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Absolute location by landmark extraction

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SUMMARY

To limit cumulative errors due to the odometer, we propose an absolute location method based on the extraction and the use of geometrical landmarks. This method also avoids the need of prior knowledge of the robot environment (no training steps) and its specified fitting (no beacons). If different measurements of the environment around the robot taken by an ultrasonic telemeter are merged, geometrical primitives appear. They are then discriminated and rebuilt. Those primitives are the landmarks used by the locating system. Hence a set of definitions and laws have been established to conjointly use few landmarks, in order to obtain the mobile robot absolute location by triangulation.

KEYWORDS: Absolute location; Mobile robots; Landmarks.

I. INTRODUCTION

Whatever the mission entrusted to a mobile robot, it must absolutely be able to locate itself in its environment. The locating system implemented then depends on the degree of sophistication of the sensor, on the nature of the environment (structured or not), as well as on its own knowledge. Two different types of locations are possible: dead reckoning location or absolute location.

The main advantages of dead reckoning location are its low cost and its easy implementation and exploitation. Unfortunately, the cumulative aspect of its errors is often incompatible with an accurate location on irregular floors. The absolute location provides results independently from the floor nature and movements, but its implementation is more complicated.

The purpose of this paper is to propose an absolute reliable location that is as cheap as possible.

II. STUDY CONTEXT

A. Resources

The mobile robot on which the study is based is one for domestic use. This application field involves low cost constraints. Hence the sensing system chosen is an ultrasonic time-of-flight ranging device. This well-tested technology had been frequently used in mobile robots,[1-3] despite the fact that errors arise due to axial accuracy (threshold of the information), radial accuracy (wide ultrasonic beam) and unusual environment.

Forcing the user to perform boring training steps or fixing definitively its working conditions outweights the help brought by such a system. Thus it is impossible to use absolute location methods based on the comparison between a map given by sensors and a pre-memorised map describing the environment as those described in references [4] or [5]. In the same way, it is impossible to adapt specifically the environment. In fact, acquiring such equipment cannot modify the user's actual environment; hence absolute location systems using passive or active beacons,as in reference [6] seem to be unacceptable.

B. Exploration method

The constraint of having no prior knowledge involves a particular exploration process. At the beginning of its mission, the robot is put in some room, in some position and orientation, which are unknown. The first step is then to establish an absolute reference chosen for the first position and orientation of the robot. It also has to determine this location; this can be done by observation of the nearest neighbouring object. From a first series of measurements taken all around the robot, ultrasonic echoes are obtained; they are the existing object marks. Unfortunately, they cannot be distinguished, one from another. This information is not sufficient to determine the mobile robot location unequivocally. New data have to be acquired from a different robot position to start the environment rebuilding necessary for the landmark extraction. But, if there is a movement, there is a danger that the robot will be lost. That is why, in a first step, information provided by an odometer is used; this implies small movements to restrict cumulative errors.

After having moved, the new data can be fused to the old ones to confirm the objects' position and to enhance the informational level of knowledge. The purpose is to obtain data on the nature of the objects and, thus, make the robot able to distinguish between them.

Successive movements can then continue the exploration. However, those movements have to be small before the robot can use groups of landmarks indispensable to its location.

C. Environment model

The environment model depends on the nature of its cluttering objects. The mobile robot studied will move in man-made environments. They are easily decomposed into geometrical forms, and the only difficulty is to extract those primitives from the ultrasonic echoes.

Previous work has demonstrated the possibility to extract particular geometric entities from an environment.[7,8] Those

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entities depend on the continuity of the ranging measurements associated to an object. The continuous nature of ranging measurements marks the presence of a wide surface (wall or face closet, for example). The discontinuous nature of the ranging measurements represents small objects like corners, edges or table legs. Combining those data geographically permits one to highlight four types of primitives: planes, rows, corners and edges. Those geometric characteristics are the objects, which can be used as landmarks for the mobile robot location.

