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INT CL **A61B, F16L**
Other: **EPODOC & WPI**

(54) Title of the Invention: **Device**
Abstract Title: **Travelling capsule with two drive mechanisms**

(57) A capsule robot 10, particularly for traversing the gastrointestinal tract, has two systems of propulsion: an inertial mass drive and driven legs. The robot comprises a housing 16 closed by two end caps 18,19, enclosing a pair of linear actuators 22, 24 and first and second sets of legs 12,14. The actuators may be solenoids or linear motors and releasably couple to the legs via grippers (36, figure 4) which can be electromagnets. When the grippers are disengaged the actuators provide an inertial drive; when engaged, the actuators extend the legs through slots 20 in the housing to engage with the wall of the lumen through which the capsule is travelling. The two sets of legs may operate sequentially to drive the capsule forwards. Preferably, the end caps carry an LED light, camera, biopsy instrument and a power and control unit.

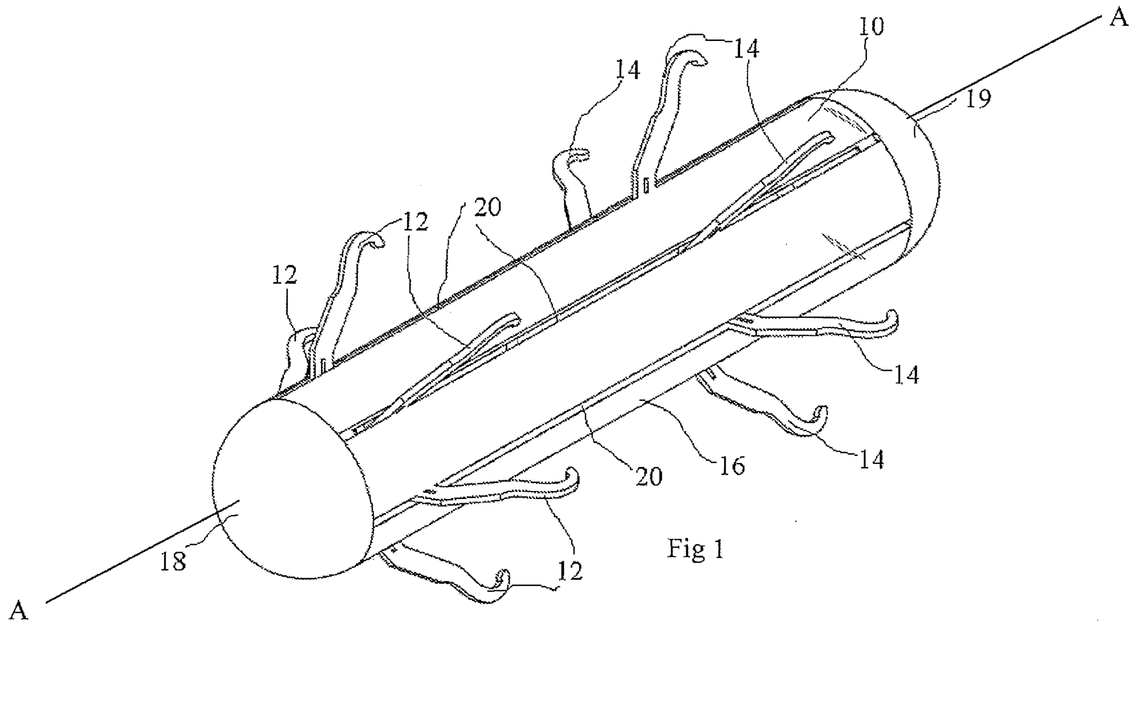

Fig 1

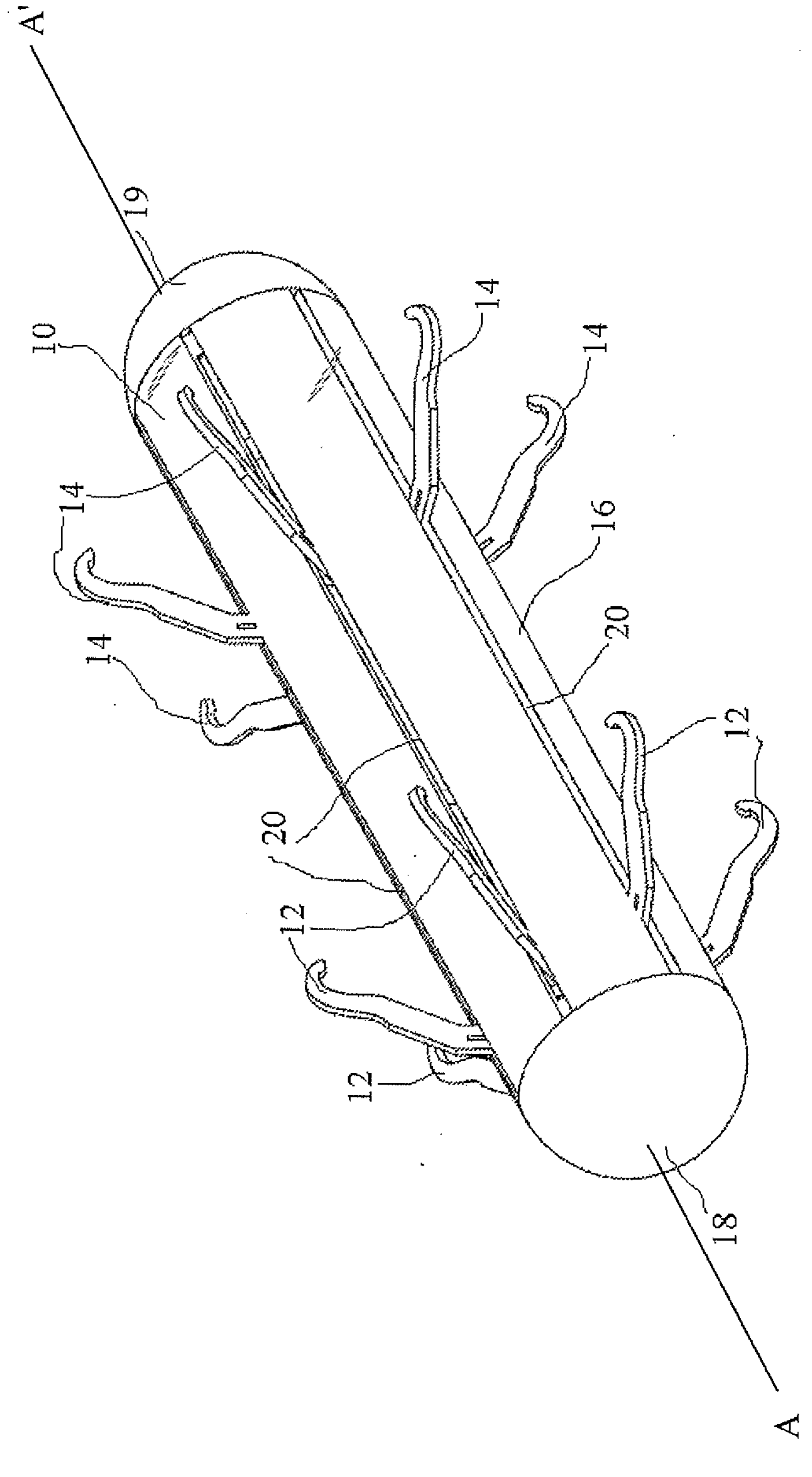

Fig 1

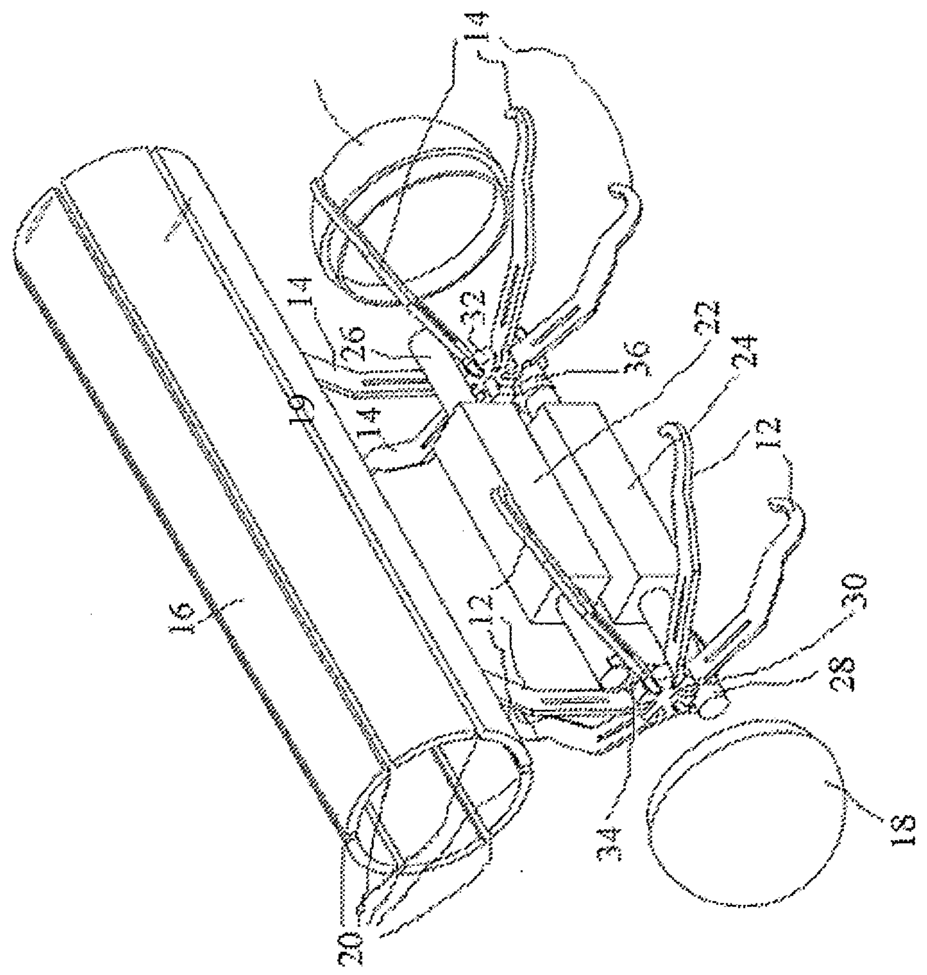

Figure: 2

