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BEIJING INDEMIND TECHNOLOGY CO, LTD.	09/20/2022

RECEIVING PARTY DATA

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PROPERTY NUMBERS Total: 1

Property Type	Number
Application Number:	18126682

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CORPORATE TO CORPORATE PATENT ASSIGNMENT	Docket Number 54626-713.601

北京盈迪曼德科技有限公司 (Beijing Indemind Technology Co., Ltd.), a corporation incorporated under the laws of the People's Republic of China, having a place of business at 901, 8th floor, Tower B, No.6 Garden, Futongdongdajie, Chaoyang District, Beijing China (北京市朝阳区阜通东大 街 6 号院 2 号楼 8 层 901) (the "Assignor"), desires to assign the entire right, title and interest in and to the Inventions and Assigned Patents (each, as defined below) to 国邦协同科技（广东）有限公司（ICE Cobotics (Guangdong) Company Limited）, having a place of business at Lushan Road, Liaobu, Dongguan City, Guangdong, China (the "Assignee"), and Assignee desires to acquire such right, title and interest, all on the terms and conditions set forth in this Patent Assignment.

NOW, THEREFORE, in consideration of good and valuable consideration acknowledged by said Assignor to have been received in full from said Assignee:

1. Said Assignor has obtained the entire right, title and interest in and to certain new and useful inventions and improvements disclosed in the appended three disclosures and full or partial translations thereof (the "Appendix") from which a PCT application titled "SYSTEMS AND METHODS FOR ROBOTIC NAVIGATION, TEACHING AND MAPPING" with a PCT patent application number PCT/CN2022/106182 was filed on July 18, 2022 in the Chinese Patent Office as Receiving Office of the Patent Cooperation Treaty (the "Listed Patent(s)"). As used herein: "Assigned Patents" means (a) the Listed Patent(s), (b) all Patents that share priority with or claim priority to or from the Listed Patent(s), including each and every Patent that is a divisional, substitution, continuation, continuation-in-part, non-provisional, or national phase application of any of the Listed Patent(s), (c) all Patents applied for on an invention disclosed within the Patents included in foregoing subclauses (a)-(b), (d) each and every Patent granting, issuing or reissuing from any of the foregoing under subclauses (a)-(c), (e) each and every reissue, reexamination, renewal or extension of any kind of any of the foregoing under subclauses (a)-(d), and (f) each and every Patent filed outside the United States and corresponding to any of the foregoing under subclauses (a)-(e). "Patents" means (i) patents, certifications of inventions, inventor's certificates and other forms of protection granted on any invention in the United States, foreign countries, or under any international convention, agreement, protocol, or treaty, including those filed under the Paris Convention for the Protection of Industrial Property, The Patent Cooperation Treaty or otherwise, and (ii) applications therefor (whether provisional, converted provisional, utility, design, plant, utility model, non-provisional or otherwise).

2. Said Assignor does hereby sell, assign, transfer and convey unto said Assignee the entire right, title and interest (a) in and to the Assigned Patents, including the right to claim priority to and from said Assigned Patents; (b) in and to the inventions disclosed in the Assigned Patents, and in and to all embodiments of the inventions (the "Inventions") and (c) in and to all claims for past, present and future infringement of the Assigned Patents, including all rights to sue for and to receive and recover for Assignee's own use all past, present, and future lost profits, royalties, and damages of whatever nature recoverable from an infringement of the Assigned Patents.

3. Said Assignor hereby covenants and agrees to cooperate with said Assignee to enable said Assignee to enjoy to the fullest extent the right, title and interest herein conveyed in the United States, foreign countries, or under any international convention, agreement, protocol, or treaty. Such cooperation by said Assignor shall include prompt production of pertinent facts and documents, giving of testimony, execution of petitions, oaths, specifications, declarations or other papers, and other assistance all to the extent deemed necessary or desirable by said Assignee (a) for perfecting in said Assignee the right, title and interest herein conveyed; (b) for filing, prosecuting or maintaining any of the Assigned Patents; (c) for filing, prosecuting or maintaining applications for reissuance of any said Assigned Patents; (d) for interference or other priority proceedings involving said Assigned Patents or Inventions; and (e) for legal proceedings involving said Inventions or Assigned Patents, including without limitation reissues and reexaminations, IPRs, opposition and other post-grant proceedings, cancellation proceedings, priority contests, public use proceedings, infringement actions and court actions; provided, however, that reasonable expenses incurred by said Assignor in providing such cooperation shall be paid for by said Assignee.

4. The terms and covenants of this assignment shall inure to the benefit of said Assignee, its successors, and assigns, and shall be binding upon said Assignor and its assigns.

5. Said Assignor hereby warrants, represents and covenants that Assignor has not entered and will not enter into any assignment, contract, or understanding in conflict herewith.

6. Said Assignor hereby requests that any Assigned Patents issuing or granting in the United States, foreign countries, or under any international convention, agreement, protocol, or treaty, be issued or granted in the name of the Assignee, or its successors and assigns, for the sole use of said Assignee, its successors and assigns.

7. This instrument will be interpreted and construed in accordance with the laws of the People's Republic of China, without regard to conflict of law principles. If any provision of this instrument is found to be illegal or unenforceable, the other provisions shall remain effective and enforceable to the greatest extent permitted by law. This instrument may be executed in counterparts, each of which is deemed an original, but all of which together constitute one and the same agreement.

CORPORATE TO CORPORATE PATENT ASSIGNMENT	Docket Number 54626-713.601
IN WITNESS WHEREOF, said Assignor has executed and delivered this instrument to said Assignee as of the date written below:	
AGREED TO BY ASSIGNOR: Date: 2022.9.20 Signature/Seal: ____ Name: 于飞 (Yufei) Title: Legal Representative	
RECEIVED AND AGREED TO BY ASSIGNEE: Date: 30 October 2022 Signature: ____ Name: 陈乃邦 (Chen, Simon Nai Pong) Title: Legal Representative	

Appendix

清洁机器人的区域覆盖规划方法

1. 介绍相关技术背景（技术背景），并描述已有的与本发明最近似的实现方案（现有技术）。

随着近年来人工智能的快速发展，机器人在人类生活中发挥着越来越重要的作用。清洁机器人，能够凭借一定的人工智能，自动完成对地面、窗户等清理工作。

清洁机器人的核心功能体现在区域覆盖规划方面，早期的清洁机器人在执行区域覆盖规划时规划的比较简单，由旋转和走直线两个动作组成：当清洁机器人遇到障碍物后就旋转一定的角度，继续走直线，直到超出规定的时间。这种区域覆盖方式效率低，遗漏面积大，在早期的清洁机器人中比较常见。