III. WHAT IS A LANDMARK?

A. Qualities and definition

- **The object has to be fixed.**

The mobile robot cannot locate itself correctly from moving entities.

- **The object has to be visible.**

To use an object as a landmark, it has to be visible or detectable. Detection is possible depending on the position and the orientation of the robot sensor comparatively to the landmark and the other objects of the environment. A landmark cannot be efficient if it can just be seen from a few positions, or, if one of its differentiating characteristics is always hidden by another object. Then there could be confusions leading to location errors. Some technical characteristics of the ultrasonic ranging device restrict the surface at the telemeter altitude from which a landmark is visible. Those characteristics are: the sensor range, the incidence angles and the landmark occultation by another object. The visible quality is memorised as a part of the floor. This part defines the surface from which the landmark can be detected.

- **The object has to be identifiable.**

If a difference cannot be made between two landmarks, then the robot will not be able to locate itself correctly, because there will always be an ambiguity. A landmark is identified from its nature and its size.

- **The location of the object has to be known accurately.**

The extraction and the observation of landmarks can directly deliver the robot's location. If the position or the orientation of one of the landmarks used is erroneous, then the robot location will be erroneous too and the location of the next founded landmark will be wrong. This problem is the same as the cumulative errors of the odometer.

Hence the definition of a landmark is: "A landmark is a fixed element, naturally present in the environment, visible, identifiable, and whose position and orientation (referring to an absolute point of the environment) can be established accurately. It is used to provide a piece of information on the robot location".

B. Landmarks qualification method

An object rarely presents the above mentioned qualities. Hence only a few objects will be suitable. That is why it is necessary to limit the claims about the landmark qualities and find a compromise between the number of objects which can be qualified and the number of qualities needed for a landmark. Then, two types of landmarks can be distinguished: the measurement landmarks and the differentiation landmarks.

(i) The differentiation landmarks. The differentiation landmark's purpose is the lifting of ambiguities in the mobile robot position and orientation. Those landmarks are not really used to extract the robot location, so they have to be visible and correctly identifiable, but an error in their location can be accepted. The criterion of visibility can be established by the surface from which the object is visible or detectable. For example, for a small size object, it can be visible from a disc, the centre of which is defined by the object and radius by the sensor range. This surface is the object visibility degree. The criterion of identification is obtained by the object's probability of belonging to the class that represents it best. This is the identification degree.

(ii) The measurement landmarks. The purpose of a measurement landmark is to provide distances necessary to compute the robot location. So they have to be visible and their location accurately known, but an error in their identification can be accepted. The criterion of visibility is the same as before. The criterion of location is estimated from the measurements made. If the landmark is a plane object then the location degree is high; if the landmark is a small size object, then the location degree is low because errors in measurements are higher due to the ultrasonic beam width.

C. Conclusion

At first, the mobile robot has to recognise particular characteristics of its environment. This information is used to locate the robot by extraction and observation of landmarks. When this step is achieved, the founded objects have to be qualified as landmarks depending on two qualities: visibility and identification for differentiation landmarks and, visibility and accurately established location for measurement landmarks.

But a single landmark is not sufficient to locate the robot. Hence it has to construct systems of landmarks to extract the three necessary distances used in triangulation methods.

IV. WHAT IS A SYSTEM OF LANDMARKS?

A system of landmarks is a group of particular environment entities. It allows the location of a robot using a triangulation method. To be efficient, the system must deliver only one position and orientation to the robot. If there remains an ambiguity in the location, then the extracted system is useless. Hence, the systems of landmarks must have certain qualities.

A. Qualities of a system of landmarks

(i) Minimal number of landmarks in a system. In this study, we suppose the robot able to extract two types of landmarks: small size objects and plane objects. They represent the basic forms, which can be found in a man-made environment.

