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Floor Sensing System Using Laser Range Finder and Mirror for Localizing Daily Life Commodities

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Abstract— **This paper proposes a new method of measuring position of daily commodities placed on a floor. Picking up an object on a floor will be a typical task for a robot working in our daily life environment. However, it is difficult for a robotic vision to find a small daily life object left on a large floor. The floor surface may have various texture and shadow, while other furniture may obstruct the vision. Various objects may also exist on the floor. Moreover, the surface of the object has various optical characteristics: color, metallic reflection, transparent, black etc. Our method uses a laser range finder (LRF) together with a mirror installed on the wall very close to floor. The LRF scans the laser beam horizontally just above the floor and measure the distance to the object. Some beams are reflected by the mirror and measure the distance of the object from virtually different origin. Even if the LRF fails two measurements, the method calculates the position of the object by utilizing information that the two measurements are unavailable. Thus, the method achieves two major advantages: 1) robust against occlusion and 2) applicable to variety of daily life commodities. In the experiment, success rate of observation of our method achieves 100% for any daily commodity, while that of the existing method for a cell-phone is 69.4%.**

I. Introduction

Developing a robot working in our daily life environment is a big challenge. It will be useful to solve various problems in our aging society. Among various issues to realize such robot, recognition of surrounding environment of the robot has been one of the most difficult ones. Instead of relying only on the on-board sensors and computers to recognize its surrounding situation, informationally structuring the environment using distributed sensors embedded in the environment is a promising approach to the issue. Successful results such as human tracking, creation of 3D map which describes the structure of the environment space and integrated database have been reported[1], [2]. However, tracking and localization of small daily life commodities is still a difficult problem. Picking up a dropped object on a floor is a frequently required task for a robot working in our daily life environment. It is difficult for a robotic vision to find a small daily life object left on a large floor. The floor surface may have various texture and shadow, while other furniture may obstruct the vision. Various objects may also exist on the floor. Moreover the surface of the object has various optical characteristics: color, metallic reflection, transparent, black etc.

In this paper, we propose a position measurement method for daily life objects placed on a floor. Our method introduces a laser range finder (LRF) and a mirror, and utilizes information that some distance measurements are unavailable due to no reflection on the object surface. The proposed method achieves two important properties for floor sensing as follows:

1) Robust against occlusions
2) Applicable for daily commodities (e.g. plastic bottle) which do not reflect sufficient laser beam to the LRF for distance measurement.

The paper is organized as follows. Section II gives some related work. Section III proposes a floor sensing system using a mirror and a LRF. Section IV describes an experimental environment and Section V shows experimental results. Section VI concludes the paper.

II. Related Work

We assume that the robot operates in a living room, dining room, bedroom, corridor etc., in which a chair, a table, a sofa, a bed, a cabinet and other furniture are placed. There are a variety of daily commodities and their location can be classified into three categories, 1) in a cabinet, 2) on furniture and 3) on a floor.

Information structurization in a cabinet is relatively easy by installing an RFID reader and a weight sensor to a cabinet. Mori proposed a position management method in which the position of objects with RFID tags is measured by an RFID reader attached to a cabinet[3]. We also proposed an intelligent cabinet using an RFID reader and a weight sensor[4]. Information structurization on furniture is also easy by using an RFID reader and a camera whose scope is above the furniture. However, it is difficult to apply these sensors for information structurization on a floor because

1) the sensing area is large,
2) many pieces of furniture are installed on the floor, and
3) human and a robot move on the floor.

Deyle et al.[5] reported the position searching method by moving a directional antenna and receiving the signal from the tag attached to the object; however, the position resolution of the method is low. Nishida et al.[6] used an ultrasonic sensor for position measurement. The position of objects with ultrasonic tag is measured by using ultrasonic receivers placed on the ceiling. However, it is difficult to attach the ultrasonic tags to many objects due to the cost and the size of the tag. Embedding pressure sensors on a floor is introduced to track human activities[7]; however, these sensors cannot detect the position of lightweight daily commodities.

