide distance data, 3. turning on/off laser by manual and automatic and 4. multiplex measures for prevention of optical interference.

Then we confirmed the effect of timestamp and measure for prevention of interference. In experiment of timestamp, two maps were constructed: one was without timestamp and the other was with timestamp. Though distance measured time lag appeared as position lag in the former, no position lag came out in the latter. Then it was made sure that timestamp made the map constructed successfully.

We thought up that to change motor speed of one sensor slightly is good solution for prevention of optical interference. To show clearly this reasoning is correct, we counted the number of interference occurred with changing motor speed. This experiment suggested that difference of motor speed which is more than 3% prevent almost the interference. We came to conclusion that mixture of some measures can prevent the interference in practical use.

Finally, we proposed Sensor Communication Interface Protocol (SCIP) ver:2.0, which was communication protocol for robotics. SCIP has various advanced functions mentioned above. Its features are 1. simple and flexible, 2. extended easily and 3. powerful additional functions.

Our future work is to consider how to present the strength of received laser light. This strength of light is different largely depending upon the substance or color of surface which laser reflects. Speaking conversely, if it reaches the point where this optical strength can be processed well, there is a possibility where it can utilize in recognition of form and the like of the object.

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