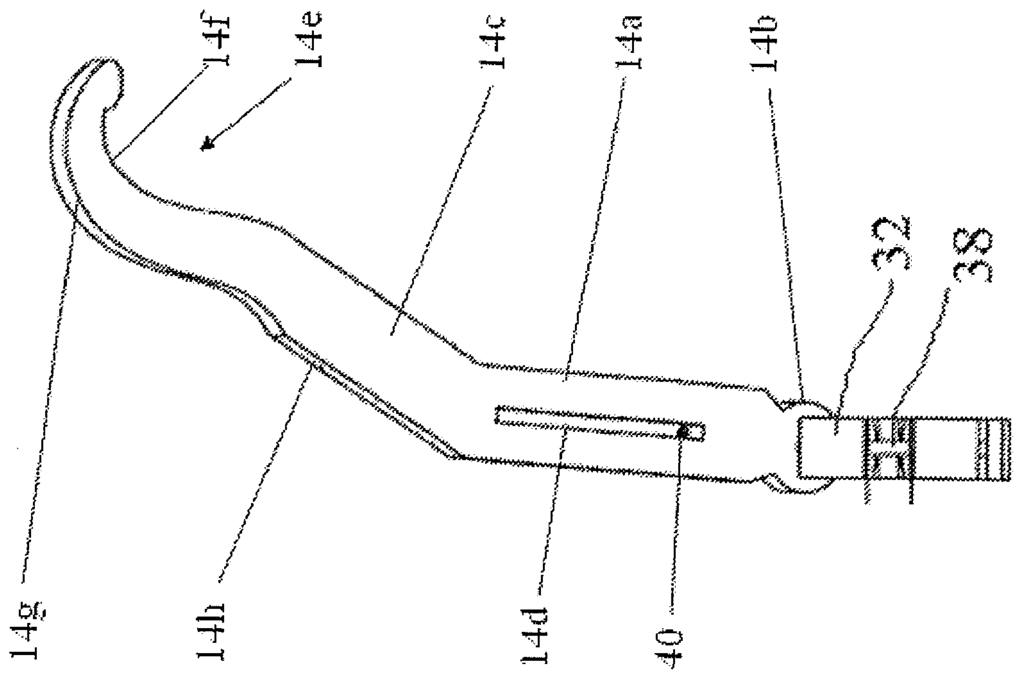

Figure 3

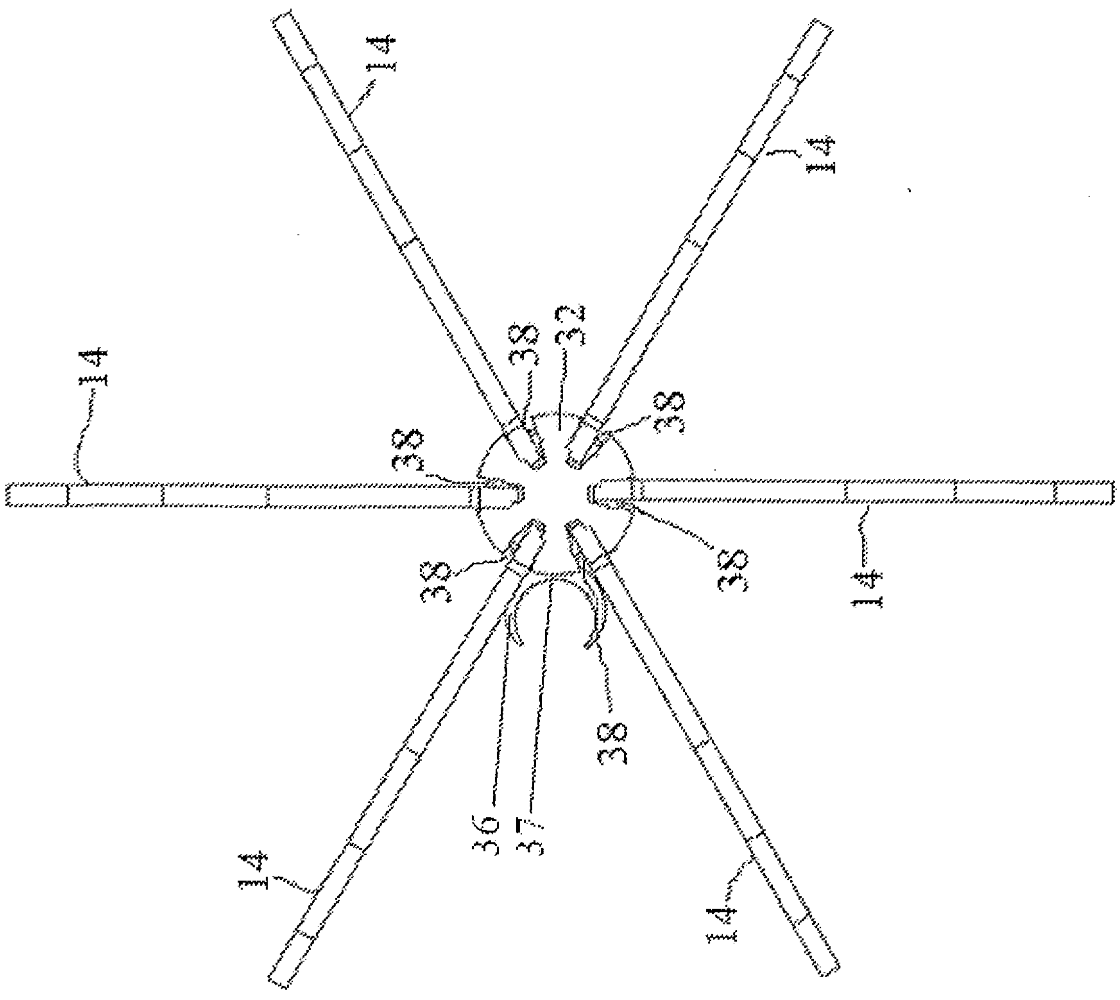

Figure 4

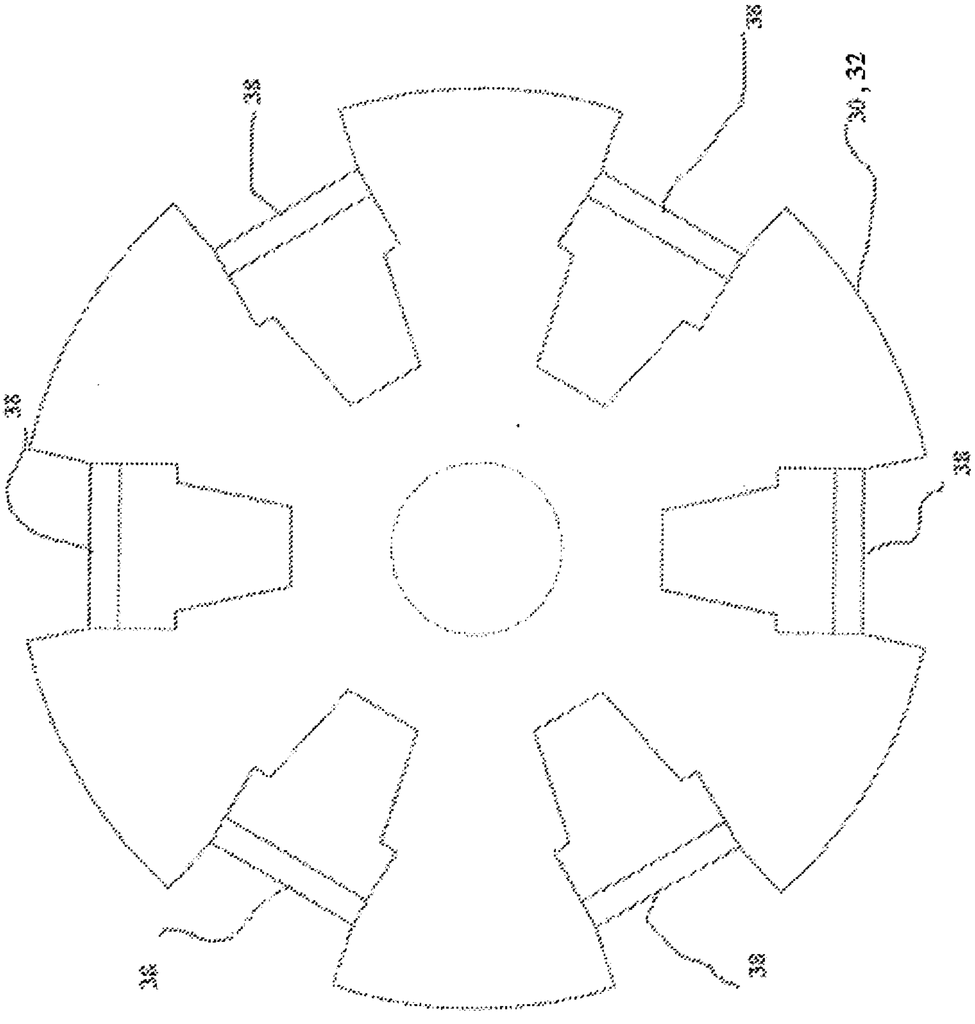

Figure: 5

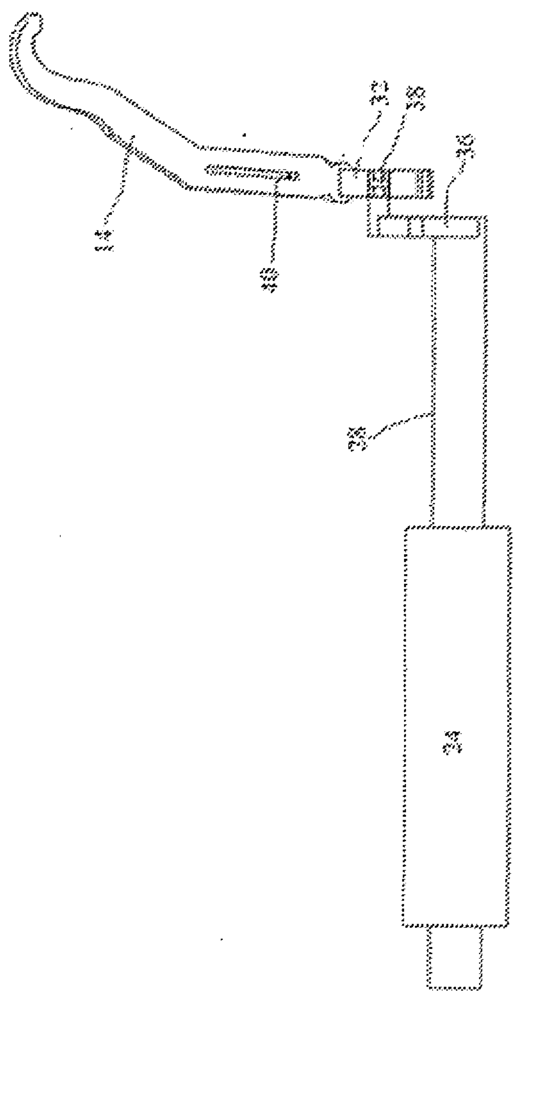

Figure 6a

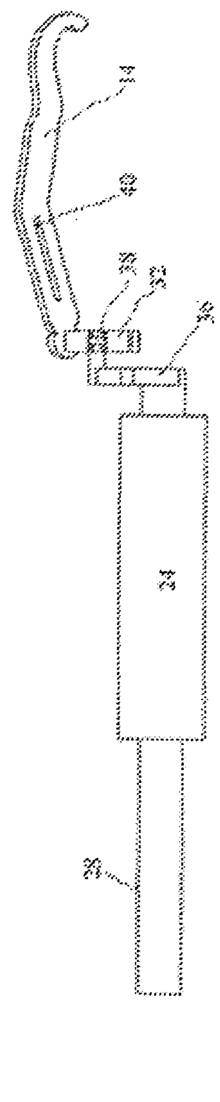

Figure 6b

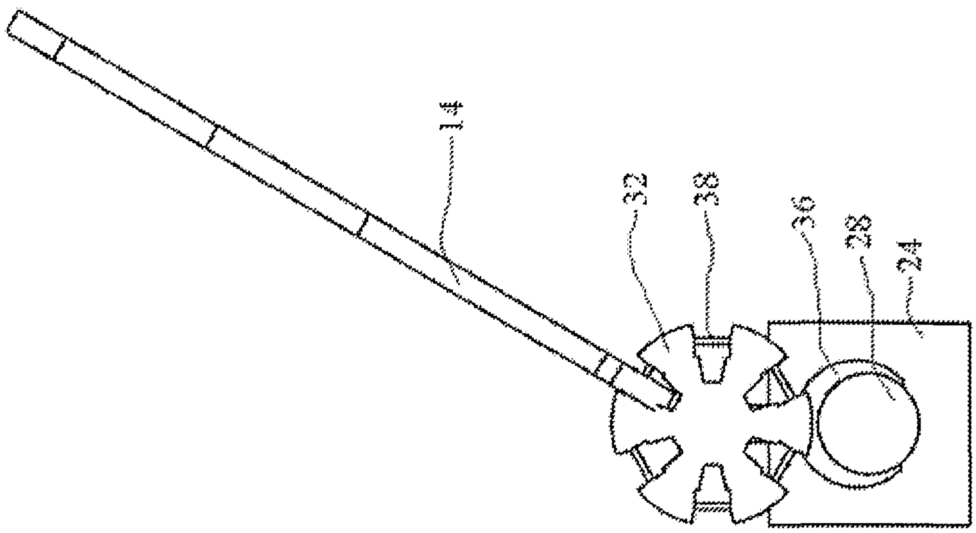

Figure 7

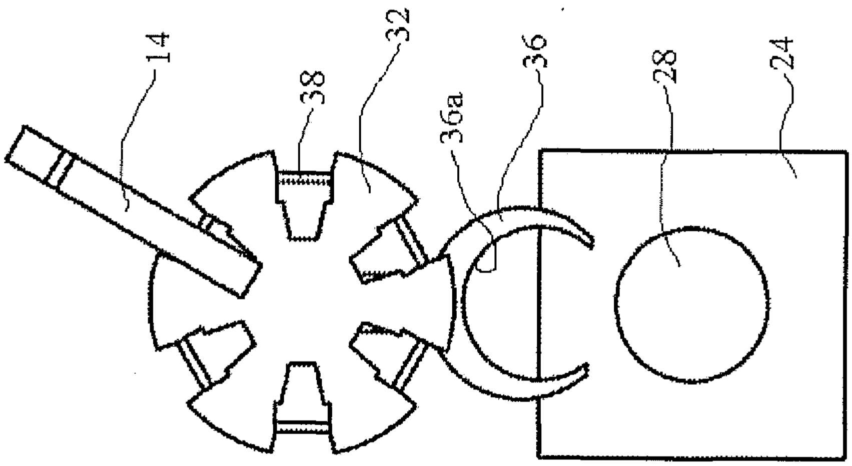

Figure 8

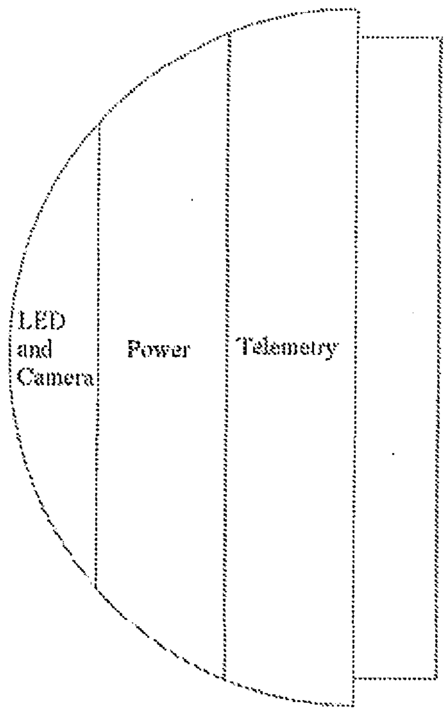
LED
and
Camera
Power
Telemetry

Fig 9a

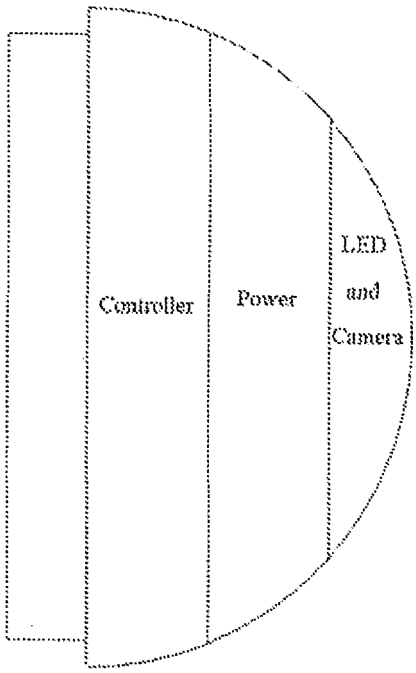
Controller
Power
LED
and
Camera

Fig 9b

Device

This disclosure relates to devices suitable for medical use and to a method of moving a device. An example relates to a capsule robot, and in particular, but without limitation, to a hybrid capsule robot for operation within the lumen of bodily vessels.