随着惯性导航技术的应用，移动机器人具备了定位功能，区域覆盖规划有了新的方向，可以规划出避开已知障碍物的路径。机器人对环境感知后建图，用户可以通过人机交互界面对建立的地图划定待清扫或者清洗区域的一个或多个边界，清洁机器人根据用户划分的边界，在每个边界约束的区域内进行完全自主规划全覆盖规划，机器人根据规划路径，完成清扫结果。

但是由于待清扫或者清洗区域的环境不可确定性，在结构化场景较为复杂的情况下，机器人很难完全自主完成全覆盖式清扫。因此，此方案一般应用与结构化较为简单场景（开阔大堂，广场等），其环境适应能力太差，应用场景有限。

2. 现有技术的缺点是什么？针对这些缺点，说明本发明的目的。

现有技术中，用户可以通过人机交互界面对建立的地图划定待清扫或者清洗区域的一个或多个边界，清洁机器人根据用户划分的边界，在边界约束的区域内进行完全自主规划全覆盖规划，机器人根据规划路径，完成清扫结果。

但是由于待清扫或者清洗区域的环境不可确定性，在结构化场景较为复杂的情况下，由于缺少人的主观意识介入，从而只能依靠机器人自身传感器对环境的感知完成区域全覆盖，而传感器

对复杂环境的感知存在局限性，从而导致机器人只能完成简单区域的清洁工作。比如，目标清扫环境包含复杂障碍物区域，如果此区域在清扫边界内，则机器人无法判别正常可清扫区域及复杂障碍物区域边界从而导致清扫失败。此方法环境适应能力较弱。

本发明的目的，为了解决在用户划分的边界内实现区域全覆盖方案中环境适应性问题。与现有技术相比，本发明提供的区域覆盖规划方法在环境适应能力，工作效率和稳定性上得到了提升。

3. 本发明技术方案的详细阐述，可以结合流程图、原理框图、电路图、时序图、表格等进行说明。

本发明结合人工示教方法（也可以称为教学（训练）方法）和人工划定区域边界的方法，来确定清洁机器人待清扫的区域。之后对待清扫的区域进行智能分区，机器人根据每个子区域的具体情况，规划采用何种清扫模式，例如，进行弓形清扫模式或者回型清扫模式。

以商用清洁机器人为例对本发明方法流程进行详述：

（1）地图及教学（训练）轨迹获取

人工手动推动商用清洁机器人在目标区域内进行清扫遍历，机器人在行进过程中，通过多种传感器感知环境信息，传感器包括：红外传感器，超声波传感器，碰撞传感器，里程计、视觉传感器（摄像头）、激光雷达，TOF 等等，其中，激光雷达和视觉传感器（摄像头）的检测范围相对较大，机器人在建图时一般主要参照这两种传感器的数据。对于安全需求较高的机器人，可以在机器人不同部位安装上述多种多个传感器，确保传感器的检测范围可以覆盖机身，将各个传感器数据纵向映射到 2D 平面填充到栅格地图中。图 1 为人工示教后，得到的目标区域的栅格地图。该地图中，包括：障碍物区域（机器人不可通行的区域）和可通行区域（机器人可以通行的区域），其中，栅格地图，把环境划分成一系列栅格，每一栅格给定一个可能值，表示该栅格被占据的概率。通常使用[0, 255]区间范围内的数值或者其他数值来定义栅格的属性，例如，障碍物区域的栅格值可以标记为 254，可通行区域的栅格值可以标记为 0。

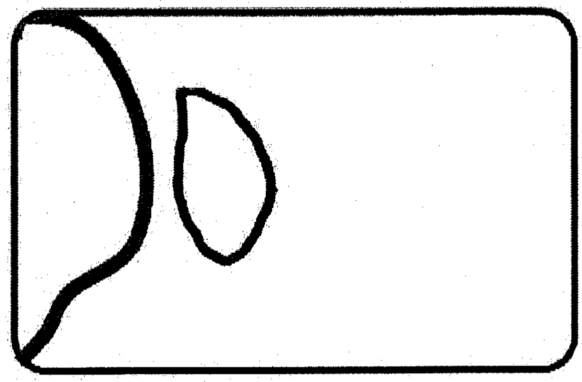


图 1

图 2 显示了完成遍历清扫的人工示教轨迹，从图 2 中可以看到人工示教轨迹完全完全避开了复杂障碍物区域。建立一张表 list1，在人工示教过程中，将人工示教轨迹对应的每一个栅格坐标按照遍历顺序，记录到该表中，之后将该表与上述栅格地图进行绑定。

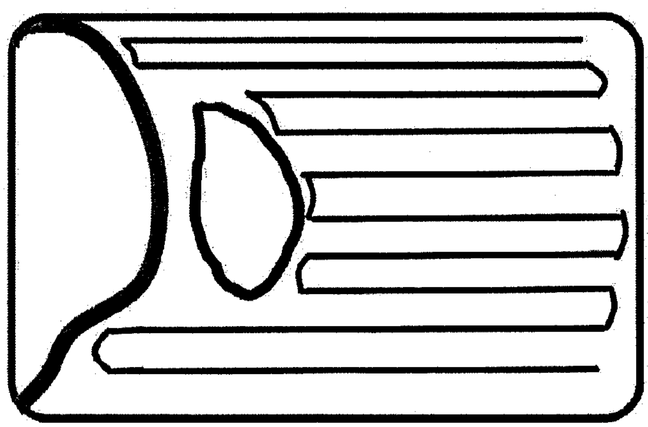


图 2

作为另一种替代方式，图 2 中的路径轨迹，除了可以是人工示教轨迹，也可以是人工示教之后，机器人跟踪人工示教轨迹行进，在自主工作过程中产生的路径。

（2）最大覆盖区域的获取

基于栅格地图及 list1，将人工示教轨迹或者机器人跟踪人工示教轨迹行进，在自主工作过程中的路径轨迹进行膨胀，比如，每条路径膨胀预定数量的栅格，膨胀后得到待清扫区域（图 3）。从图 3 中可以看出此区域完全覆盖了人工示教的清扫区域且排除了机器人无法完全自主可完成的复杂障碍物区域。可以认为此区域为机器人可完成清扫的最大覆盖区域，将最大覆盖区域的数据导入到新建的 map1 中，最大覆盖区域是可通行空域，栅格值为 0。

需要说明的是，本文中的人工示教方式，除了用户推动商用清洁机器人在目标区域内进行清扫遍历的方式之外，还可以采用其他的方式，例如，用户遥控商用清洁机器人在目标区域内进行清扫遍历，或者在机器人的工作场景中放置具有指向性的特殊标识，或者为机器人设定特定的物理特征，机器人循着这些标识或者特征进行清扫遍历等等。