- **Systems composed of one landmark**

When the robot can only detect one landmark, its location is totally impossible. The only known datum is the more or less accurate distance between the robot and the detected landmark: the robot location is not unique.

If the landmark is a small size isolated object, then the possible locations for the robot describe a circle the centre of which is the landmark and the radius is the ranging measurement. If the landmark is a plane object, the locations describe a line which is parallel to the landmark. In both cases, an infinity of locations is possible.

- **Systems composed of two landmarks**

When two landmarks are detected, the number of possible locations is about to decrease in comparison with the previous described systems. This decrease depends on the geometry of the two landmarks and their relative positions.

If the robot detects two small size landmarks, they present a central symmetry, and if it detects two plane landmarks, they present an axial symmetry: the robot location cannot be unique. A particular case appears when the two plane objects are parallel. Then, the number of possible positions for the robot is not reduced and the locations describe a line which is parallel to the two landmarks.

- **Systems composed of three landmarks**

The principle of the absolute location by triangulation is based on distances between the robot and three objects. But, though this condition is necessary, it is not sufficient.

(ii) Unequivocal system identification. The robot uses a system composed of three landmarks for its absolute location. But, if two or more systems are similar, then there will have two or more possible locations.

(iii) Asymmetrical systems. If the landmark configuration presents one or more symmetries, the number of two for each symmetry will multiply possible locations.

(iv) Methods used to lift ambiguities. There is ambiguity when the mobile robot location is not unique. In this case the system of landmarks is useless. To use the information, the system has to be modified or completed. This can be done by: adding a landmark; using different nature and size landmarks in systems; using odometer data if they are not too much erroneous.

B. Qualification of a system of landmarks

To be qualified, a system of landmarks has to be asymmetric and differentiable.

The system is asymmetric:

- If the three landmarks have different sizes or natures;
- Or if the third landmark is not situated on the midperpendicular line formed by the two other landmarks.

The system is differentiable:

- If one of the three landmarks has a different size or nature from those used in the previous systems;
- Or if the geometrical configuration of the landmarks is different from the configurations of the previous systems.

C. Conclusion

All the above systems are not necessarily efficient for the mobile robot location. That is why the qualification method has been developed. Each system of landmarks extracted has to fulfil the three conditions presented above.

V. EXAMPLE IN A ROOM

A. Introduction

This last chapter proposes a qualitative example of the landmark and system extraction and of the qualification methods.

The main goal is to illustrate and validate the definitions presented in the two previous sections. The method has been tested off-line but only using real ultrasonic ranging measurements. We remind readers that the environment is totally unknown for the robot, the only knowledge concerns its structured aspect.

B. Demonstration

The robot is situated in a room furnished by a table, a chair, a closet and two leaning planes. The robot makes a first series of ultrasonic measurements (Figure 1).

On this figure, the disc designates the robot. Echoes are the first knowledge; they represent objects more or less accurately. Errors due to the ultrasonic beam width are clearly shown (1 to 6). Working directly with those measurements will lead to many errors. That is why echoes are fused in segments, as shown in Figure 2.

From one series of ultrasonic measurements, the robot cannot obtain the nature of the detected object, hence, it cannot identify them; it can only replenish odometer data. At this stage, the robot cannot be located in an absolute meaning.

However, surfaces in which safe movements can be achieved are constructed. These surfaces correspond to the visibility surfaces:

- If the movements of the robot are perpendicular to the segment and if the robot goes closer to the segment, then it will always detect it;

