

# Mobile SOKUIKI Sensor System: Accurate Range Data Mapping System with Sensor Motion

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## Abstract

2D laser range finders are commonly used for constructing range data maps in robotics. In order to construct such maps, sensor's position and posture when it is performing each scan should be estimated accurately. However, in conventional laser scanning system the sensor is not synchronised with the modules, which estimate its position and posture. Therefore, correct position and posture of the sensor cannot be acquired if the sensor moves while it is scanning. This causes many errors in map construction. This paper first describes the timing registration method that makes the sensor synchronised with position estimation modules. Then, effectiveness and usefulness of this method are evaluated by the 2D and 3D scanning experiments.

**Keywords:** SOKUIKI sensor, range data map, timing registration

## 1 Introduction

2D laser range finders are commonly used for constructing range data maps or obstacle avoidance in robotics. In order to construct range data maps, the robot on which the sensor is mounted moves around so that the sensor scans<sup>1</sup> the whole environment. To construct maps by using these scanned range data, the positions and postures of the sensor when it measures each range data are needed. Generally, in order to acquire the positions and postures, exact time when the sensor measures each range data should be acquired. There are two steps shown below in order to acquire accurate timing.

1. Detect a period of time while the sensor perform a scan.
2. Find the exact moment when the sensor measures each range data in the period of time detected in first step.

The second step is not difficult because the time intervals between each measurement of range data are constant. However, first step is not easy because the sensor is not synchronised with the robot and the response time<sup>2</sup> of the sensor is ambiguous. In most of conventional scanning method, in order to acquire the

<sup>1</sup>In this paper, we call it "scan" that a laser of the laser range finder rotates 360 degrees and call it "measure" that the sensor measures a range of a direction in one scan.

<sup>2</sup>The time which the sensor takes to send the range data after data request.

positions and postures of the sensor, the robot stops every time when the sensor performs scan. For this reason, constructing range data map takes long time.

We develop a system which solves this time registration problem by using a SOKUIKI sensor which is a super small sized 2D laser range finder. With this system, the sensor accurately scans the environment even if it moves fast. We call this system Mobile SOKUIKI Sensor System. This paper describes the algorithm and structure of the system in section 2. Experiment of 2D scanning which proves effectiveness of the system is treated in section 3 and a new 3D scanning method is explained in section 4.

## 2 Mobile SOKUIKI Sensor System

### 2.1 Structure of the System

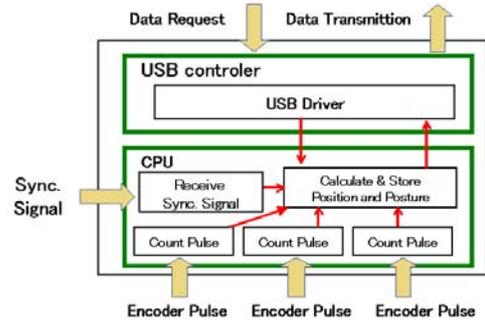
Figure 1 shows appearance of a SOKUIKI sensor URG-04LX manufactured by HOKUYO AUTOMATIC ([1, 2]). Table 1 shows main specification of the sensor.

This sensor outputs a synchronous signal at a specific scanning angle when it finishes every scan. The system uses this signal to acquire the exact time when the sensor scans.

Structure of Mobile SOKUIKI Sensor System is shown in figure 2. The system consists of a SOKUIKI sensor, a PC and a timing registration module which we developed. The SOKUIKI sensor is carried by a motion mechanism. After it finishes scanning, the sensor outputs a synchronous signal to the timing registration



**Figure 1:** SOKUIKI sensor URG-04LX

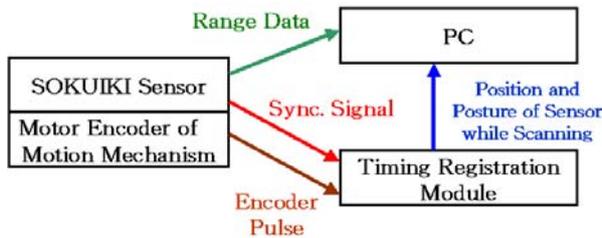


**Figure 3:** Architecture of the timing registration module

**Table 1:** Specification of URG-04LX

Detectable distance	0.02 to 4[m]
Accuracy	0.02 to 1[m]: $\pm 10$ [mm] 1 to 4[m]: $\pm 1\%$ of distance
Resolution	1[mm]
Scanning angle	240[degrees]
Angle resolution	Approx. 0.36[degrees]
Scanning time	100[ms]
Weight	Apporox. 160[g]
External dimension	50×50×70[mm]

module. The module estimates the position and posture of the sensor by counting encoder pulses from the motor of the motion mechanism and stores them as logs. The PC constructs range data map using the range data and sensor's position and posture.