In our daily life, we often leave daily commodities on a floor or drop them on the floor. Therefore, the detection and the position measurement of daily life commodities on a floor is an important issue when structuring information of daily commodities.

III. Floor Sensing System Using Mirror and LRF

We propose a method of position measurement using a laser range finder (LRF) and a mirror. Many position measurement methods using a LRF are proposed[8]. Koshihara et al. [9] proposed a method of human shape measurement using a LRF and mirrors. However, these methods do not consider unobservable cases due to the characteristic of the objects because the targets of these methods are human etc. Our method not only introduces a mirror into a position measurement method using a LRF but also utilizes information that no distance data is obtained because the LRF cannot receive sufficient reflection from the object.

A. Position Measurement Using LRF and Mirror

Fig. 1 shows a principle of a position measurement using a LRF and a mirror. We install a LRF on a floor to scan on the floor. A strip of mirror is installed along a wall to reflect the laser beam from the LRF. The overlap area of both direct beam scanning from the LRF and indirect beam scanning via the mirror is a measurement region.

A continuous line in the figure shows the laser beam from the LRF to the object. The distance between the LRF and the object via the mirror is equal to the distance between the position A' and the object, where A' is a reflection of the LRF's position A with respect to the mirror. $\angle CA'D$ equals to $\angle BAD$. Thus, we can treat a position measurement using a mirror reflection beam as a position measurement using a virtual LRF which is placed on the position A'. Therefore, the position of the object C is calculated using the distance data measured by the LRF. Since the point B is the intersection of the mirror and the line $A'C$, we obtain the actual path of laser beam as line ABC.

If 1)the mirror exists in the direction of the beam and 2) the measurement data is larger than the distance between the mirror and the LRF, the distance data is measured by a reflection beam. Otherwise, the data is measured by a direct beam.

B. Three Measurement Modes

If no object is placed on the floor, the LRF measures the distance to an opposite wall. If an object is placed on the floor, the LRF measures the distance to the object or the LRF cannot obtain any distance data according to the reflection property of the object.

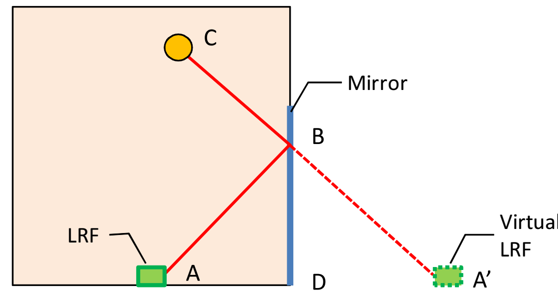

Fig. 1. Position measurement on the floor using mirror and LRF (Top view)

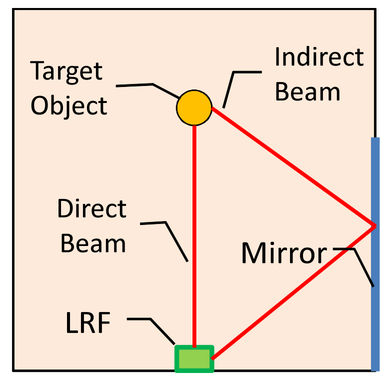

Fig. 2. Object that reflects laser beam

1) Object That Reflects Laser Beam: If an object reflects a sufficient laser beam to the LRF, the LRF obtains the distance not to the wall but to the object. The system detects the existence of the object from this difference, and calculates the position using the distance and the angle of the laser beam. Moreover, two types of the measurement result can be obtained. One of the results is obtained using the direct laser beam from the object, and the other is obtained from the indirect laser beam via the mirror (See Fig. 2). We refer the former measurement as “direct measurement mode”, and the latter one as “indirect measurement mode”. The system can measure the position of the object if either direct measurement or indirect measurement succeeds, thus the system is robust against occlusions.