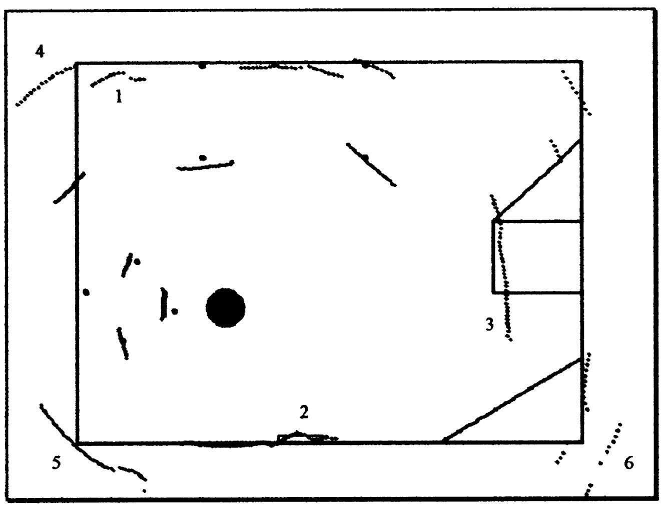

Fig. 1. First series of ultrasonic measurements.

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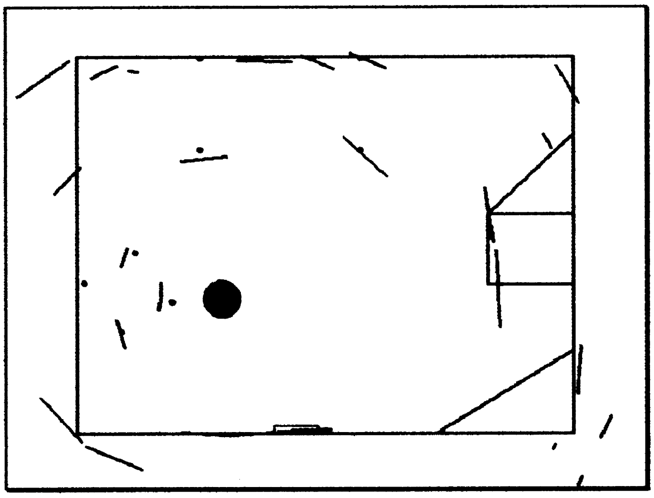

Fig. 2. Segments obtained for the first series of ultrasonic measurements.

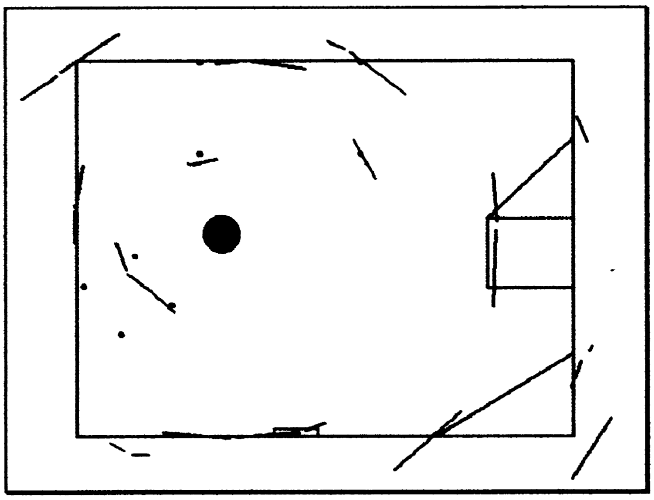

Fig. 4. Segments obtained for the second series of ultrasonic measurements.

– If the movements of the robot are parallel to the segment without leaving the boundaries of the segment, then it will always detect it.

Thus the visibility surface of a segment is a rectangle whose length is defined by the distance between the current robot position and the segment, and the segment length defines its width (Figure 3).

Without risk of being lost, the robot can move in a three-surface intersection. After the movement, a second series of ultrasonic measurements is taken and echoes are fused into segments (Figure 4).

As explained in references [7] or [8], these two views taken independently don't provide the object's nature. The robot has then to work with pairs of segments to be able to identify the detected objects.

As it can be seen on Figure 5, segment merging provides an idea of the detected object's nature. For example:

– 1, 2 and 3: the segments in those pairs are crossing each other, their middles are near and their relative bearing is not equal to zero. Those pairs correspond to discontinuous surfaces (1: a table leg; 2 and 3: chair legs).