**Figure 2:** Signal flow of the system

## 2.2 Architecture of the Timing Registration Module

The architecture of the timing registration module is shown in figure 3. The system clock of the CPU called M16C is 24MHz and it counts three encoder pulse simultaneously. A USB controller enables the module to realise USB communication.

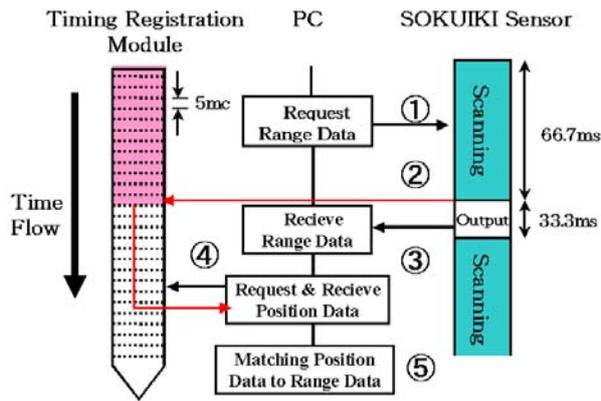
The module estimates the position and posture of the sensor every 5ms and stores them. When the module receives synchronous signal, it picks up the sets of the position and posture data when the sensor had been scanning out of logs and sends them to the PC.

## 2.3 Procedure of Timing Registration

Figure 4 shows the procedure how each position and posture data is matched to each measurement point. The timing registration module estimates and stores position and posture of the sensor every 5ms. The SOKUIKI sensor repeats measurement periods and transaction periods continuously. In measurement period, the sensor measures ranges. Then it calculates the measured range data in transaction period. The measurement period and transaction period take 66.7ms and 33.3ms respectively. At the moment when measurement period finishes, the sensor outputs a synchronous signal to the module. If the sensor receives request for range data from the PC, the sensor start sending range data after the transaction period. Range data is sent through DMA channel so that this process does not use CPU power. The procedure of timing registration is explained as follows.

1. The PC sends request to the SOKUIKI sensor for range data.
2. The sensor outputs synchronous signal to a timing registration module at the moment when measurement period finishes.
3. The SOKUIKI sensor sends the range data to the PC.
4. The PC sends request to the module for the positions and the postures of the sensor, and then, the timing registration module sends the sets of the positions and the postures at which the SOKUIKI sensor is scanning.
5. Each position and posture is matched to each range data on the PC.

While sensor's positions and postures are estimated every 5ms, time intervals between each measurement point are 0.1ms. Therefore, the positions and postures are interpolated for matching to every measurement point.



**Figure 4:** Procedure of matching the position and posture data to range data

### 3 2D Scanning Experiment

The effectiveness of the Mobile SOKUIKI Sensor System in constructing 2D range data map is evaluated in this section. In order to construct 2D range data maps, the sensor needs to move around the environment. Therefore, a mobile robot is used as the motion mechanism of Mobile SOKUIKI Sensor System. Figure 5 shows the mobile robot on which a Note PC, timing registration module and a SOKUIKI sensor are mounted. The sensor is attached to a robot in such a way that its scan plane is parallel to horizontal floor. The position and posture of the sensor is equivalent to those of the robot. the position and posture of the robot are estimated at the timing registration module by counting encoder pulses of wheels of the robot.

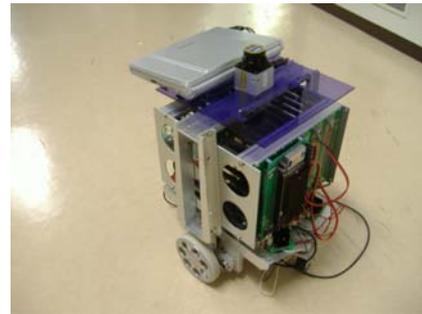
We performed an experiment in which the robot constructs 2D range data map in the following three ways. The robot moves at a speed of 300mm/s and turns 30rpm at most.

