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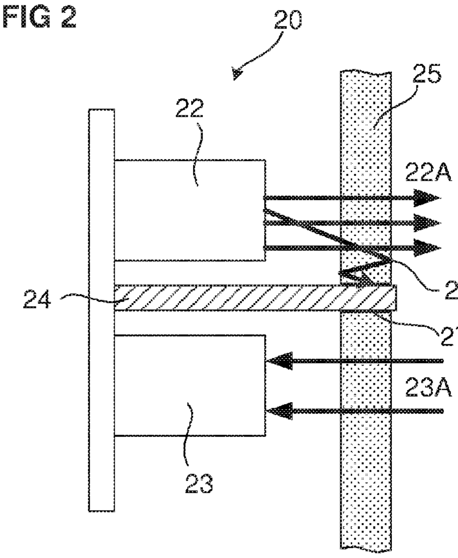
(54) **Title:** A SENSOR HOUSING ON A MOBILE ROBOT

FIG 2



(57) **Abstract:** A mobile robot comprising: a main body comprising at least one sensor housing; and at least one optical sensor enclosed within the sensor housing, the optical sensor comprising an emitter and a receiver; wherein the sensor housing comprises an outer cover that forms part of an outer surface of the mobile robot, the outer cover comprises at least one slot, the slot being formed in the outer cover at a position between the emitter and receiver.

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A Sensor Housing on a Mobile Robot

The present invention relates to mobile robots, and in particular to sensor housings on mobile robots.

Mobile robots are becoming increasingly commonplace and are used in such diverse fields as space exploration, telepresence, home assistance, lawn mowing and floor cleaning. Recently there has been a rapid advancement in the field of domestic robots, the primary objective of which is to navigate a user's home autonomously and unobtrusively carrying out various operations such as vacuuming and cleaning, whilst requiring as little assistance from a human user as possible and preferably none.

In performing such tasks, mobile robots must be able to autonomously navigate and negotiate obstacles within their environment. To do this effectively, mobile robots are typically provided with a number of sensors, and often have a selection of different types of sensors that are optimised for sensing different aspects of the environment around them. For example, some typical sensors are micro-switches which act as physical bump sensors, optical sensors such as position sensitive devices (PSDs) or Time of flight (TOF) sensors, or cameras in vision systems.

Figure 1 shows a cross-section through an example of an optical sensor 1 as known in the prior art. The optical sensor 1 may be, for example a PSD or TOF sensor. The optical sensor 1 comprises an emitter 2 and a receiver 3. The emitter 2 emits light, as represented by the arrows 2A. The light 2A emitted by the emitter 2 may be, for example, infra-red (IR) light, and is directed towards the environment around the sensor. Incident light that has bounced off an obstacle near the sensor is received by the receiver 3, as represented by the arrows 3A. A rib 4 is positioned between the emitter 2 and the receiver 3 and prevents any light emitted from the emitter 2 from passing directly into the receiver 3. Light that is able to pass from the emitter 2 to the receiver 3 without being sent into the environment as intended is known as crosstalk, and causes errors and false readings in the sensor 1 which, among other things, can lead to degradation in the accuracy sensor output. The rib 4 prevents any direct crosstalk.

The optical sensor 1 would typically be housed within a sensor housing on a product, and part of a sensor housing cover 5 is shown. The sensor housing cover 5 is made of a material that allows the light produced at the emitter 2 to pass through it into the environment surrounding the sensor, or alternatively may be provided with a window formed of such a material. A small amount of light, shown by arrow 6, is internally reflected within the material of the sensor cover 5, and is able to pass into the receiver 3. This light is also a form of crosstalk, and can give rise to the same detrimental effects as the direct crosstalk described above.

This invention provides. a mobile robot comprising: a main body comprising at least one sensor housing; and at least one optical sensor enclosed within the sensor housing, the optical sensor comprising an emitter and a receiver; wherein the sensor housing comprises an outer cover that forms part of an outer surface of the mobile robot, the outer cover comprises at least one slot, the slot being formed in the outer cover at a position between the emitter and receiver.