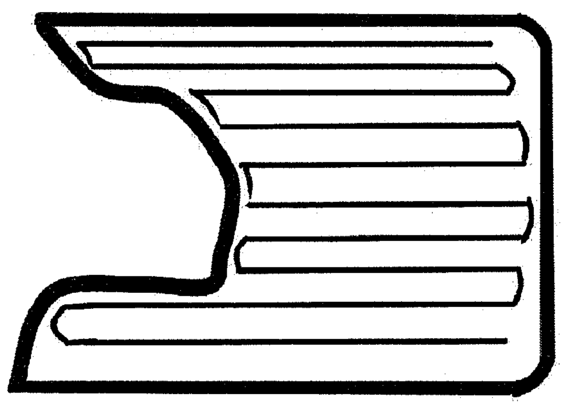


图 3

（3）人工指定清扫区域的边界

在区域清扫模式下，人工手动推动商用清洁机器人在目标区域内划定清扫边界，记录划定的边界点。

如图 4 中的虚线部分，为人工推动机器人行走划定区域边界，划出了一块指定清扫区域，将这块区域的边界点坐标记录到表 list2 中。并将边界以及该边界围成的区域导入新建的 map2 中，在 map2 中导入的数据的栅格值设置为 1。

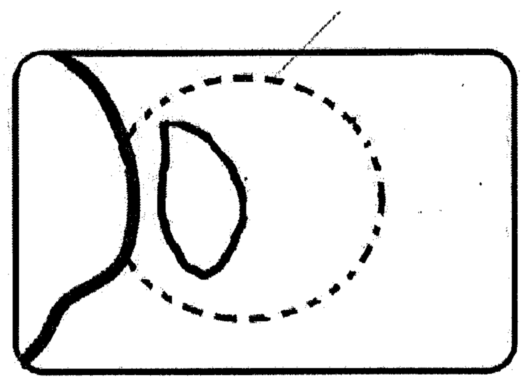


图 4

（4）新建地图导入数据，得到最终的待清扫区域

新建地图 map3，将 map1 中栅格值为 0 的最大覆盖区域数据导入 map3，之后遍历 map2，将 map2 中的数据导入 map3 中栅格值为 0 的区域，注意，在导入 map2 的数据时，如果对应的是 map3 中栅格值不为 0 的区域，则当前数据不再导入。在每次导入一个数据后，将 map3 中栅格值为 0 的栅格更改为 1。

在完成数据导入后，map3 中栅格值为 1 的区域，为最终的待清扫区域。如图 5 中的阴影区域。

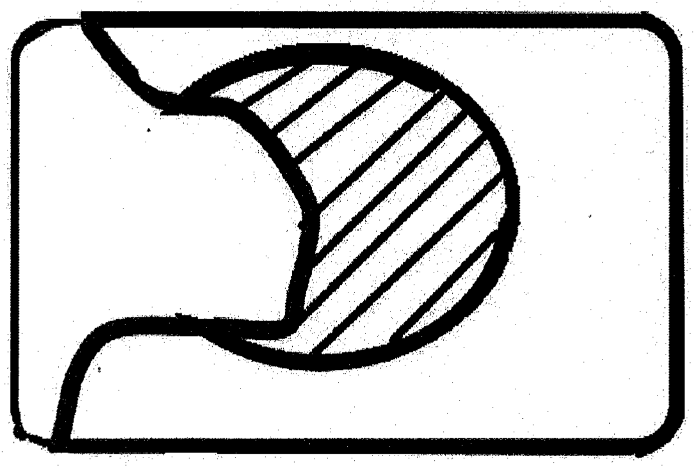
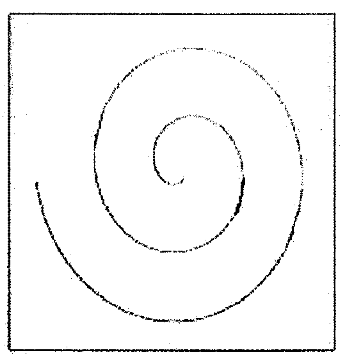


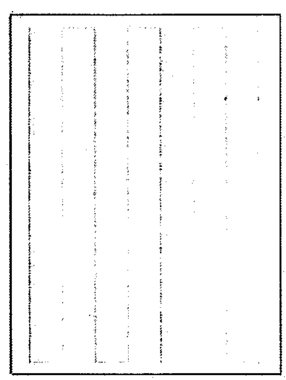
图 5

（5）路径规划，执行清扫任务

对于上述栅格值为 1 的待清扫区域，可以根据实际情况，对于简单的区域轮廓，可以执行全局路径规划操作，选择回形全局覆盖的遍历方式或者选择弓形全局覆盖的遍历方式，参见图 6。



回形



弓形

图 6

如果上述栅格值为 1 的待清扫区域，是复杂的区域轮廓，为了实现清扫的目的，需要将复杂轮廓转变为简单轮廓，对此区域进行分区和排序从而实现有序遍历清扫。

对于分区，都可以使用弓形路径遍历，也可以都采用回型路径遍历。当然，也可以根据实际情况，自适应选取回形或者弓形的遍历方式，例如，可以部分分区采用弓形路径遍历，部分分区采用回型路径遍历方式。

如果是同一个机器人执行清扫任务，可以按照顺序，逐块分区清扫；如果是多个机器人，也可以互相协作，每个机器人分别在一个分区内独立清扫，清扫工作可以并行实施，进一步提高清扫效率。

扩展实施方案：

作为对上述实施方式的一个扩展，可以增加另一种实施方式：由人工推动机器人分别划定多个边界（两个或者两个以上的边界），之后将多个边界与上述最大覆盖区域进行整合，得到最终的待清扫区域。

下面以人工划定两个边界为例进行说明。如图 7 中的虚线部分，为人工推动机器人行走划定区域边界 a 和边界 b，划出了两块指定清扫区域，分别将这两块区域的边界点坐标记录到两个表 list_a 和 list_b 中。并将边界 a 以及该边界围成的区域导入新建的 map_a 中，在 map_a 中导入的数据的栅格值设置为 1，并将边界 b 以及该边界围成的区域导入新建的 map_b 中，在 map_b 中导入的数据的栅格值设置为 1。