1. A robot with a conventional SOKUIKI sensor system scans environment. It stops for every scanning.
2. A robot with a conventional SOKUIKI sensor system scans environment. It does not stop for scanning.
3. A robot with the Mobile SOKUIKI sensor system scans environment. It does not stop for scanning.

figure 6a shows the environment for the experiment. Figure 6b, 6c and 6d are 2D range data maps constructed by the first, second and third procedures respectively. Green points in the middle of the maps are the positions at which the robot scans. Red points are the measurement points. In the first scanning procedure, the robot stops and estimates its position and posture before scanning so that the map is not affected by the timing registration problem and does

not have any errors. In the second scanning procedure, because of lack of synchronization between the robot and the sensor it cannot estimate the exact position and posture at the moment when the sensor scans. Instead, the robot uses the position and posture when it receives the range data from the sensor. The positions and the postures used for map construction are not correct so the map has a lot of errors obviously. Figure 6d shows the map constructed by the third procedure. Though the robot does not stop for scanning, accuracy of the map is as same as figure 6b because of synchronization.

Another experiment is set to evaluate the system in a more detailed way. In the experiment, the sensor rotates horizontally at a speed of about 60rpm and scans the corridor once. Figure 7a shows the result of scanning without synchronization and figure 7b shows the result of scanning with the Mobile SOKUIKI Sensor System. Though the scanning results should be shown like two paralleled lines, the lines of figure 7a are distorted. The reason is that the robot treats the measurement points as if they measured at the same time though they are not. In figure 7b, the measurement points figured the corridor accurately. These two experiments prove the advantage of the 2D mapping system with the Mobile SOKUIKI Sensor System.



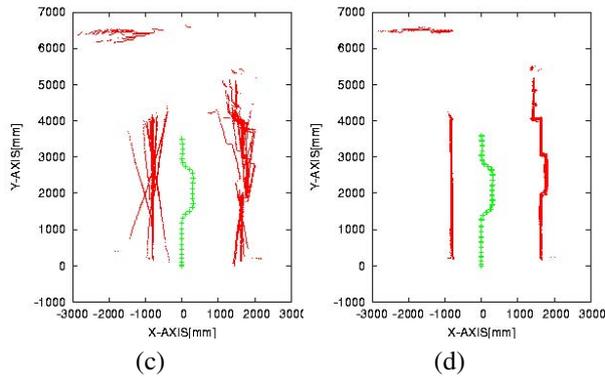
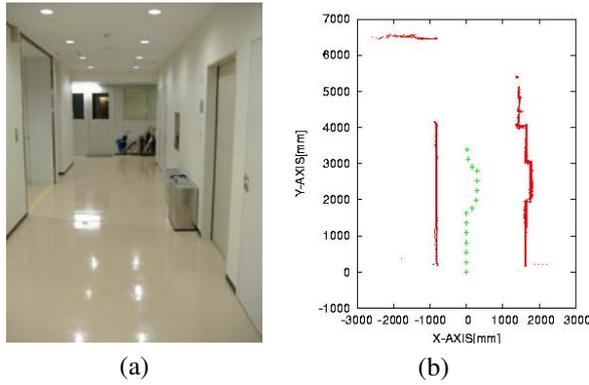
**Figure 5:** Robot equipped with the Mobile SOKUIKI Sensor System

## 4 Constructing 3D range data map

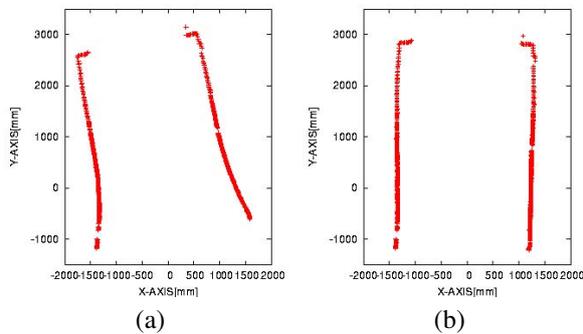
### 4.1 Rotating Mechanism for 3D Scanning

In constructing 3D range data map with a 2D laser range finder, changing the angle of scan plane is a common way for acquiring 3D range data. There are some ways to change its angle[3]. In our research, we rotate the sensor as it is shown in figure 8. This rotating method has vertical scan plane and rotate the plane around upright z-axis. With this method, measurement density focuses on z-axis (see figure 8b).