As a result, there is a significant reduction in crosstalk caused by the internal reflection of light within the outer cover of the sensor housing. And as the outer cover of the sensor housing forms part of the outer surface of the mobile robot, there are no further sources of crosstalk.

The slot may extend through the outer cover to define a through-hole. As a result, a physical barrier through the full thickness of the sensor housing is provided, further reducing the risk of crosstalk.

The optical sensor may be a photoelectric sensor, and may be one of a time of flight sensor and a position sensitive detector (PSD).

The outer cover may comprise at least one window formed of IR transparent material. As a result, the whole sensor housing cover does not need to be formed of the IR transparent material.

The at least one optical sensor may be positioned behind the at least one window. As a result, the optical sensor is positioned to emit and receive light through the window such that the risk of crosstalk and other signal noise is reduced.

The at least one slot may be formed in the at least one window.

The outer cover may be formed of an IR (infra-red) transparent material. As a result, the sensors housed within the sensor housing are able to emit and receive IR signals through the outer cover of the sensor housing. Furthermore, if the outer cover is formed of an IR transparent material, it will not be necessary to provide windows in the outer cover that are made of a different material, and as such the cost of the sensor housing can be minimised.

The IR transparent material may be polycarbonate. As a result, the outer cover of the sensor housing is formed of a light yet strong and resilient material which is able to withstand the typical bumps and impacts that would be expected to be experienced by the outer surface of a mobile robot.

A non IR transparent material may be inserted into the slot in the outer cover. As a result, an IR block is provided within the slot to more robustly prevent crosstalk occurring through the sensor housing material.

The non IR transparent material may be over-moulded to the outer cover. This ensures good placement of the non IR transparent material within the slot, and reduces the risk of misalignment of the non IR transparent material with the slot during assembly.

The non IR transparent material may be fixed to the optical sensor. As a result, the non IR transparent material will have accurate positioning with the emitter and receiver of the optical sensor in order to reduce cross talk most effectively.

A width of the slot may be substantially equal to a width of the optical sensor. As a result, crosstalk will be reduced across the full width of the optical sensor.

A plurality of optical sensors may be housed within the at least one sensor housing, and a slot for each optical sensor may be provided in the outer cover.

In order that the present invention may be more readily understood, embodiments of the invention will now be described, by way of example, with reference to the following accompanying drawings, in which:

Figure 1 shows a prior art example of an optical sensor within a sensor housing;

Figure 2 shows a first embodiment of an optical sensor within a sensor housing;

Figure 3 shows a second embodiment of an optical sensor within a sensor housing;

Figure 4 is a mobile robot;

Figure 5 is the mobile robot with a part of the outer cover removed;

Figure 6 shows a partially exploded view of the sensor housing of the mobile robot of Figure 4; and

Figure 7 is a cross section view through the assembled sensor housing of Figure 6.

Figure 2 shows a cross section through an optical sensor 20. The optical sensor 20 comprises an emitter 22 and a receiver 23. The emitter 22 emits electromagnetic radiation in the form of IR light 22A. The IR light 22A leaves the emitter 22 and then passes through a sensor housing cover 25 which is formed of an IR transparent material, allowing the IR light to be emitted into the environment surrounding the sensor. If an obstacle is nearby, the IR light 22A will hit the obstacle and incident light is reflected off the obstacle in the form of reflected light 23A. The reflected IR light 23A passes back through the IR transparent sensor cover 25 and is received by the receiver 23. The sensor housing cover 25 has a slot 27 formed therein, and a rib 24 associated with the optical sensor 20 is received within the slot 27. The rib 24 is formed of a non IR transparent material and, together with the slot 27, it prevents any IR light from being internally reflected through the material of the sensor housing cover 25 and passing directly from the emitter 22 into the receiver 23, and therefore prevents crosstalk between the two. This is crosstalk prevention is shown in Figure 2 where IR light represented by arrow 26 is being internally reflected through the sensor housing cover 25, but which is stopped when it reaches the slot 27 and the rib 24. A slot 27 on its own may go some way to reducing crosstalk. However, the non IR transparent rib 24 ensures that no IR light is able to pass through.