– 4 and 5: segments are quite aligned and they don't really overlap each other. Then the detected surface is continuous (in fact, the segments represent walls).

But some pairs don't provide the object's nature (6, 7 and 8). As a matter of fact, the segments are quite aligned and superimposed. These pairs appear when the movement has been perpendicular to the object. Even if it is impossible to identify the nature of the object, those pairs are still interesting, because the object's position is more accurately known due to information redundancy.

Other pairs represent another object than the real one (9, 10 and 11). Those confusions can arise because the ultrasonic beam width cause expansion (9 and 10) or by an unlisted object in the control map. That is the case for the pair number 11. Here, two different bearing segments represent the wall; they should represent a discontinuous surface. In fact, there is a water pipe lying on the wall, this pair of segments cannot be considered as an error.

Finally, a part of that new knowledge will not be used at this step, when segments are isolated (12, 13 and 14). Now those preliminary observations are discriminated by an

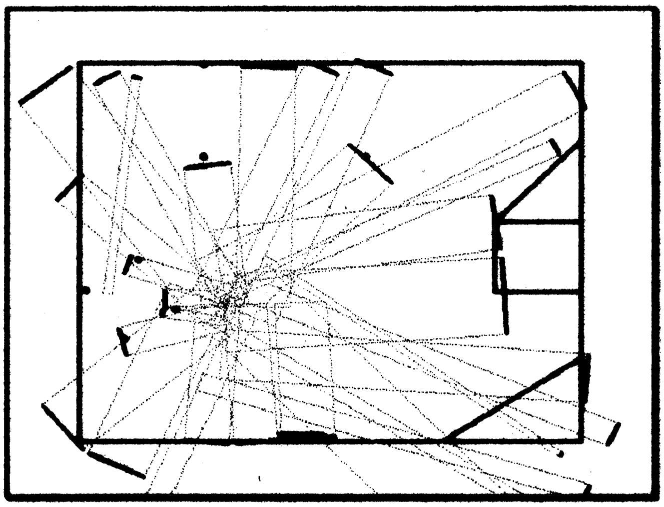

Fig. 3. Safety robot move surfaces.

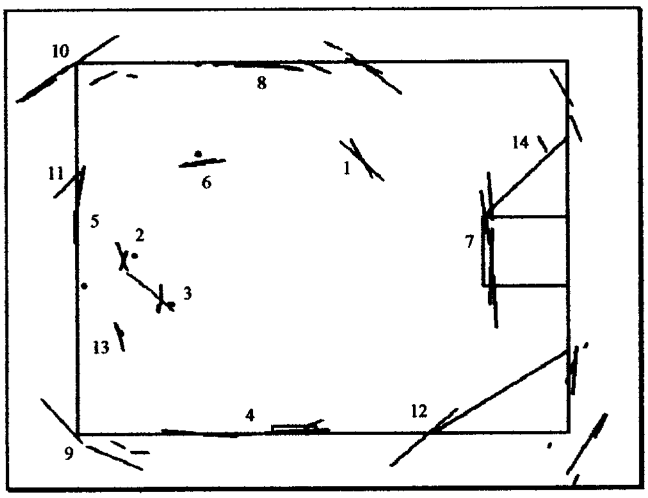

Fig. 5. Merging of the two series of ultrasonic measurements.

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algorithm based on Bayse rules. It provides the posterior probability for a pair to belong to a class of objects. This discrimination method is explained in reference [8]. For a structured environment, the classes are: continuous surface, discontinuous surface, superimposed segments, and too distant segments. Three features allows to discriminate classes: the relative bearing, the middle proximity and the overlapping degree of the two segments. After this discrimination, the preliminary observations are rebuilt. For two aligned segments, the mean square calculus constructs a new segment; for two segments which are crossing each other, the intersecting point is extracted to represent the small size object as shown in Figure 6.