The rotating device is shown in figure 9a. A DC motor manufactured by Maxon Motor rotates the sensor. A slip ring manufactured by Tsubame Radio Co.,Ltd. is

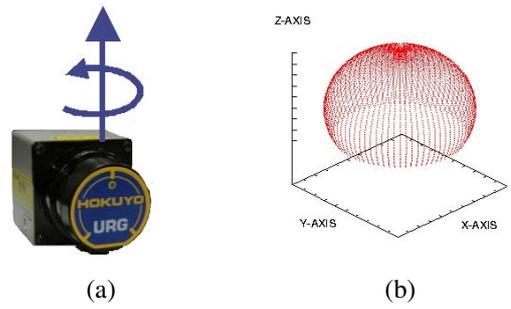


**Figure 6:** Scanning experiment of 2D environment: (a) environment, (b) result of scanning with halts for every scanning, (c) result of scanning without halt, (d) result of scanning without halt by using Mobile SOIKUIKI Sensor System

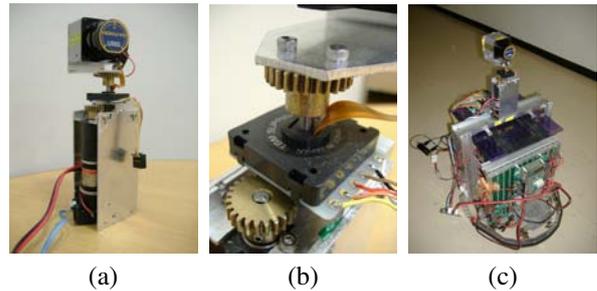


**Figure 7:** Comparison of scanning result: (a) result of one scanning without the Mobile SOKUIKI Sensor System, (b) result of one scanning with the Mobile SOKUIKI Sensor System

attached to the rotating shaft and all the cables from the sensor are though it so that the sensor rotates unlimitedly (see figure 9b). Note that the maximum rotating velocity of the slip ring is 60rpm. We mount this unlimitedly rotating device on a mobile robot (see figure 9c). The timing registration module estimates the sensor's position and posture by counting the pulses from the three motor encoders. Two of them are attached to the motors of wheels and the other is to the unlimitedly rotating device.



**Figure 8:** Scanning method: (a) rotating method, (b) measurement density distribution

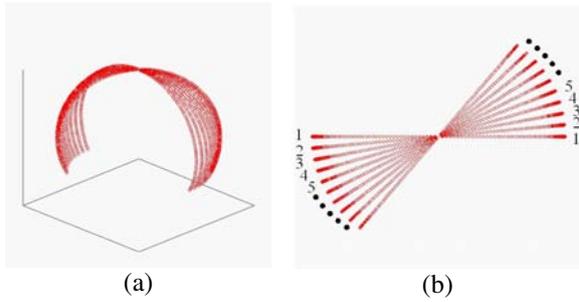


**Figure 9:** Motion mechanism: (a) unlimitedly rotating device with the sensor, (b) slip ring, (c) robot with the rotating device

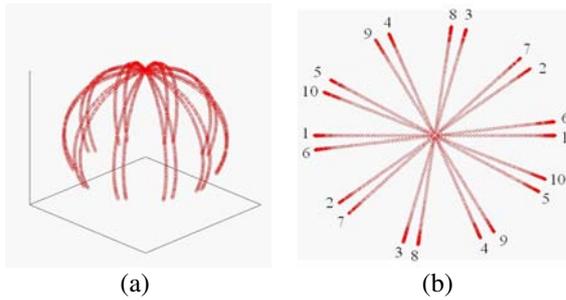
## 4.2 Rotating Velocity of the Unlimitedly Rotating Device

In most of conventional method for constructing 3D range data map with a SOKUIKI sensor, the scan plane of the sensor is rotated slowly around 5rpm because of timing registration problem. If it is rotated fast, the scanning result includes a great amount of errors. Figure 10a shows an image of the change of measurement density scanned by rotating the sensor slowly. Figure 10b is a top view of figure 10a. Numbers in figure 10b represent scanning order. We see from figure 10 that the measurement points increase in two directions. If the robot changes its moving direction before the sensor rotates 180 degree, the range data map has two big holes in which there is no measurement point.

In order to solve this problem, we rotate the sensor fast, around 60rpm in our research, to construct 3D range data maps. The change of measurement density is shown in figure 11. If we see figure 11 we will see that the measurement points increase in many directions. This rotating method decreases holes in the map. When rotating the sensor fast, the velocity of rotation should be determined carefully. If the sensor rotates exactly at a velocity of 60rpm, it scans at only 5 different angles.