Figure 3 shows an alternative embodiment of an optical sensor 30. As with the optical sensor 20 of Figure 2, the optical sensor 30 of Figure 3 comprises an emitter 32 and a receiver 33. The emitter 32 emits electromagnetic radiation in the form of IR light 32A. The IR light 32A leaves the emitter 32 and passes through a sensor housing cover 35 formed of an IR transparent material, allowing the IR light to be emitted into the environment surrounding the sensor 30. If an obstacle is nearby, the IR light 32A will hit the obstacle and incident light is reflected off the obstacle in the form of reflected light 33A. The reflected IR light 33A passes back through the IR transparent sensor cover 35 and is received by the receiver 33.

However, in the embodiment of Figure 3, the rib 34 associated with the optical sensor 30 does not extend through the slot 37 in the sensor housing cover 35. Instead, a separate crosstalk prevention rib 38 formed of a non IR transparent material prevents any IR light, as represented by arrow 36, from being internally reflected through the material of the sensor housing cover 35 and passing directly from the emitter 22 into the receiver 23. The crosstalk prevention rib 38 may be over-moulded to the sensor housing cover 35, or could be attached to the optical sensor 30.

Figure 4 shows a mobile robot 40. The mobile robot 40 is a robotic vacuum cleaner and has a floor cleaning system comprising a cyclonic separating system 46 and a cleaner head 44. A vacuum motor (not shown) provided inside the main body 42 of the mobile robot 40 draws dirty air in through the cleaner head 44, through the cyclonic separator 46 where the dirt particles are removed from the airflow, and then expels the clean air through a vent (not shown) in the back of the robot 40. The mobile robot 40 has drive actuators in the form of tank tracks 48 which can be driven to move the mobile robot 40 around an environment in which it is located. The mobile robot 40 has a navigation sensor comprising a fish-eye lens camera 50 which is able to capture images of the area around the mobile robot 40. The mobile robot’s control system uses Simultaneous Localisation and Mapping (SLAM) techniques on the images captured by the camera 50 in order to build a map of the environment and to identify the position of the mobile robot 40 within that map. The SLAM techniques carried out by the control system also use odometry measurements provided from the driven tank tracks 48, and also information provided from other sensors, such as proximity sensors, located in the sensor housings 52 positioned either side of the cyclonic separator 46. Each of the sensor housings 52 has a sensor housing cover 56, which forms part of the outer surface of the main body 42 of the mobile robot 40. Each of the sensor housing covers 56 has a number of windows 54 formed therein. Behind each of these windows 54 is an optical sensor, such as a PSD or TOF sensor which can be used to determine the distance away from objects and obstacles in the environment around the mobile robot.

Figure 5 shows the mobile robot 40 with one of the two sensor housing covers 56 removed. With the sensor housing 56 removed, a number of optical sensors 60, 62 and 64 are visible. A comparison with Figure 4 shows how the optical sensors 60, 62, and 64 are positioned in such a way that they are positioned immediately behind the windows 54 of the sensor housing cover 56. A number of optical sensors are provided in each sensor housing 52. The optical sensors 60, 62 and 64 are each oriented differently in order that they can sense different areas of the environment around the mobile robot 40. For example, sensor 60 is directly substantially forwards in order to be able to detect obstacles in front of the mobile robot 40 as it travels in a forward direction, sensor 62 is oriented so it can detect nearby obstacles towards the side of the mobile robot 40, and sensor 64 is a long range time of flight (TOF) which is directed out to the side of the mobile robot 40, but which is able to detect obstacles at larger distances to sensor 62.

Additional sensors in other orientations may also be provided. For instance, the mobile robot 40 has additional optical sensors which are not shown, and which are directed downwards towards the floor surface on which the mobile robot 40 is travelling. These downward facing sensors can detect changes in the distance to the floor, and therefore are able to detect large drop offs such as stairs before the mobile robot 40 travels over the edge. These downward facing sensors are typically referred to as cliff sensors.