From this step, the robot has the necessary knowledge to qualify the detected objects in landmarks and, then their qualification in systems of landmarks. Each rebuilt object has degrees of visibility, identification and accuracy of location. They allow to extract measurement and differentiation landmarks. The different degrees are established from the following considerations.

- **Visibility degree**

It is calculated from the floor surface from which the landmark is detectable.

- **Identification degree**

The more an object is identifiable, the higher its identification degree is. Discontinuous surfaces represent small size objects more or less isolated. They can easily be differentiated one from another, then their identification degree is increased of one each time that this type of object is extracted. On the other hand, continuous surfaces are found for large size objects. Sometimes, from two different views, two different continuous surfaces can be found for the same wall, those two different objects cannot really be identified. The identification degree of a continuous surface is always equal to zero. Finally, superimposed segments don't provide the object's nature. The object cannot be identifiable, then the value of the identification degree of superimposed segments is maintained.

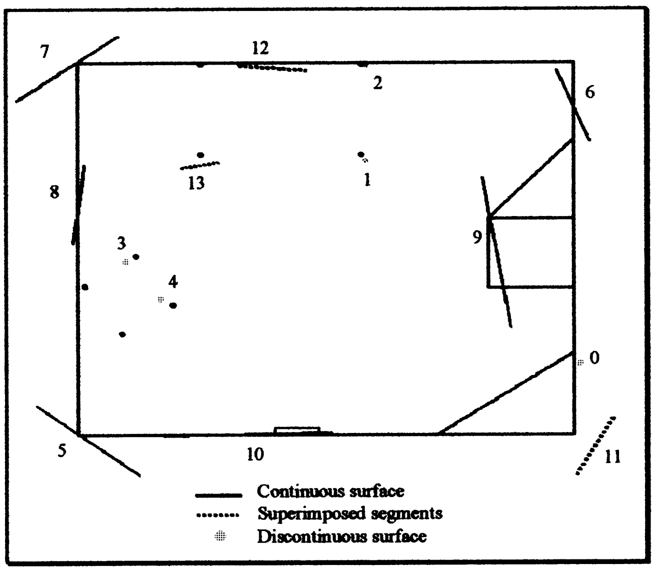

Fig. 6. Discrimination and rebuilt of pairs.

- **Location degree**

A discontinuous surface represents small size objects; the ultrasonic beam is then not reflected but refracted, so that higher measurement errors are involved. These errors can be equal or greater than the object's size. Then, the location of this object is not accurate and its location degree is always equal to zero. A continuous surface represents a wide size object; measuring errors are small (sensor inaccuracy) and then the location degree of such an object is increased by one each time it is detected. The redundancy of the data provided by superimposed segments limits errors when the two segments are fused into a unique one. The location degree of superimposed segments is increased by two each time this object is extracted.

A new movement and a new series of ultrasonic measurements are now necessary to continue to perform the environment exploration.

The new segments obtained after having fused the ultrasonic echoes will have different uses:

- They will confirm or contradict the robot's location from the identification of this new segment against the previous extracted landmarks.
- If the identification is not complete, then the new segment is labelled as an additional information for the landmark.
- If there is no identification, then the new segment is labelled as potentially describing an unknown landmark (Figure 7).

Knowledge provided by the third series of measurements is integrated into the old one by three different methods:

- The segment is identified as belonging to an already known landmark (1, 2, 3, 4, 5, 6, 7, 8 and 9). This