2) Object That Diffuses Laser Beam: If the placed object does not reflect the sufficient laser beam to the LRF, e.g. a transparent plastic bottle diffuses the laser beam, the LRF becomes unable to get any distance data. This information, i.e. ‘becoming unable to get any distance data’, implies some object is placed somewhere on the line from the LRF to the wall. Also if the LRF fails “indirect measurement”, some object is placed on the line from the LRF to the wall via the mirror. Dashed lines in Fig. 3 show these two lines. By integrating two pieces of information, we can calculate the position of the object as the intersection of the two lines. We call this mode of measurement “diffuse measurement mode”.

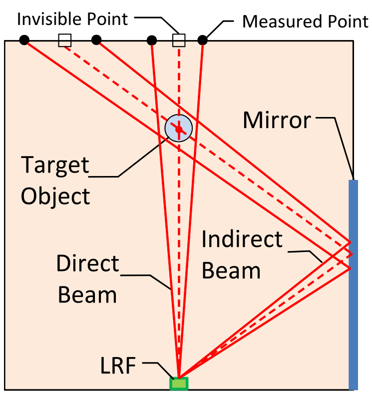

Fig. 3. Object that diffuses laser beam

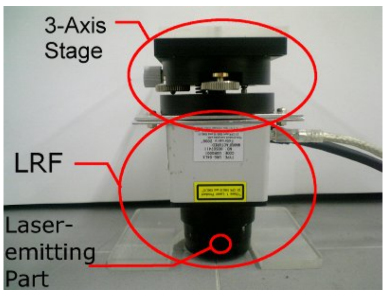

Fig. 4. Laser range finder

IV. Experimental Environment

A. System Components

URG-04LX, manufactured by Hokuyo Automatic Co. Ltd. is a laser range finder whose maximum measurement range is 4m. URG-04LX is installed on a floor so that the laser beam scans just above and very close to the floor (See Fig. 4). A mirror made by acrylic is installed on the side wall of the room (See Fig. 5). In order to adjust the alignment of the axis of the laser, the LRF is mounted on a three-axis rotation stage and the mirror is mounted on a one-axis stage. We adjust both stages so that the laser scans a horizontal plane at 16mm above the floor.

B. Measurement Area and Resolution

The size of a floor sensing room is 2m$\times$2m. The upper left corner of the room in Fig. 6 is the farthest point from the LRF via the mirror, and the distance to the point is about

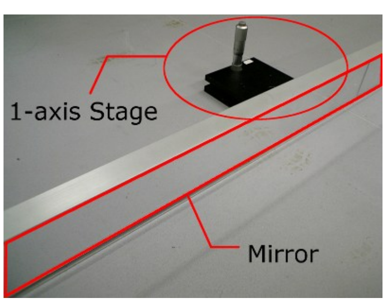

Fig. 5. Mirror

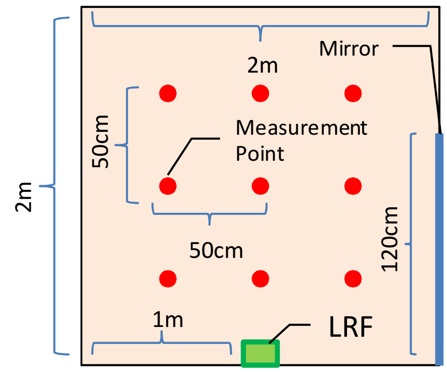

Fig. 6. Experimental environment

3.6m. Since the farthest distance is less than the maximum range of the LRF, the LRF gets the distance to the wall when no object is placed on the floor.

Since we used a 1.2m-long mirror, the reflect beam cannot reach to the right corner of the room. Since the angle resolution of the LRF is $2\pi/1024$[rad], an object whose width is larger than 22.1mm can reflect at least one laser point and the system can measure the position of the object wherever the object is placed on the floor.