Figure 6 shows part of the sensor housing 52 in more detail, and where the sensor housing cover 56 is separate from the rest of the sensor housing 52. The sensors 60, 62 and 64 are mounted to a frame 65. A rib 70 is formed as part of the frame 65, and is associated with the sensor 64. The rib 70 is positioned between the emitter 66 and the receiver 68 of the optical sensor 64. A further rib 74 is formed as part of the frame 65, and is associated with sensor 60. Sensor 60 is smaller than sensor 64, but the rib 74 is similarly positioned between emitter and receiver parts of sensor 60. Another rib 78 is formed as part of the frame 65, and is associated with optical sensor 62. As with the other ribs 70, 74, the rib 78 is positioned between emitter and receiver parts of sensor 62. Each of the ribs 70, 74, 78 extends the full width of the optical sensor to which it is associated, ensuring maximum protection against crosstalk across the full width of the sensor.

The sensor housing cover 56 comprises three windows 54, each window being associated with one of the optical sensors 60, 62, 64, and each window comprises a slot 72, 76, 80. When the sensor housing cover 56 is put in position as indicated by arrow A, the rib 70 is inserted into slot 72, the rib 74 is inserted into the slot 76, and the rib 78 is inserted into slot 80.

Figure 7 shows a cross-section through the sensor housing 52. The cross section is taken through the sensor housing at a point where the cross-section passes through the middle of sensor 64. This view shows how the emitter 66 and the receiver 68 of the optical sensor 68 are positioned immediately behind the window 54 formed in the sensor housing cover 56, and how the rib 70 is positioned within the slot in the window 54 such that is lies between the emitter 66 and the receiver 68. The rib 70 extends the entire way through the window 54, ensuring that there is no possibility for any light to pass directly from the emitter 66 to the receiver 68 by being internally reflected within the material of the sensor housing cover 56.

Whilst particular examples and embodiments have thus far been described, it will be understood that various modifications may be made without departing from the scope of the invention as defined by the claims. For instance, the slots within the sensor housing covers described and shown herein are embodied as slots that extend through the whole sensor housing cover. However it will be appreciated that in some embodiments, the slot may extend only partially through the thickness of the wall of the sensor housing. In this way, the outside appearance of the sensor housing cover would appear “cleaner” having no visible breaks, however this could potentially come at a slight detriment to the level of crosstalk prevention. Nevertheless, a sufficient level of crosstalk prevention could be achieved by a slot that extends partially through the wall of the sensor housing cover.

In addition, in Figures 5 and 6 the ribs are shown as being integral with a frame to which the optical sensors are mounted. However, it will be appreciated that there are number of alternative embodiments for the ribs which would still achieve the same result, for example the ribs may be over-moulded to the sensor housing cover, or could be mounted to or integral with the optical sensors themselves.

Furthermore, the embodiments described and shown herein all have windows formed in the sensor cover. However, it is not always necessary for the sensor cover to be provided with windows if the sensor cover is formed of an IR transparent material. Of course, a window may still be provided even if the whole sensor housing cover is formed of the IR transparent material. The use of a window can ensure the optical sensor is positioned behind a part of the cover that is optimised for the optical sensor to function to its highest potential, but whilst making the sensor cover easy and cheap to manufacture as a single injection moulded part made of a single material.

CLAIMS

1. A mobile robot comprising:

   a main body comprising at least one sensor housing; and

   at least one optical sensor enclosed within the sensor housing, the optical sensor comprising an emitter and a receiver;

   wherein the sensor housing comprises an outer cover that forms part of an outer surface of the mobile robot, the outer cover comprises at least one slot, the slot being formed in the outer cover at a position between the emitter and receiver.

2. A mobile robot as claimed in claim 1, wherein the slot extends through the outer cover to define a through-hole.

3. A mobile robot as claimed in claim 1 or claim 2, wherein the optical sensor is a photoelectric sensor.

4. A mobile robot as claimed in any one of the preceding claims, wherein the optical sensor is one of a time of flight sensor and a position sensitive detector (PSD).

5. A mobile robot as claimed in any one of the preceding claims, wherein the outer cover comprises at least one window formed of IR transparent material.