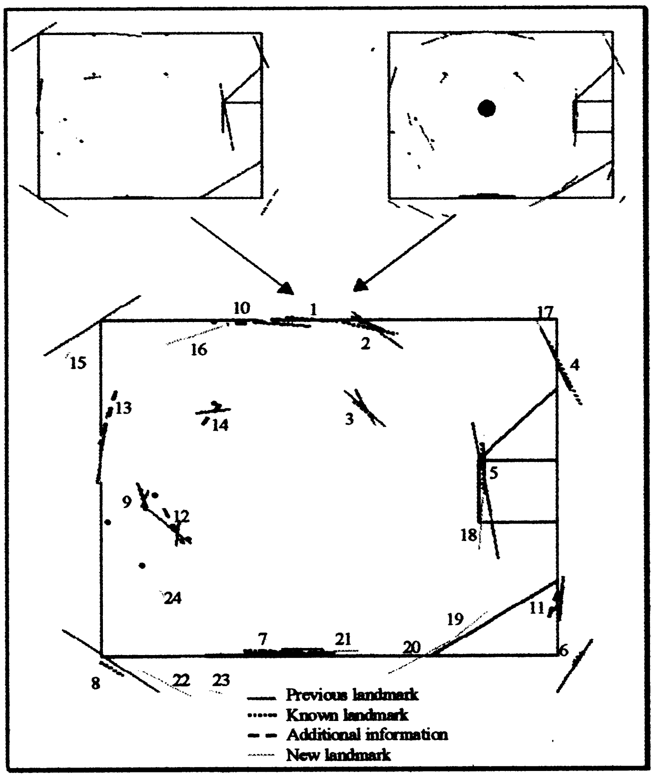

Fig. 7. New segment identification against previous landmarks.

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identification is possible when the new and the old segments are quite equal, i.e. when their relative bearing is null and the overlapping maximal. There is no new knowledge, but the old data are refined by the redundancy.

– The segment gives a complementary knowledge for an already known landmark (10, 11, 12, 13 and 14). The additional information can be qualitative; for example, the segment number 14 is merged into a superimposed segments measurement landmark. These data don't provide the object nature, but the new segment allows to extract the discontinuous nature of the object (a table leg). The associated landmark which was qualified as a measurement landmark is now qualified as a differentiation landmark. In another case, the additional information is quantitative; for example, the segment number 13 is merged into a measure landmark. The new segment has a similar orientation, their middles are close and they partially overlap each other. In that case, the new and the old segments represent a continuous surface. The qualitative level is the same, but the continuous surface grows so its visibility and location degrees grow too.
– The segment is considered as a potential new landmark (15, 16, 17, 18, 19, 20, 21, 22, 23 and 24). Here, the environment knowledge is detailed; for example, segments number 19 and 20 highlight the leaning plane. This improvement permits, once more, to raise the informational level qualitatively as well as quantitatively.

After discrimination and rebuilding steps, the environment is mapped, as shown in Figure 8.

Now the robot has the first landmarks necessary for its absolute location. Systems of landmarks can be constructed. At first, the robot has to verify that the system is unique. If the systems use different nature or different size landmarks then they have greater possibilities to be unique. But the nature or size of landmark could not be sufficient.

Figure 9 presents two systems of landmarks. The first one is constituted by two differentiation landmarks (1 and 2) and one measurement landmark (3), the second group is also constituted by two differentiation landmarks (1 and 2) and one measurement landmark (4).

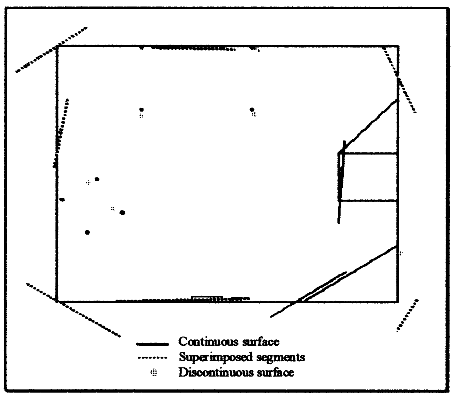

Fig. 8. Environment knowledge after three series of ultrasonic measurements.