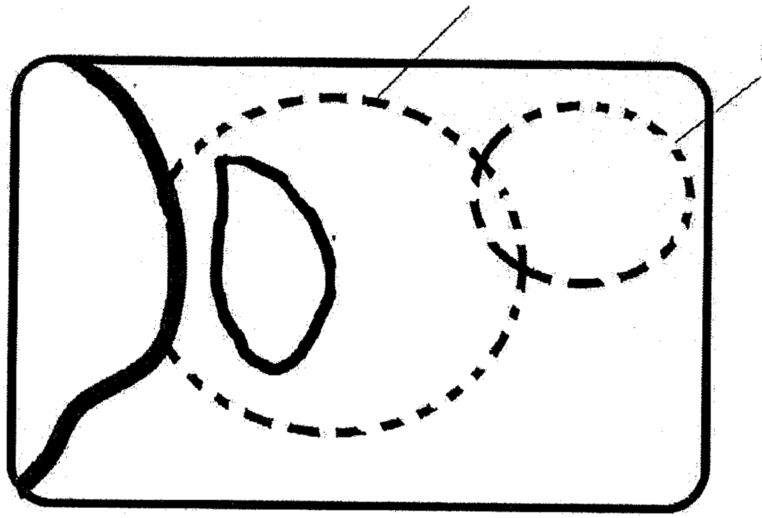


图 7

新建地图 map4，将 map1 中栅格值为 0 的最大覆盖区域数据导入 map4，之后遍历 map_a，将 map_a 中的数据导入 map4 中栅格值为 0 的区域，注意，在导入 map_a 的数据时，如果对应的是 map4 中栅格值不为 0 的区域，则当前数据不再导入。在每次导入一个数据后，将 map4 中栅格值为 0 的栅格更改为 1。

之后，继续将 map_b 中的数据导入 map4 中，遍历 map_b 中的数据，将 map_b 中的数据导入 map4 中栅格值为 0 的区域，如果对应的是 map4 中栅格值不为 0 的区域，则当前数据不再导入。在每次导入一个数据后，将 map4 中栅格值为 0 的栅格更改为 1。

在完成数据导入后，map4 中栅格值为 1 的区域，为最终的待清扫区域。如图 8 中的阴影区域。从图 8 中可以看出，由于将多个边界与最大覆盖区域进行了整合，之后再对整合后的区域进行清扫，多个边界围成的区域中的交集部分，不会被机器人重复清扫，因此进一步提高了机器人的清扫效率。

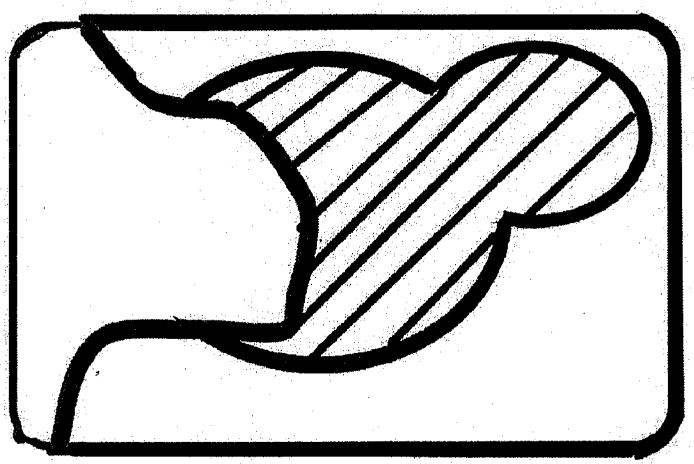


图 8

上述栅格值为 1 的区域，具有复杂轮廓，为了实现清扫的目的，需要将复杂轮廓转变为简单轮廓，对此区域进行分区和排序从而实现有序遍历清扫。

智能分区的算法比较多，可以采用现有技术 boustrophedon cellular decomposition 算法对上述最终的待清扫区域进行自动分区，将复杂的区域划分为多个简单轮廓的分区，便于实现机器人的清扫，能够适应各种复杂的场景，并提高机器人的清扫效率和稳定性。如图 9 所示，将最终的区域智能划分为三个分区 1, 2, 3。

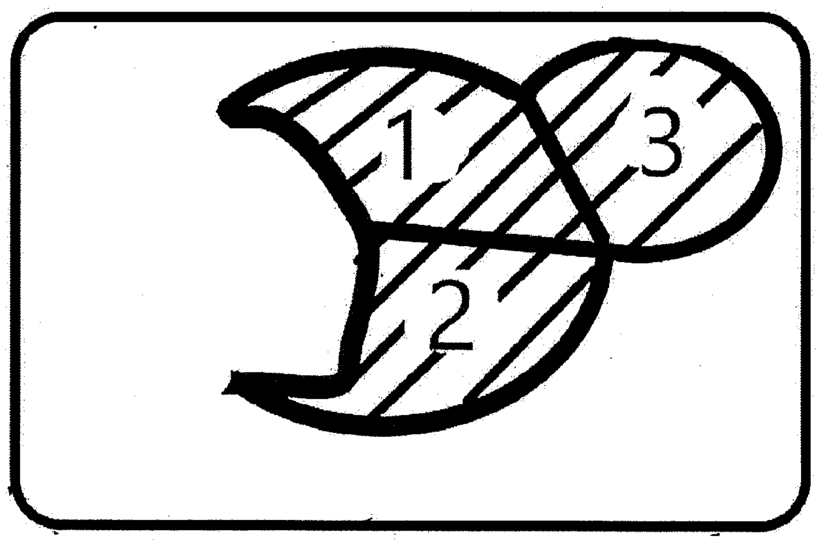


图 9

对于上述 3 块分区，都可以使用弓形路径遍历，也可以都采用回型路径遍历。当然，也可以根据实际情况，选取合适的遍历方式，部分分区采用弓形路径遍历，部分分区采用回型路径遍历方式。

如果是同一个机器人执行清扫任务，可以按照顺序，逐块分区清扫；如果是多个机器人，也可以互相协作，每个机器人分别在一个分区内独立清扫，清扫工作可以并行实施，进一步提高清扫效率。

4. 本发明的关键点和欲保护点是什么？以及本发明所带来的技术效果。

现有技术中基于边界全覆盖方法具有较大环境适应差等问题。

本发明结合人工示教方法和人工划定区域边界的方法，来确定清洁机器人待清扫的区域。之后可以采用全局回形或者弓形的覆盖方式规划路径，也可以对待清扫的区域进行智能分区，机器人根据每个子区域的具体情况，规划采用何种清扫模式。由于将复杂轮廓区域转变为简单轮廓区域，可以解决现有技术中基于边界全覆盖方法具有较大环境适应差等问题，从而可以保证清洁机器人稳定、高效地实现复杂环境区域的清洁工作。

Coverage planning method for cleaning robots

Problems in prior arts

In prior arts, the user can define one or more boundaries of the area to be cleaned on a map via a human-computer interaction interface. The cleaning robot performs an autonomous path planning in the area constrained by the boundary, and completes the cleaning task according to the planned path. However, the robot may fail to distinguish the area to be cleaned and complex obstacle boundary due to limited detection capability of sensors.

Embodiment

The invention combines (i) manual teaching and (ii) manual boundary delineation to determine the area to be cleaned. Then, the robot traverses the determined area by either spiral mode or zigzag mode or a combination thereof.