The gastro-intestinal tract (GI tract) processes food and carries matter for removal from the body. In addition to the conventional risks associated with exposing any bodily vessel, the matter carried in the GI tract would be dangerous to the rest of the body if it leaked from the GI tract, for example, a leak of faecal matter into the bloodstream could easily result in septicaemia. It is therefore desirable not to breach the GI tract for the purposes of diagnosis or therapy and instead to access the inner lumen of the tract via either the mouth or anus. Intraluminal intervention in the GI tract can facilitate observation and localisation of, for example, ulcers, inflamed mucal lining of the intestine, colonic/large/small bowl bleeding, and abnormal growths. Furthermore, such intervention can also enable targeted delivery of therapy.

In one aspect there is provided a device for medical use comprising a capsule body having an inertial mass and means for selectively moving the inertial mass so that the capsule body is urged to move, the device further comprising outwardly deployable engagement means for engaging with an external surface and means for moving the engagement means for translation of the capsule body.

In such a device, the means for selectively moving the inertial mass may comprise an actuator, and the outwardly deployable engagement means may comprise plural legs, said legs being mounted to the capsule body to be rotatable with respect thereto. Such a device may further comprising gripping means selectively operable in a first (legless) mode to allow said inertial mass to be moved on its own and in a second (legged) mode to cause movement of the inertial mass to rotate said legs with respect to the capsule body.

A device may have two actuators, each with an associated inertial mass, and two sets of legs, each set having associated gripping means.

In a device the or each gripping means may have an associated electromagnetic means operable to cause it to grip the associated inertial mass.

The or each means for selectively moving the inertial mass may comprise a solenoid or linear motor, and the inertial mass is the rod of the solenoid or linear motor.

At least one on-board battery may be provided for supply of power to on-board components.

A wireless control device may be provided.

In some embodiments the capsule body carries one or both of a camera and biopsy means.

In another aspect there is disclosed a method of moving a capsule body within the channel of a tubular structure comprising selectively moving an inertial mass within the capsule body to urge the body to translate with respect to the channel and selectively outwardly deploying engagement means into engagement with the wall of the channel, and causing the engaged engagement means to move with respect to the capsule body whereby the capsule body moves with respect to the channel.

Advantageously, in some examples, a single actuator can be employed to cause both legged and legless propulsion of the capsule robot.

A hybrid miniature robot having both capsule and legged modes of motion may be better suited for locomotion within a lumen of the human body when compared to robots having only a single means for propulsion.

By providing a robot that has both legged and capsule (legless) modes of motion, the most appropriate mode of motion may be selected in order to minimise, or remove, the chance of causing harm to the vessels through which the robot passes. Furthermore, changing between motion modes may be effected by way of a smooth switching strategy so as to maintain motion of the robot in a smooth manner.

The provision of a legged motion mode may enable the robot to selectively exert a relatively large force upon the vessel within which the robot lies. This may beneficially facilitate navigation of the robot about corners or along regions that are highly tortuous. In some examples, robots have two sets of independently movable legs, each set of legs comprising 4, 6, or 8 legs. Also, robots may be arranged to effect motion in both backward and forward directions in either or both capsule and legged motion modes.

These and various other elements of the disclosure will become apparent from the following detailed description which is given by way of example only and which is described with reference to the accompanying figures in which:

Figure 1 shows a perspective view of an example of capsule robot;
Figure 2 shows a partially exploded perspective view of the capsule robot of Figure 1;
Figure 3 shows a side view of an example of one of the legs of the capsule robot of Figure 1;
Figure 4 shows an end elevation of a gripper, leg, and nut assembly of a capsule robot;
Figure 5 shows an end view of a nut and pin assembly of a capsule robot;
Figure 6a and 6b show side views of a linear actuator, leg, and nut assembly of a capsule robot when configured for legged motion;
Figure 7 shows a rear end view of one of the linear actuator, leg, and nut assemblies;
Figure 8 shows a rear end view of the actuator, leg, and nut assembly; and
Figure 9a shows a front end cap with an LED and camera, power source, telemetry; while Figure 9b a rear end cap with a controller, power source, an LED and camera.

Referring to Figure 1, a capsule robot (10) has a first set of projecting legs (12) and a second set of projecting legs (14). In this example each set consists of six legs. The capsule is formed of an elongate generally circular-cylindrical housing (16) and a pair of hemispherical end caps (18, 19), being a front end cap (18) and a rear end cap (19). The housing (16) of the capsule robot (10) has a longitudinal axis A-A' and a plurality of axis-parallel elongate slots (20) within which the first and second set of legs (12, 14) are operable to slide in a longitudinal direction. The legs (12, 14) are operable both to retract through the elongate slots (20) so as to be entirely contained within the housing (16) and to project through the elongate slots (20). The first (12) and second (14) legs are identical in this example.