V. Experimental Results

A. Basic Performance

We have evaluated the accuracy of three different modes of measurement: direct mode, indirect mode, and diffuse mode. Due to the difference of view angle, the reflection points obtained by the direct measurement on the object surface are different from those obtained by the indirect measurement as shown in Fig. 2. Therefore, we use a cylinder and estimate the position of its center for relevant comparative evaluation of measurement error. We used a paper cylinder(Fig. 7) and a cylindrical transparent plastic bottle (PET) filled with water (Fig. 8). Radius of these cylinders is 33mm. In direct or indirect mode, the gravity center of the measured points on the cylinder surface is computed and retracted by the value of cylinder radius along the line connecting the LRF origin and the gravity center. This retracted gravity center is estimated to be the center of the cylinder(See Fig. 9). In diffuse mode, the center line of multiple lines in an adjacent angle is calculated as the estimated center line of the object(See Fig. 10). The estimated center position of the object is obtained as the intersection of the two estimated center lines. In the experiment, nine different points are selected in the measurement area of the floor as shown in Fig. 6. Each cylinder is placed three times at these 9 points to obtain 27 measurement data in total. Before this experiment, we have calibrated the location of LRF using the least square mean error method with estimated position of the paper cylinder from LRF measurement and the grand truth.

Table I shows the experiment results. The average error of measurement for the paper cylinder using the direct measurement is 14.8mm. The average error using the indirect

Fig. 7. Paper Cylinder

Fig. 8. Plastic Bottle

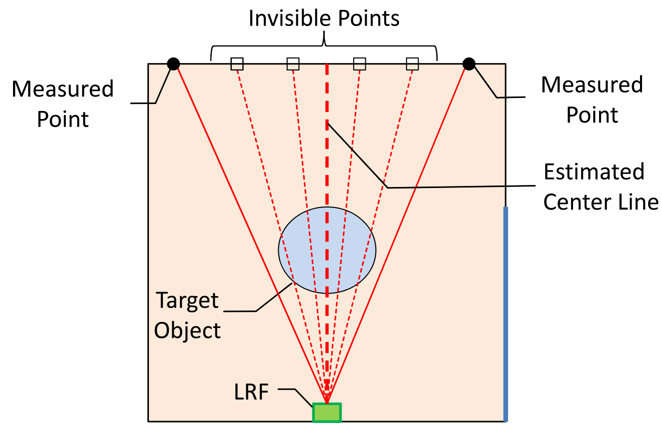

Fig. 10. Estimated center line of object (Diffuse mode)

TABLE I
RESULTS OF MEASUREMENTS FOR CYLINDRICAL OBJECTS

	Direct		Indirect		Diffuse		Total
	Err. [mm]	SRO [%]	Err. [mm]	SRO [%]	Err. [mm]	SRO [%]	SRO [%]
Paper	14.8	100.0	28.6	100.0	-	0.0	100.0
PET bottle	134.7	33.3	62.2	3.7	26.6	100.0	100.0

measurement is 28.6mm. The reason of this larger error may be that the indirect mode needs longer measurement of LRF than the direct mode. A small fluctuation may be induced in the laser light phase by mirror reflection. All measurements of the paper cylinder using the direct measurement succeeded, and measurements using the indirect mode also succeeded. The diffuse mode has not been applied to the paper cylinder.

The average error of measurement for the transparent plastic PET bottle using the direct mode is 134.77mm and success rate of observation(SRO) is 33.3%. The measurement accuracy of the plastic bottle is worse than that of paper cylinder because water prevents a laser beam reflection. On the other hand, the measurement error using the diffuse mode is 26.6mm and SRO is 100%. This is because the system can measure the position of an object using either the direct mode or the indirect mode if the LRF receive a sufficient reflection beam from the object, otherwise the system can measure the position using the diffuse mode. Therefore, our method is suitable for a variety of daily commodities having various reflection properties. The rate of successful measurement using either direct or indirect or diffuse modes, total SRO, is 100% and is larger than SRO using the direct mode only.