The method of the invention comprise the following steps (1)-(5).

(1) Manually teaching a trajectory

The user manually pushes the robot to traverse a target area and teaches a trajectory. The sensers onboard the robot (infrared sensor, ultrasonic sensor, collision sensor, odometer, visual sensor (camera), laser Radar, TOF, etc) senses the environment during the teaching. The sensor data is projected to a 2D grid map. Fig. 1 shows a grid map obtained after manual teaching. The grid map includes obstacle areas (areas that robots cannot pass through) and transitable areas (areas that robots can pass through). Each grid in the grid map is assigned with a value (e.g., 0-255), which value indicates the probability that the grid is occupied. For example, the grid value in the obstacle area can be set as 254, and the grid value in the transitable area can be marked as 0.

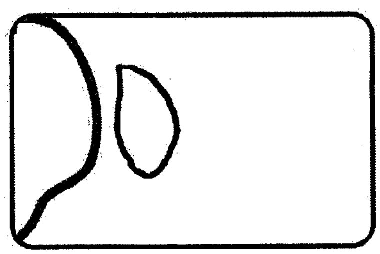


Fig. 1

Fig. 2 shows the taught trajectory, which avoids the complex obstacle area. A table list1 is established. During the manual teaching process, coordinates of each grid on the taught trajectory is recorded in the table in the traversal order, and then the table is bound to the grid map.

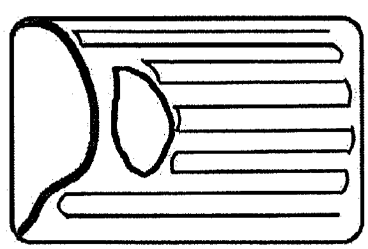


Fig. 2

(2) Obtaining the maximum coverage area

The taught trajectory is expanded based on the grid map and the table list1. For example, each path is expanded by a predetermined number of grids to obtain the area to be cleaned, as shown in Fig. 3. As can be seen from Fig. 3, the expanded area completely covers the taught trajectory but excludes the complex obstacle area. Therefore the obtained area is the maximum coverage area that the robot can clean. The data of the maximum coverage area is imported into a newly created map1, in which the grid values are 0.

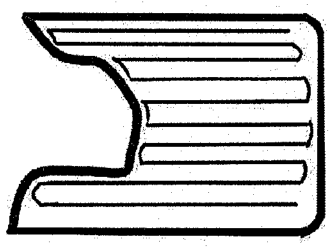


Fig. 3

(3) Manually delineating the boundary of area to be cleaned

The user manually pushes the robot to specify/delineate a cleaning boundary in the target area. The delaminated boundary points are recorded.

As shown in Fig. 4, the dotted line is the boundary of area to be cleaned. The coordinates of the boundary point are recorded in a table list2. The boundary and the area enclosed by the boundary are imported into a newly created map2. The grid value of the imported data in map2 is set to 1.

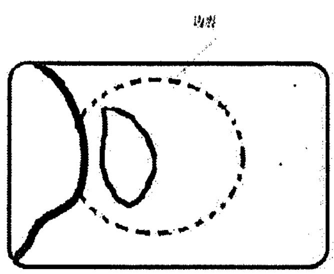


Fig. 4

(4) Obtaining the area to be cleaned

A new map3 is created. The map1 obtained in step (2) (maximum coverage area, in which the grid value is 0) and the map2 obtained in step (3) (area enclosed by the boundary, in which the grid value is 1) are imported into map3. As a result, the area in map3 where the grid value being 1 is the area to be cleaned, as shown by shaded area in Fig. 5.

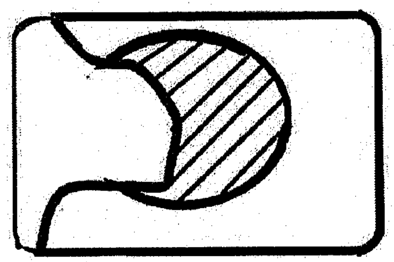


Fig. 5

(5) Planning a path and performing a cleaning task

For the area to be cleaned having a grid value 1, a general path can be planned if the area has a simple contour. The general path can be either a spiral path or a zigzag path, as shown in Fig. 6

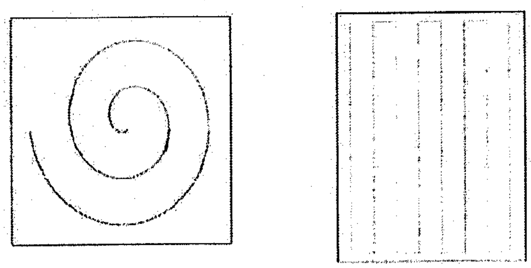


Fig. 6 spiral path zigzag path

If the area to be clean has a complex contour, it is necessary to convert the complex contour into a simple contour by partitioning the area into sub-areas and sorting the sub-areas for a more efficient cleaning. In each sub-area, either a spiral path, a zigzag path or a combination thereof can be used. For various sub-areas, a fleet of robots can be used.

Further embodiment

In a further embodiment, the user can manually push the robot to specify/delineate two or more cleaning boundaries in the target area. As shown by the dotted line in Fig. 7, a boundary a and a boundary b are delineated by manually pushing the robot. The coordinates of the boundary a are recorded in a table list_a.

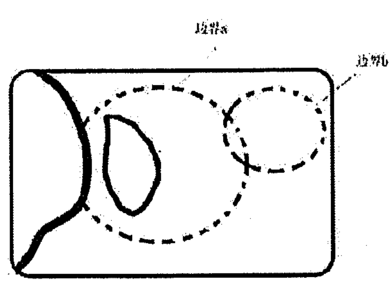


Fig. 7

In step (3), the coordinates of the boundary b are recorded in a table list_b. The boundaries and the areas enclosed by the boundaries are imported into a newly created map_a. The grid value of the imported data in map_a is set to 1. In step (4), a new map4 is created. The map1 obtained in step (2) (maximum coverage area, in which the grid value is 0) and the map_a obtained in step (3) (areas enclosed by the boundaries, in which the grid value is 1) are imported into map4. As a result, the area in map4 where the grid value being 1 is the final area to be cleaned, as shown by shaded area in Fig. 8.

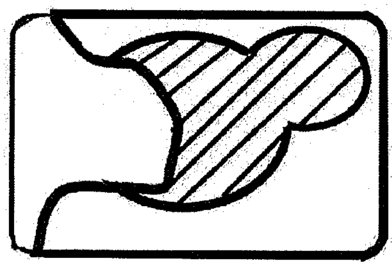


Fig. 8

The existing "boustrophedon cellular decomposition algorithm" can be used to automatically partition the final area to be cleaned. As shown in Fig. 9, the complex area is divided into multiple partitions with simple contours.