Referring now to Figure 2, it can be seen that the housing (16) is substantially hollow and is arranged to house a pair of actuators (22, 24). Each actuator (22, 24) is arranged to move its associated rod (26, 28) in the axial direction. Each set of legs (12, 14) is pivotally coupled to a respective nut (30, 32), and each nut is coupled respectively to an associated gripper mechanism (34, 36). Each gripper mechanism (34, 36) is arranged to be able to both grip and release an associated rod (26, 28). In the example of Figure 2, a gripper (34) is activated and engaged to a rod (26) so as to mechanically couple the rod (26) to the first set of legs (12) so that actuation of the actuator (22) that is arranged to move the rod (26) moves not only the rod (26), but also the gripper (34), the nut (30), and the first set of legs (12) in a direction substantially parallel to the robot axis. Likewise, in Figure 2, the other gripper (36) is engaged to the other rod (28) so that actuation of the other actuator (24) brings about motion of the second set of legs (14) in a direction substantially parallel to the robot axis. When the first and/or second set of legs (12, 14) project through slots (20), and the grippers (34, 36) engage the rods (26, 28), actuation of the respective actuators (22, 24) causes the sets of legs (12, 14) to slide in the slots (20) thereby enabling the sets of legs (12, 14) to push and/or pull the capsule robot (10) relative to matter surrounding the capsule robot – for example, when the capsule robot is located in a bodily lumen, the legs may push or pull the capsule robot (10) along that lumen. In the example of Figures 1 and 2, the actuators are linear motors or solenoids – for example a Quickshaft LM 1247 series

Linear DC-Servomotor as produced by Faulhaber (http://www.faulhaber-group.com) - and the grippers (34, 36) have electromagnets (not shown) that can be energised to enable to the gripper (34, 36) to hold the respective rod (26, 28).

Referring to Figure 3, the legs (12, 14) are each a unitary structure that is generally planar. Each leg consists of a first straight elongate portion (14a) extending from a pivot region (14b) by which it is pivotally secured to the nut (32). At the distal region of the first portion (14a), it extends into a second straight elongate portion (14c) that is raked backwardly (to the right as seen in Figure 4) by an angle of about 40 degrees. The first straight elongate portion has a central elongate slot (14d) extending along most of its length to receive a pin (40). The second straight elongate portion (14c) extends into a hooked end region (14e). The hooked end region (14e) has an inner curved edge region (14f) that extends on the backward side of the leg (to the right as seen in Figure 4). The inner curved edge region (14f) extends via an outer curved edge region (14g) to the outer straight edge (14h) of the second straight elongate portion (14c).

In this example, all the legs are of identical length. This is not however necessary for the invention and arrangements with legs having differing lengths are envisaged.

Referring now to Figure 4, one (36) of the grippers (34, 36) can be more clearly seen. In this example, each gripper (34, 36) has an arcuate gripping face (37) for gripping the corresponding rod (26, 28), the arcuate surface being profiled to correspond to the profile of the corresponding rod (26, 28) to facilitate gripping thereof.

The free end of the leg with a hook-like structure is to make sure that the legs (12, 14) movement makes the capsule robot (10) move in one direction.

By having leg portions that project from the housing (16) of the capsule robot (10) and which are angled relative to the long axis of the capsule robot, the legs may be used as a wedge for opening up occlusions or expanding/distending a narrowing in a vessel –

for example, one set of the legs driven by one linear actuator may be arranged to project when the other linear actuator of the capsule robot is in a legless propulsion mode and legless propulsion may be employed to 'hammer' the consequently wedge-shaped robot into the occlusion or narrowing.

Continuing to refer to Figure 4, each of the six legs (14) is coupled to the nut (32) via a respective pin (38) about which that leg is rotatable so as to enable retraction of that leg through the slot (20) so that the leg lies entirely within the housing (16). Likewise, each leg (14) is also rotatable by means of the associated pin (38) so as to enable that leg to be deployed from the retracted configuration, through the slot (20), so as to project therefrom.

Advantageously, by employing a plurality of pin-like legs in a spider-like configuration - as opposed to sheet materials in, for example, an umbrella-like configuration, the legs may be fully retracted within the housing (16) so that they cannot impede legless propulsion of the capsule robot. Furthermore, by arranging the legs in the shown spider-like configuration, the first rod (26) may move through the gaps in the set of legs (12) coupled to the second rod (28) and the two sets of legs (12, 14) may be independently actuated without the first rod (26) colliding with the set of legs (12) coupled to the second rod (28) – and vice versa.

Figure 5 shows a close up end view of a nut (30, 32) and the pins (38) for coupling legs (12, 14) to the nut.

Figures 6a and 6b show a side view of an actuator(24), leg(14), and nut (32) assembly of a capsule robot in first and second positions. As can be seen, the gripper (36) is engaged with the rod (28). The leg (14) is coupled to the nut (32) by way of a pin (38) as explained with reference to Figure 4. Furthermore, a constraining pin (40) that is fixed relative to the housing (16) is disposed in the slot of the leg (14). In this example, one constraining pin (40) per leg is provided. Continuing to refer to Figure 6a, the side view of the actuator (24), leg (14), and nut (32), shows the assembly in a first configuration (Figure 6a) in which the leg (14) is slightly extended whereas Figure 6b shows the same assembly, but in a second configuration following actuation of actuator (24) so that the leg has been rotated clockwise (in the sense illustrated). To move between the first (Figure 6a) and second (Figure 6b) configurations, the actuator (24) is actuated in order to move the rod (28) so as to draw the nut (36) towards the actuator (24) The leg (14) is coupled to the nut (32) by the pin (38) and the leg is free to rotate about the pin (38) subject to the constraints of the constraining pin (40). The constraining pin (40) is fixedly coupled to the housing (16) and passes through the slot in the leg (14). Accordingly, movement of the nut (32) draws the end of the leg (14) that is coupled to the nut (32) inwardly towards the actuator. The constraining pin (40) rides in the slot in the leg (14) so as to cause rotation of the leg (14) in the clockwise direction as illustrated. Accordingly, the combination of the pin (38), the constraining pin (40) and the slot in the leg 14 act to translate linear motion of the actuator (24) into rotational motion of the leg (14).