Error of position measurement by direct mode is larger when the object is placed at longer distance from the LRF. Error of position measurement by indirect mode is larger when the object is placed at longer distance from the mirror. This is due to the fact that the measurement error of the LRF becomes larger proportional to distance to an object, as its characteristic nature.

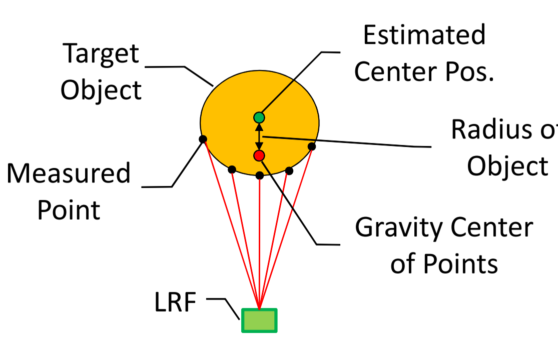

Fig. 9. Estimated position of object (Direct/Indirect mode)

B. Measurements of Daily Life Commodity

Next, we performed the measurement experiment for daily life commodity. Objects that are used in the experiment are cell-phone (W112 × D52 × H25mm, See Fig. 11), pencil box made of dark brown cloth (W195 × D46 × H55mm, See Fig. 12) and green eyeglass case (W155 × D69 × H28mm, See Fig. 13). We placed each object at nine different points of Fig. 6. At each point, the orientation of the object was changed to 4 different pose: rotation around vertical axis by 0, 45, 90 and 135 degrees. In direct/indirect mode, number of available measured points was not sufficient to estimate the shape and the position of the center of the object, so we computed difference between the gravity center of the measured points and the position of the object place. In diffuse mode, the estimated center of the object is obtained by the calculation described in the previous subsection.

Table II shows the result. Detection and measurement have been succeeded for each object in 36 different poses, which means 100% of SRO is achieved. SRO using direct mode of the cell-phone is only 69.4% because the shape of the cell-phone is complicated. On the other hand, the

Fig. 11. Cell-phone

Fig. 12. Pencil box

system achieves 100% of total SRO for any daily commodity, including the cell-phone. Average value of the positional difference between the measured one and the actual one is 50mm. The difference is approximately 100mm at most. The diffuse mode of measurement is important when the object is placed far away from LRF because the farther the object is located the less reflection is obtained at the LRF receiver and consequently the position measurement by both direct mode and the indirect mode often fails.

Based on the experiment results, accuracy of position measurement of the system might not seem sufficient for robotic picking up operation. However, it is sufficient for a mobile robot to approach the object. Then, the robot will be able to grasp it using on-board vision system, proximity sensor or tactile sensor equipped on the gripper.

Fig. 13. Eyeglass case

TABLE II

RESULTS OF MEASUREMENTS FOR DAILY LIFE COMMODITIES

	Direct		Indirect		Diffuse		Total
	Diff. [mm]	SRO [%]	Diff. [mm]	SRO [%]	Diff. [mm]	SRO [%]	SRO [%]
Cell-phone	49.8	69.4	36.9	5.6	35.9	66.7	100.0
Pencil box	34.9	100.0	-	0.0	45.3	25.0	100.0
Eyeglass case	37.1	100.0	-	0.0	47.0	44.4	100.0

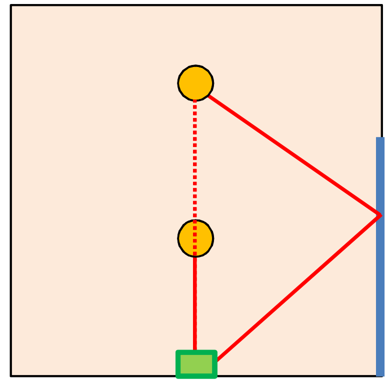

Fig. 14. Case of successful measurement

C. Measurements of Multiple Objects

Finally, we performed the measurement experiment for multiple objects existing in the scene. The system succeeds position measurement of objects if the objects are observed by either direct mode or indirect mode. The simple use of LRF without a mirror cannot measure the position of the farthest object in Fig. 14, which is in dead angle of the direct beam; however, our method can measure the position of all the objects.