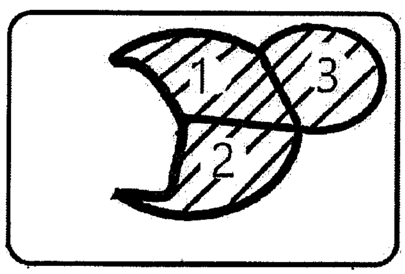


Fig. 9

Key Features

The invention combines (i) a manual teaching and (ii) manual boundary delineation to determine the real area to be cleaned. Then, the robot traverses the determined area by either spiral mode or zigzag mode or a combination thereof.

文档说明：

本文档对 ICE 商用清扫机器人项目 ToF 传感器提升精度的设计文档，用于方案确认。

ToF 传感器精度提升方案

一、背景

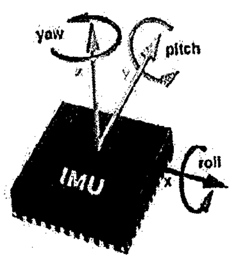
目前机器人避障采用 ToF 传感器进行低矮障碍物识别及避障，因为结构安装精度达不到设计预期，导致 TOF 识别精度降低，因此导致机器人避障效果无法满足市场预期需求。

二、优化方案

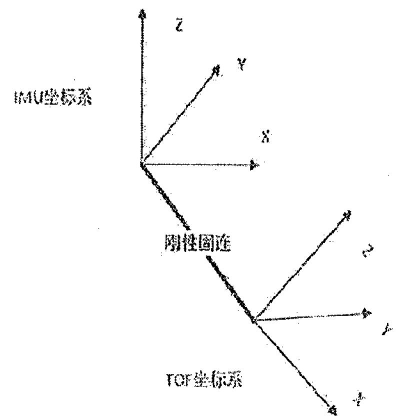
ToF + IMU 融合方法补偿安装误差，并定期进行自标定补偿损耗误差，同时基于姿态检测算法升级进一步提升避障精度。

三、硬件端升级

实现方法：在 ToF 模块中增加 IMU，实现 ToF 模块和 IMU 的短基线杆臂刚性连接，理论简化模型为刚体连接，可以实现 IMU 对 ToF 运动及振动特性的完整感知和检测。



IMU（Inertial Measurement Unit）



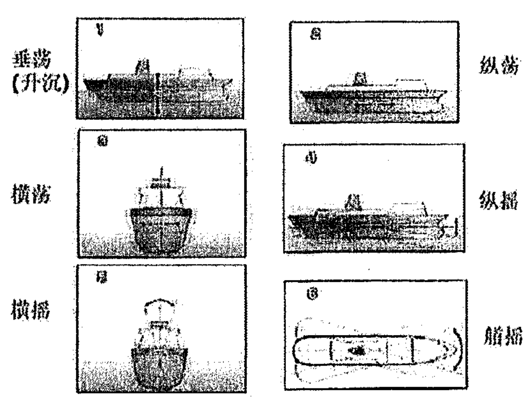
ToF 与 IMU 短基线刚性固连

四、算法端升级

1）在 ToF 模组增加 IMU 后，IMU 可以实现 TOF 在 3D 空间中的动态检测，检测频率最高可到 500Hz（IMU 频率 1000Hz），即实现机器人本体动态动态检测，同时 IMU 通过加速度计的感知可以实现实时姿态信息感知和检测。

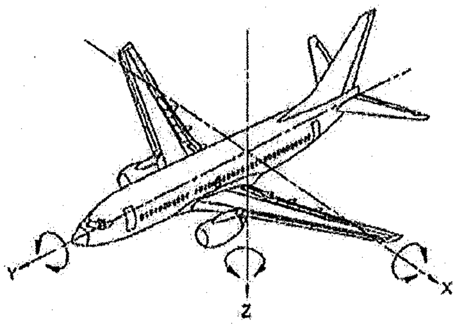
2）基于 IMU 动态信息，首先对 TOF 信息进行距离域和频率域的补偿，距离域指动态幅

度补偿，频率域指因车体振动动态导致 TOF 传输多普勒效应引起噪声，并在频域进行偿处理；



惯性技术对于升沉等运动的检测及补偿

3）IMU 姿态信息感知和检测是指 IMU 包含 3 轴加速度计和 3 轴陀螺仪，可以通过算法动态检测 TOF 姿态，实现更为高精度的 TOF 信息投影

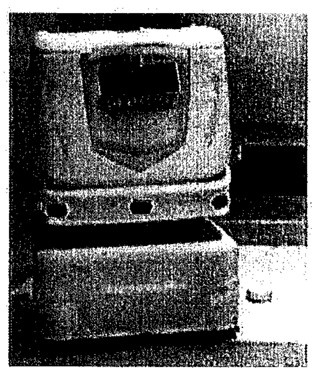


基于 IMU 的姿态检测

4）结合 3 年机器人结构姿态变化进行误差评估，算法可以覆盖并满足 3 年姿态变化影响

5）因机器人姿态变化过大仍然会导致障碍物检测误差增大，因此不建议进一步降低机器人安装精度误差

6）综上，采用 TOF+IMU 融合方法，可以降低 TOF 噪声，并提升投影精度，进而提高 TOF 避障精度和效果，以满足机器人使用全生命周期的低矮障碍物避障需求



基于外固定 IMU 的低矮障碍物检测算法验证测试
（详情可查阅相关视频：ToF&IMU 方案测试实况）

五、测试结论

在考虑到安装精度，磨损与变形清下， ICE 保证 3D ToF 与地面的夹角，横滚角，航向角，双目摄像头的横滚角，航向角的角度公差都会控制在±1° 情况下，我们经测试及模拟

仿真等方式，确认该方案目前可以满足 3 年总体检测精度:6*6*6 cm 检测率≥99%; 4*4*4 cm，检测率≥80%。

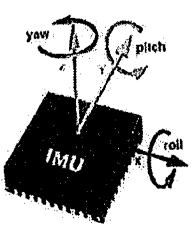
System of Increasing a ToF Sensor Accuracy

1. Background

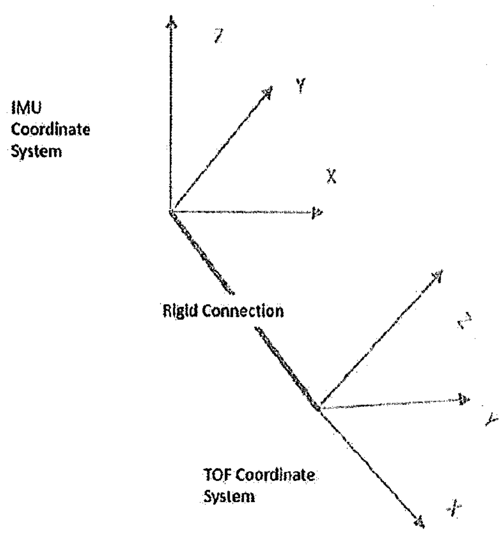
In prior arts, ToF sensor is used to detect a low attitude obstacle in obstacle recognition and avoidance. However, an accuracy in ToF recognition is low due to a low installation accuracy of ToF on robot.