6. A mobile robot as claimed in claim 5, wherein the at least one optical sensor is positioned behind the at least one window.

7. A mobile robot as claimed in claim 5 or claim 6, wherein the at least one slot is formed in the at least one window.

8. A mobile robot as claimed in any one of the preceding claims, wherein the outer cover is formed of an IR (infra-red) transparent material.

9. A mobile robot as claimed in any one of claims 5 to 8, wherein the IR transparent material is polycarbonate.

10. A mobile robot as claimed in any one of the preceding claims, wherein a non IR transparent material is inserted into the slot in the outer cover.

11. A mobile robot as claimed in claim 10, wherein the non IR transparent material is over-moulded to the outer cover.

12. A mobile robot as claimed in claim 10, wherein the non IR transparent material is fixed to the optical sensor.

13. A mobile robot as claimed in any one of the preceding claims, wherein a width of the slot is substantially equal to a width of the optical sensor.

14. A mobile robot as claimed in any one of the preceding claims, wherein a plurality of optical sensors are housed within the at least one sensor housing, and a slot for each optical sensor is provided in the outer cover.

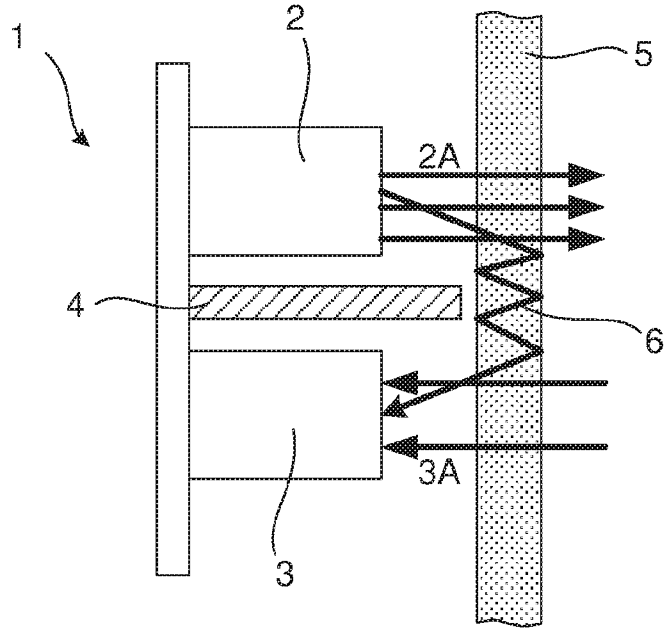
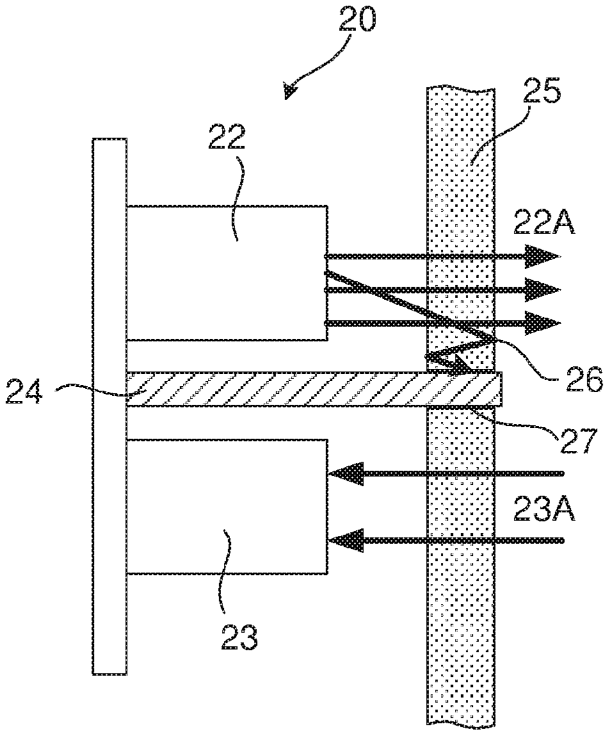


FIG 1
(PRIOR ART)