On the other hand, there are some cases that a single object can be measured but multiple objects cannot be measured. The farthest object in Fig. 15, which is in dead angle of both direct beam and indirect beam, is one example of the cases. The object in dead angle of both direct beam and indirect beam cannot be measured by diffused mode. Therefore, we must decrease the area of dead angle of LRF to increase success rate of observation. Mirrors that are placed in both sides of the room enable multiple paths of a laser beam, thus the system with multiple mirrors decreases unobservable cases. We install a very narrow but long strip of mirror on both sides wall of the room. Each mirror is slightly tilted so that the reflected laser beam scans upper outside of the opposite mirror. Thus, all the scan of the laser returns back the distance to the wall when there exists no object.

In some cases, the system cannot determine the positions of objects using the diffuse mode observation. Fig. 16 shows this example. If two objects (e.g. plastic bottles) are placed in the position A and D, the system returns five position candidates from A to E, which are intersections of diffuse mode lines. The same observation is obtained when two objects are placed in the position B and C. Moreover, there are total 16 pairs of position candidates[1] if we do not restrict the number of the objects to two. If only the observation result of Fig. 16 is given, the system cannot determine the positions whether the two objects are placed in the positions (A,D) or (B,C).

[1]The candidates are combinations of variables that make the Boolean formula: (A+B+E)(C+D+E)(A+C)(B+D)=AD+BC+ABE+CDE to true. For example, a pair of (A,B,E) and a pair of (B,C,D) satisfy this condition.

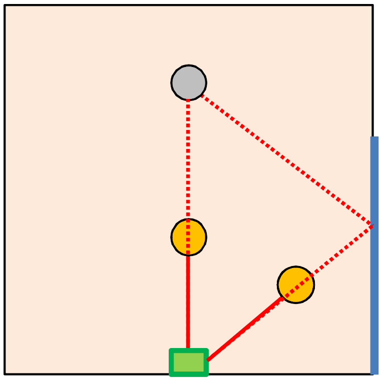

Fig. 15. Case of failed measurement (1)

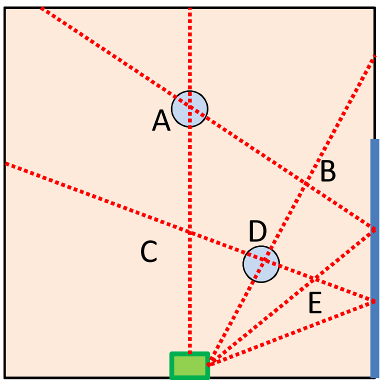

Fig. 16. Case of failed measurement (2)

The sensing system detects objects and measures their position if the objects appear in the sensing area one by one. For example, if the system recognizes that the single object is placed in the position A at the beginning, and then observation result of Fig. 16 is given, the system can determine that the added object is placed in the position C because other cases are rejected by the assumption.

VI. Conclusion

We proposed a new floor sensing system using a laser range finder (LRF) and a mirror for localizing daily life commodities. Since a mirror enables observation of an object from two directions, the system can reduce area of the dead angle of the LRF and is robust against occlusions. Using the mirror and utilizing information that no distance data is obtained due to no-reflection on the object; the system determines the position of the object even if the LRF cannot obtain the sufficient reflection beam of the object. Thus, the system is applicable for a variety of daily commodities with various reflection properties. In the experiment, success rate of observation of our method achieves 100% for any daily commodity, while that of the existing method for a cell-phone is 69.4%.

Acknowledgments

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