2. Improvement in Hardware

In the invention, a ToF sensor and a IMU sensor are coupled with rigid connection. A self-calibration is regularly performed to compensate for a loss error. The IMU can sense and detect the motion and vibration characteristics of the ToF.



IMU（Inertial Measurement Unit）



IMU is coupled to ToF via Rigid Connection

3. Improvement in Algorithm

(1) Once the IMU is coupled to the ToF module, the IMU can implement a dynamic detection of the TOF in 3D space. A frequency of detection can be up to 500Hz (IMU frequency 1000Hz), that is, a dynamic detection of the robot body can be realized. Meanwhile, a real-time attitude can be detected by IMU.

(2) Based on the dynamic information from the IMU, the TOF information is compensated in a distance domain and a frequency domain. The distance domain refers to the dynamic amplitude. The frequency domain refers to the noise caused by the TOF transmission Doppler effect due to the vibration of the vehicle body.

(3) IMU contains a 3-axis accelerometer and a 3-axis gyroscope. IMU attitude information detection refers to dynamically detecting the attitude of ToF by an algorithm to achieve a TOF information projection with higher accuracy.

4. Test Results

If a tolerance of the angle between the 3D ToF and the ground, the roll angle of ToF, the yaw angle of ToF, the roll angle of binocular camera and the yaw angle of binocular camera being controlled within ±1°, our test shows that the ToF + IMU scheme meets the overall detection accuracy over 3 years is 6*6*6 cm with detection rate ≥99%, and 4*4*4 cm with detection rate ≥80%.

一种基于双目视觉的自适应环境亮度调整 marker 识别方法

1. 介绍相关技术背景（技术背景），并描述已有的与本发明最近似的实现方案（现有技术）。

随着人工智能的发展，清洁机器人（比如，扫地机、洗地机等）必然会成为一个大的发展趋势。智能清洁机器人是被构造成不需要用户控制，在任意区域行进的同时，执行清洁任务的设备，通常用于将地面上的污渍进行清理。

在清洁机器人工作的初始化阶段，需要获知机器人的起始位置，该位置信息通常由视觉标记板（也可以称为 Marker）得出。Marker 是唯一标识号，并且能够确定机器人与标记物之间的相对位姿（位置与姿态角）。常见的 Marker 有 ArUco，Charuco ，ARtag，CALTAG，CALTAG，Apriltag 等。基于 Marker 定位世界系源点的技术因成本低廉，定位快速，使用简单越来越受青睐。基于 Marker 的技术一般使用相机检测标记板并解算相机与标记板之间的位姿（位置与方位角），实现机器人的初始化定位过程。

现有技术中，通常基于单个相机（单目）识别 Marker 标记板进行机器人的位姿解算，该方法的缺点，基于单目的方案，解算得到的位姿精度较低，并且当单个相机被遮挡则无法观测到 Marker 标记版，进而无法定位机器人相对于 Marker 的位姿，导致机器人后续的任务无法继续进行。

此外，基于相机的方案还存在不利的一面，容易受外界环境的影响，例如，在弱光或者黑暗的环境下，相机很难或者识别不到 Marker，同样在非常强烈的太阳光下也存在类似的问题。

2. 现有技术的缺点是什么？针对这些缺点，说明本发明的目的。

基于单目 Marker 标记板位姿（位置和方位角）的解算，该方法的缺点是解算得到的位姿精度较低，且当相机被遮挡则无法观测到 Marker 标记板，进而无法定位机器人在平面 Marker 中的位姿，导致机器人后续的任务无法继续进行。

此外，当在黑暗、弱光的环境，Marker 识别率大幅降低甚至不能识别到 Marker， 二是当在强光反射的环境中 Marker 识别率大幅降低甚至不能识别到 Marker，这样就限制了机器人的使用环境，降低了工作效率。

因此需要提出一种新的方案，提高 Marker 识别率以及位姿解算精度。

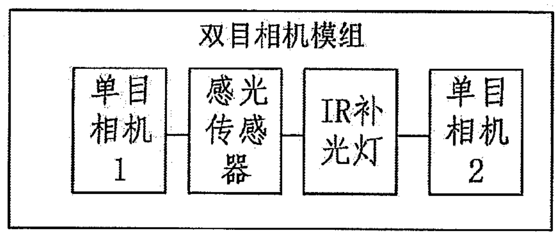
3. 本发明技术方案的详细阐述，可以结合流程图、原理框图、电路图、时序图、表格等进行说

明。

本专利使用双目相机检测单个标记板（以 apriltag 为例）的方案，方案包括模组结构设计、标记板的识别与位姿解算：

Ⅰ．模组结构设计

为了尽可能的提高识别率，双目相机模组使用下图所示的设计，该模组包含两个单目相机，一个补光灯，一个感光传感器。



* 两个单目相机左右水平分开构成双目相机，用来检测识别 Marker 标记板

*IR 补光灯，在弱光或者黑暗环境中使用

* 感光传感器的作用是用来检测光照度，作为外部环境否在光照不足（弱光，黑暗）或者强光下的一种辅助判断。例如根据感光传感器判断环境光照不足，此时可打开补光灯，增加相机的识别平面标记板的能力。

II. 检测识别策略

本专利以 apriltag 的 Marker 标记板为例（但不限于此，如也可以使用 ARTag, ARToolkit, aruco），使用 apriltag 库检测 apriltag 标记板。在扫码的过程中，由于自然场景导致的相机过爆或者光照不足导致的相机看不到标记板，或者解算精度过低导致机器人无法定位，从而无法继续后续的工作，针对上述问题，提出了以下的解决方法：

* 使用双目相机检测 Marker 标记板，如检测不到 Marker 标记板或者只有一个相机检测到 Marker 标记板，可通过感光传感器检测光线过爆或光线不足情况。