**Figure 10:** Change of measurement point density in rotating slowly: (a) side view of measurement point density, (b) top view of measurement point density

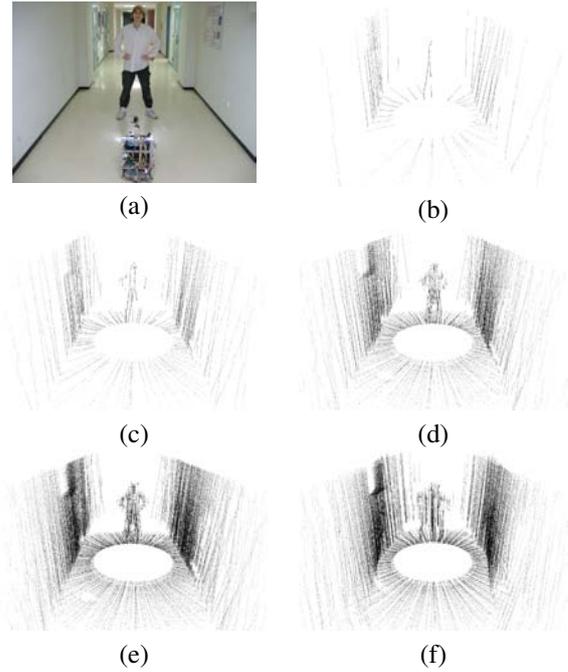


**Figure 11:** Change of measurement point density in rotating fast: (a) side view of measurement point density, (b) top view of measurement point density

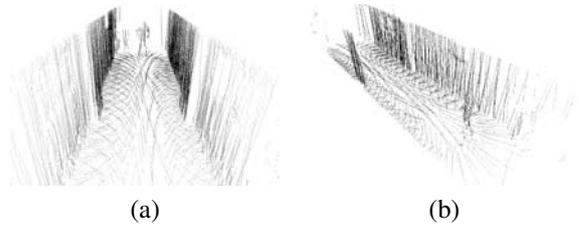
### 4.3 3D Scanning Experiment

Two experiments were performed to evaluate the effectiveness of our 3D scanning method. First, the robot does not move and only uses rotating device to scan environment. The sensor rotates at a speed of 58rpm. The result of experiment is shown in figure 12. Figure 12a, 12b, 12c, 12d and 12e each shows the experimental environment, result of scanning in 2s, 5s, 15s and 30s. As time passed, the density of the measurement points increases relatively uniformly. Figure 12f shows the result of scanning in 30s without the Mobile SOKUIKI Sensor System. We see from figure 12f that the human in the middle of the corridor is blurred and the walls are curved. Without the system, the range data map has a number of errors.

In the second experiment, the robot moves and the sensor scans 30s with the sensor rotating in the corridor, which is the same environment as the previous experiment. The robot moves along the corridor at a speed of 300mm/s and the sensor rotates at a speed of 58rpm. The result of the experiment is shown in figure 13. Figure 13a shows the 3D range data map from the viewpoint in the middle of the corridor. Figure 13b shows the result from a different viewpoint. The measurement points of the ceiling are not displayed in figure 13a and those of the ceiling and the left wall are not displayed in figure 13b to facilitate clear view of the scan data. Even if the robot moves around the environment, there are less error and no big holes in the map.



**Figure 12:** Robot does not move and scans corridor: (a) environment, (b) scanning 2s, (c) scanning 5s, (d) scanning 15s, (e) scanning 30s, (f) scanning 30s without Mobile SOKUIKI Sensor System



**Figure 13:** Robot moves and scans Corridor: (a) from the viewpoint in the corridor, (b) side view

## 5 Conclusion

This paper proposes a sensing system based on time synchronization between a position estimation module and a SOKUIKI sensor. The synchronization is realised by using synchronous signal from the SOKUIKI sensor. Our system can construct an accurate range data map of an area even if the sensor itself changes its position and posture continuously. The effectiveness of the system is shown through experiments. The accuracy of the system is mainly based on accuracy of the position and posture of the sensor. If the accumulative error of the position and posture has increased, the accuracy of the map is not assured. To solve that problem, another method is applied together.

The timing registration problem restricts the action of robots and manipulators on which 2D laser range finders are mounted in map construction. Our proposed system removes this restriction, so future systems could be implemented using Mobile SOKUIKI sensor system.

## 6 Acknowledgement

We would like to thank Mr. Luis Yoichi Morales Saiki of The University of Tsukuba for his assistance in assistance in preparing this manuscript.

## 7 References

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