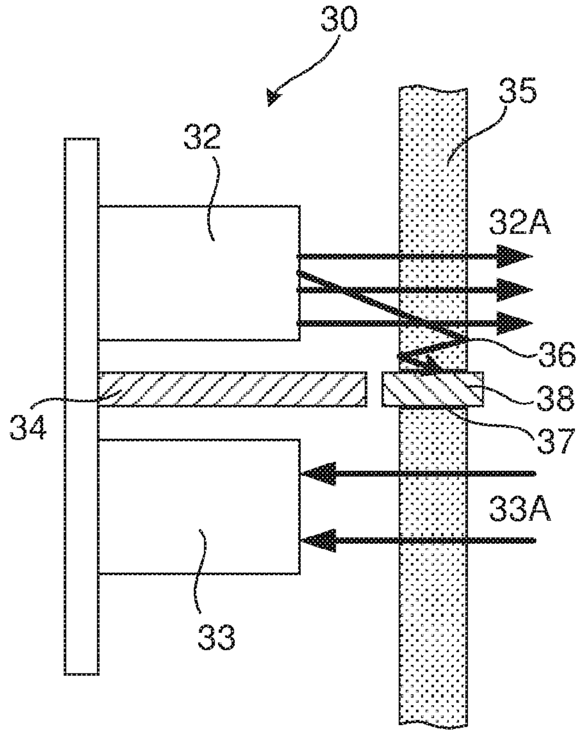


FIG 2

FIG 3

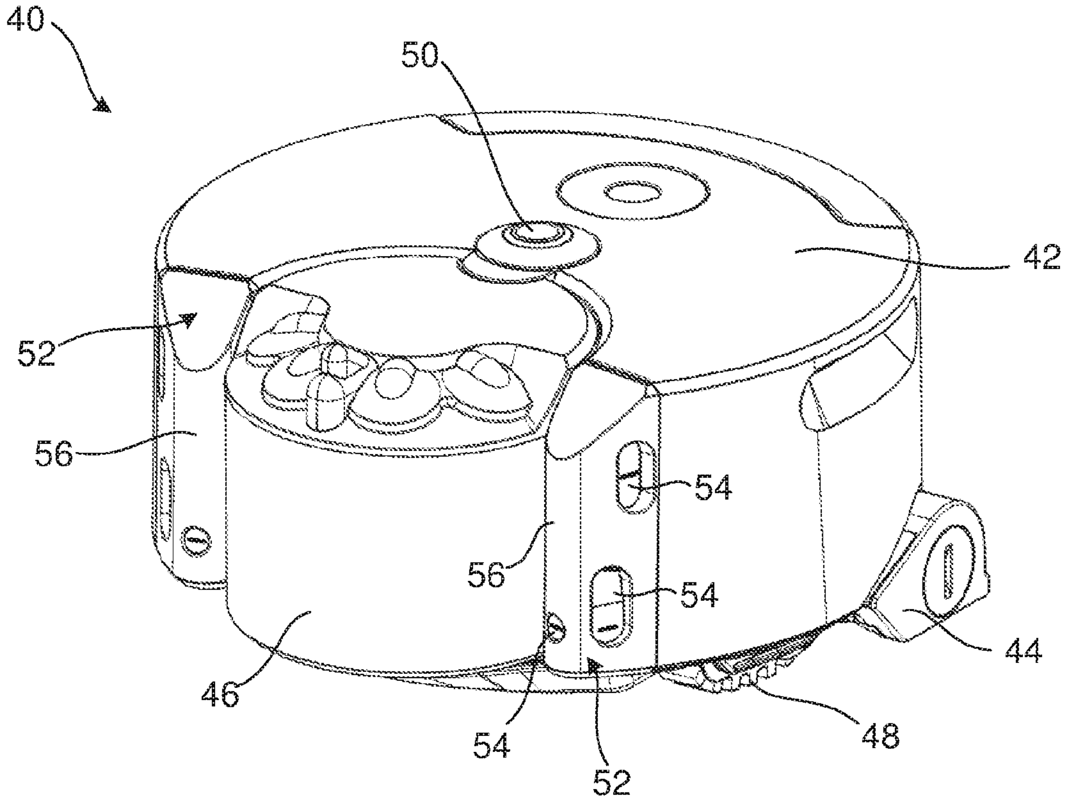


FIG 4

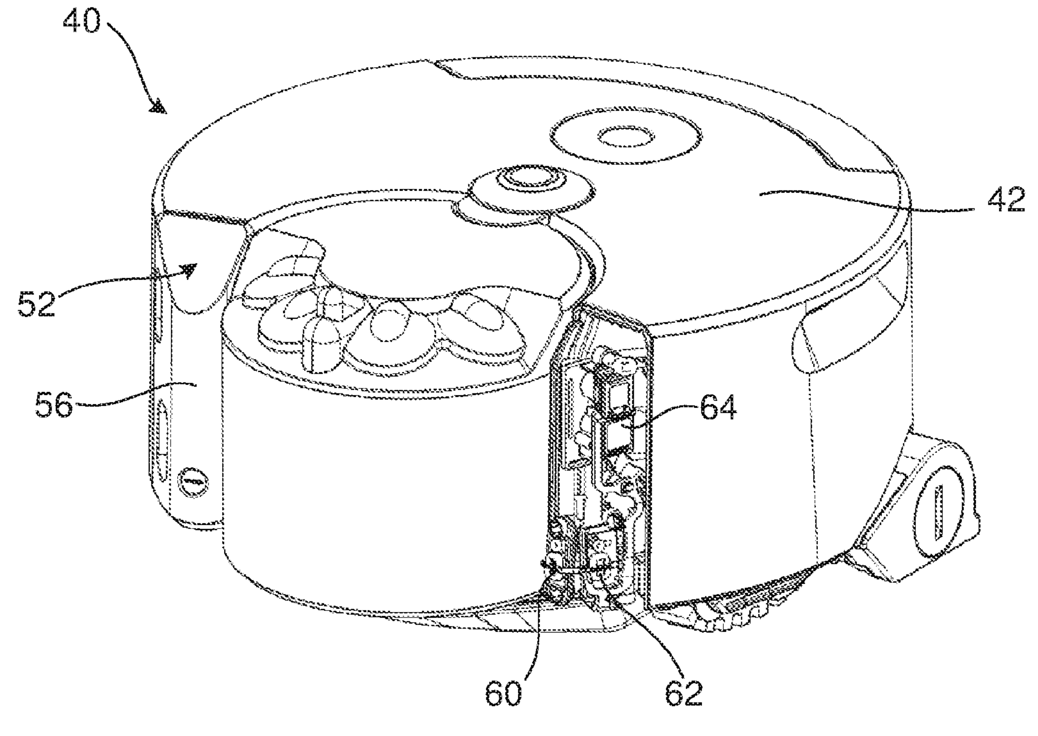


FIG 5

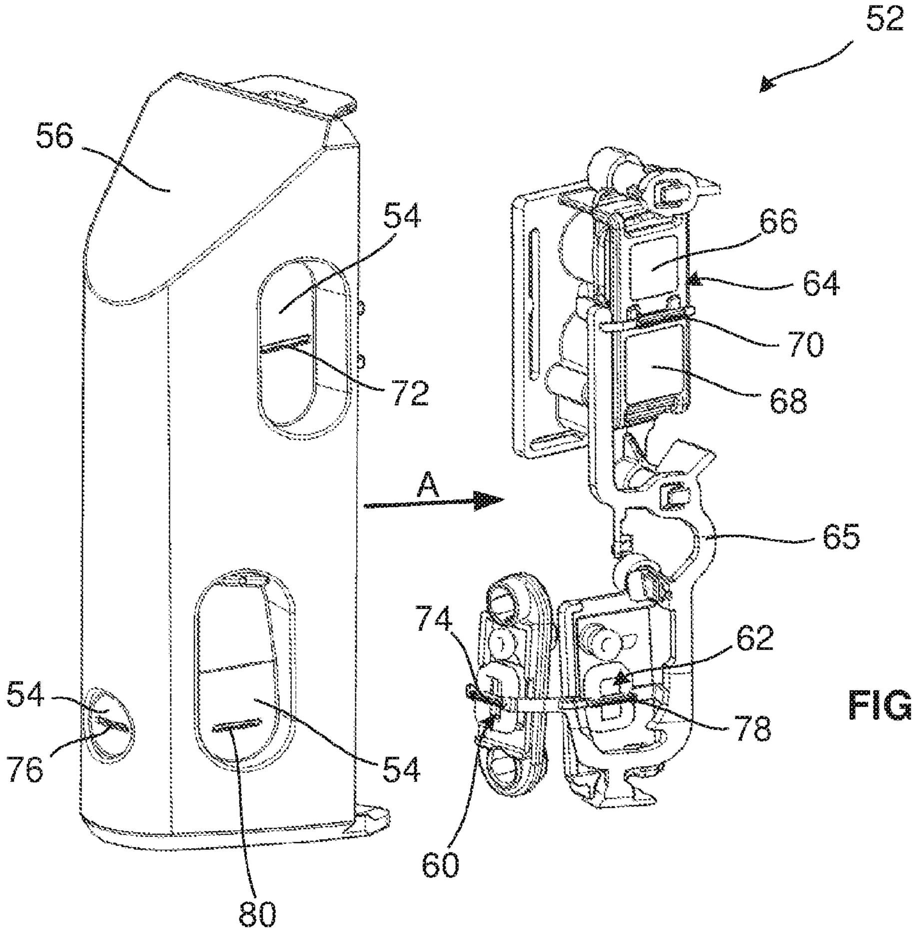


FIG 6

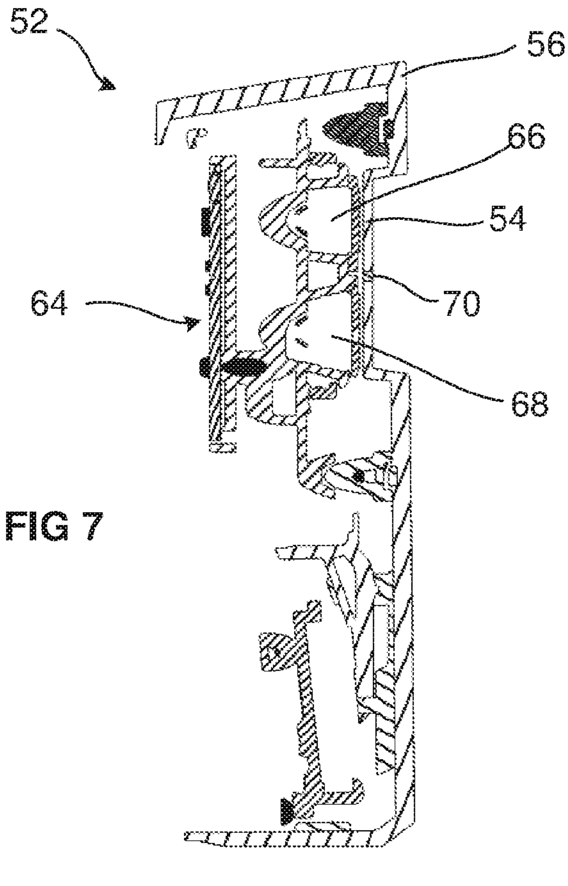


FIG 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/051629

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/481 G01S17/88
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/026020 A1 (GEIGER JENS [CH]) 25 January 2018 (2018-01-25) abstract; figures 1,4 paragraphs [0001] - [0002], [0015] - [0021]	1-14
X	US 2015/340351 A1 (ROSSI MARKUS [CH] ET AL) 26 November 2015 (2015-11-26) abstract; figures 1,2,3A,3B paragraphs [0002], [0020] - [0027], [0034], [0037] - [0039]	1-14
X	JP H09 113621 A (MITSUBISHI ELECTRIC CORP) 2 May 1997 (1997-05-02) abstract; figures 2,3	1-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
10 September 2019	17/09/2019

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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