*在确定过曝时，通过调节相机的曝光时间/增益， 然后上报给扫码应用，继续使用双目相机检测 Marker 标记板。

* 在感光传感器检测确定光照不足时，然后上报给扫码应用，扫码应用接收到光照不足的指令时，开启补光灯调节补光亮度，然后尝试扫码，如果此时双目相机在补光策略的依次调整（例如，模组补光灯亮度值范围为[0, 100]，在这个范围中抽取多个亮度档，0, 10, 20, 30，...90, 100, 可以从最高档开始，依次下调亮度值的档位，也可以从最低档开始，依次上调亮度值的档位）的情况下，每次调整亮度值之后，就尝试扫码，依次调整亮度值档位，直至扫码成功（即双目都识别到 Marker 标记板），如果调整所有档位之后，还是无法成功，则也有可能因为双目相机的一目（左目或者右目）在补光调整策略下一直处于过爆的情况（由于开启了补光灯导致的过爆），可以接着调整增益（或者曝光时间）进一步尝试扫码。

* 光照不足或者过爆情况下，通过上述调整之后，如果双目都能检测识别到 Marker 标记板，则需要判断机器人位姿解算精度是否满足条件（具体判断策略参照下文的 III 部分）。

* 如果位姿解算精度不满足条件，则选择 Marker 标记板的感兴趣区域，然后针对感兴趣区域做亮度均衡化处理，继续判断位姿解算精度是否满足条件，循环执行此步骤，直至位姿解算精度满足条件。

III 判断位姿解算精度是否满足条件的策略方法

相机与标记板之间的位姿解算一般使用 PNP(Perspective-n-Point)算法求解 3D(三维)到 2 D（二维）的透视投影方法。但当相机远离标记板使得投影到相机平面的标记板很小，导致投影模型弱化成类透视投影模型，使得求解的旋转具有二异性（有两个旋转解），另外投影到相机平面的标记板过小时，图像噪声的影响更加明显，同样也增加了旋转的二异性。为了解决该问题我们使用更为鲁邦的 IPPE（Infinitesimal Plane-based Pose Estimation）算法，该算法能够求解两个解，但无法分辨哪个解是正确的。可以利用双目的优势找出正确的那个解，具体的方法为：

* 左右目分别利用 IPPE 方法求解位姿，然后将 IPPE 的位姿解作为初始解利用 LM 优化方法进一步优化，例如，用 T11 = [R11, t11]，T12 = [R12, t12]表示左目的两个优化的位姿，T21 = [R21, t21]，T22 = [R22, t22]表示右目的两个优化位姿。对于旋转角 R 而言，R11 分别对应着 R21 和 R22，R12 也分别对应着 R21 和 R22，则一共可以形成四组关联的组合：{R11，R21}，{R11，R22}，{R12，R21}，{R12，R22}，分别计算每组两个旋转角度的误差，即，R11 和 R21 的误差 1，R11 和 R22 的误差 2，R12 和 R21 的误差 3，R11 和 R22 的误差 4，比较这四个误差，取其中最小的误差，如果四组中{R11，R21}的误差最小，则将 R11 对应的位姿解 T11 确定为左目相对于标记板的正确位姿解，将 R21 对应的位姿解 T21 确定为右目相对于标记板的正确位姿解。

之后根据上面得到的正确解，可以通过以下公式计算得到左右目之间的相对位姿 T：

$T = T21 * (T11)^{-1}$，其中，$(T11)^{-1}$表示 T11 的逆矩阵。

由于双目之间的位姿 T’是已知的，可利用 T 与 T’的误差来判断是否满足位姿解算的精度要求。

当 T 与 T’的误差小于或者等于预设误差阈值时，则满足位姿解算的精度要求，将 T21 和 T11 作为当前帧的位姿解算结果。

4. 本发明的关键点和欲保护点是什么？以及本发明所带来的技术效果。

基于双目检测识别 Marker 标记板的方案，提高 Marker 识别率以及位姿解算精度。

Adaptive Method for Recognizing Visual Marker Board

1. Problems in prior arts

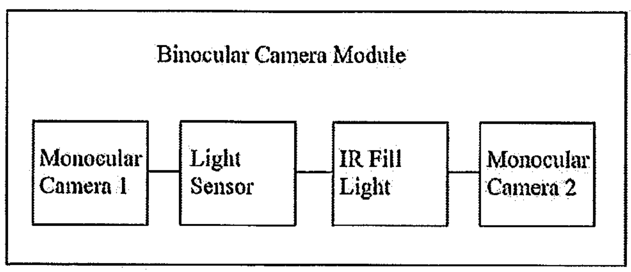
In initializing a cleaning robot, the starting position of the robot is needed. The position information is usually obtained by a recognizing a visual marker board (also called "marker"). A marker is a unique identification number and can be used to determine the relative pose (position and attitude angle) between the robot and the marker. Markers include ArUco, Charuco, ARtag, CALTAG, CALTAG, Apriltag, etc.

In prior arts, a single camera (monocular) is used to solve the pose of the robot. However, an accuracy in monocular solution is low. And the monocular may not be able to detect the marker in a dark or bright environment.

2. Embodiment of Invention

(2.1) Hardware configuration

In order to improve the recognition of the camera, a binocular camera module is used in the invention as shown in the figure below. The binocular camera module includes two monocular cameras, a fill light, and a light sensor.



The two monocular cameras are separated laterally to form a binocular camera, which is used to detect and identify the marker board. The IR fill light is activated in a low illumination or dark environment. The light sensor is used to detect the environmental illuminance. For example, if the sensor data from the light sensor indicates a dark environment, then the fill light can be turned on.

(2.2) Marker detection and identification strategy

The binocular camera is used to detect the marker plate. If the marker plate is not detected or only one camera detects the marker plate, then the light sensor can be activated to detect the environmental illuminance (e.g., under-exposure or over-exposure).

If it is determined as over-exposure, then an exposure time/gain of the camera can be adjusted. The binocular camera is used to detect the marker plate with the adjusted exposure time/gain.

If it is determined as under-exposure, then the fill light is activated. The fill light can provide a illuminance range [0, 100]. In an example, the binocular camera can attempt to detect the marker plate with the fill light providing a lowest illuminance. If the binocular camera fails to recognize the marker plate (e.g., both monocular cameras recognize the marker plate), then the illuminance of the fill light can be increased.

Once both monocular cameras recognize the marker plate, it is necessary to determine whether the accuracy of the robot pose calculation meets the requirements (refer to Section 3 below).

3. Determine whether the accuracy of the robot pose calculation meets requirements

In prior art, PNP (Perspective-n-Point) algorithm is used in the pose calculation between the camera and the marker board to solve the perspective projection from 3D (three-dimensional) to 2D (two-dimensional). However, PNP algorithm does not work well when the camera is far away from the marker board. To solve this problem, IPPE (Infinitesimal Plane-based Pose Estimation) algorithm, which is more robust, is used in the invention

--- details of using IPPE algorithm to solve the pose of binocular camera module with respect to the marker board.

4. Key features of the invention

Use of binocular camera module to solve the pose of binocular camera module with respect to the marker board.