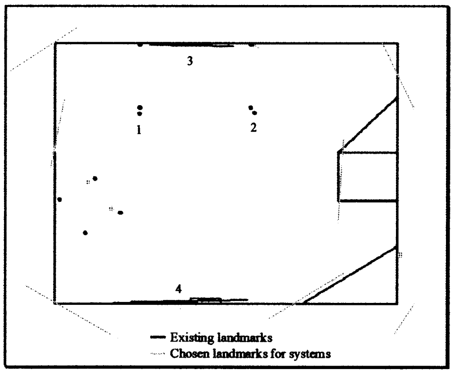

Fig. 9. Extraction of two systems of landmarks.

If the landmarks are only characterised by their nature, then the groups cannot qualify as systems of landmarks because they cannot be differentiated. But if the size, or more generally, the relative location of the three landmarks of each group is taken into account in the uniqueness test, the two groups can be differentiated, and then they can be qualified as systems of landmarks. In the example, the measurement landmark numbered 3 is closer to the two differentiation landmarks than the measurement landmark numbered 4. So they qualify as systems of landmarks. Now the robot has to choose the better system for its location.

At first, the visibility degree of each system is calculated. The most visible system is then chosen. But if these degrees are equal, a new criterion using identification and location degrees has to be found.

In the first case, we suppose that the robot has to correct its location given by the odometer; the chosen system is the one whose location degree is higher.

Figure 10 presents a system of landmarks constituted by three measurement landmarks. Its visibility degree (shown as shaded) allows for the covering of the middle of the room. The measurement landmarks have a good location degree because of their continuous nature surfaces. Then, this system is the best one to correct the odometer data.

In the second case, we suppose that the robot is completely lost, so it has to choose the highest identification degree system to approximately find its position, and after, the higher location degree system to precise this position.

Figure 11 presents a system of landmarks constituted by two differentiation landmarks and one measurement landmark. The differentiation landmarks have a good identification degree because of their discontinuous nature

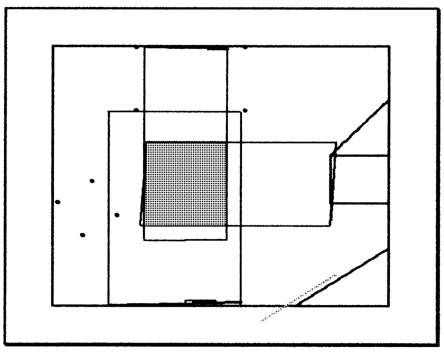

Fig. 10. Higher location degree system.

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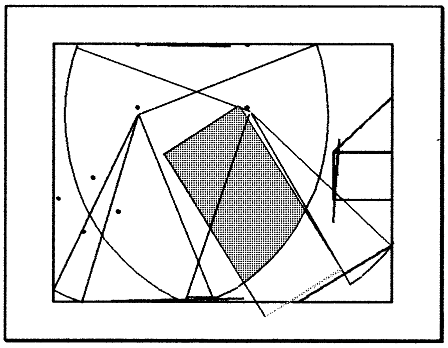

Fig. 11. Example of choice between two possible systems.

surfaces. They will allow to determine the robot location approximately. Then the use of one measurement landmark will refine it. Then this system is the best when the robot's location is totally unknown.

C. Conclusion

This last section is an illustration of the comments made in previous sections. From an example of a partially cluttered domestic unknown room, extraction and utilisation steps of landmarks and systems have been shown. To produce this example, real ranging measurements have been taken, but algorithms have worked off-line.

VI. CONCLUSION

In this paper, we have presented an absolute location method based on the extraction and the use of landmarks to explore unknown environments. The location depends on three distinct and indispensable steps. The first is a partial or total environment rebuilding; the second is a method, which permits to verify object particularities to qualify them as measurement or differentiation landmarks. Then the third consists in the conjoint use of few landmarks to calculate the robot's location. When several systems are extracted, the robot can move from systems to systems without risk. This method has been tested for several environments (one of them is presented in the last chapter). In the future we want to extend those considerations to non-furnished environments.

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