Figure 7 shows a rear end view of the actuator (24), leg (14), and nut (32) assembly in which the pin (38) that connects the nut (32) to the leg (14) can clearly be seen. Furthermore, Figure 7 also shows the gripper (36) engaged with the rod (28) so as enable a legged mode of operation.

Turning now to the mode in which motion takes place due to interia effects, termed herein “legless mode”, referring to Figure 8 not only is the gripper (36) not engaged with the rod (28), but it is also vertically offset therefrom. As one possibility, the gripper (36) is laterally moveable between a disengaged position in which the gripper (36) does not engage the rod (28) and an engaged position in which the gripper is fixedly coupled to the rod (28). The gripper may be laterally movable by means of a motor, or solenoid and a person skilled in the art will appreciate other manners in which the gripper (36) may be laterally moved. As another possibility, the gripper (36) is not laterally movable relative to the rod (28) and instead, when in an unengaged configuration, the rod (28) is moveable within an inner bore (36a) of the gripper and, when in an engaged configuration, the gripper (36) is activated so that its inner bore (36a) is fixedly coupled to the rod (28).

In a first mode of operation – a force static-friction or legless mode – the rods (26, 28) act as inertial masses to cause propulsion. The legs (12, 14) of this example are retracted within the housing (16) so as to reduce the amount of force required to overcome friction when propelling the capsule robot along and the grippers (34, 36) are disengaged from their associated rods (26, 28) so that the rods (26, 28) can move relative to the grippers (34, 36). One, or both, of the actuators (22, 24) is then actuated so as to move the rods (26,28) in a direction substantially parallel to the robot axis and with an acceleration such that the resultant force on the housing (16) is sufficient not only to overcome friction between the outer surface of the capsule robot (10) and its surrounding environment, but to further cause the housing (16) of the capsule robot (10) to move in an opposite direction to the rod (26,28) and thereby to propel the capsule robot (10) in that opposite direction. The rod (26, 28) is then be returned to its original position relative to the housing (16) of the capsule robot (10) using a force inferior to the friction forces acting between the outer surface of the capsule robot (10) and its surrounding environment so that returning the rod (26, 28) to the original position does not overcome those frictional forces and consequently does not result in propulsion of the capsule robot (10).

By following the procedure described below the robot (10) in the legless mode can move forward in the onward and return journey of the rods.

A. Cycle 1

1) Step 1: A rod, (26, 28) forming the inertial mass starts to move backwards by its actuator(22,24) with a high negative acceleration motion (with the positive direction being the net forward direction of the robot) and the robot (10) receives a reaction force in the forward direction. If the reaction force is big enough to overcome the friction, the robot (10) moves forward

2) Step 2: The rod (26, 28) continues to move backward but with a small positive acceleration. The robot (10) continues to move forward but slows to a stop caused by frictional engagement with its surroundings. The robot (10) remains at a standstill for the remaining time of step 2 as the friction force dominates over the reaction force. The rod (26, 28) reaches its end point at the end of step 2 and stops.

3) Step 3: The rod (26, 28) moves forward slowly with a small positive acceleration and, as the friction force dominates, the robot (10) remains at a standstill.

4) Step 4: The rod (26, 28) moves forward with a high negative acceleration motion and the robot (10) moves forward with a positive acceleration. The rod (26, 28) reaches to the right end at the end of this step and stops. It instantaneously reverses its direction and enters to step 1 of cycle 2.

By repeating the cycles the robot (10) is moved forward. The robot (10) moves in steps 1 and 4, and a portion of step 2 and, it remains stationary for the remaining steps. By changing the acceleration direction of the rod (26, 28), the robot (10) can be moved in the opposite direction. By changing the acceleration magnitude the robot (10) can be moved with different average velocities.

By changing the acceleration and duty cycle of actuation, the linear motion of the actual robot may be changed. Furthermore, as two actuators (22, 24) are employed in the embodiment of Figure 2, not only may linear motion of the capsule robot be effected, but also the capsule robot may move in two dimensions as activation of actuators (22, 24) in opposite directions at the same time will bring about a rotational force on the housing (16) of the capsule robot (10). A person skilled in the art will appreciate that different permutations of actuators may be employed in order to provide the capsule robot with different degrees of legless locomotion. For example, a triplet of linear actuators having parallel but non-planar movement axes may be employed in order to provide the capsule robot with three dimensional movement capabilities. As another possibility the actuators could be arranged to have movement axes in non-parallel directions so as to effect different movements of the capsule robot.

In a second mode of operation (a legged mode), the grippers (34, 36) engage the rod (26, 28) and the legs (12, 14) are extended so as to project from the slots (20). The actuators (22, 24) are then actuated so as to make the legs (12, 14) move within the slots thereby enabling the legs to push/or pull the capsule robot, within a lumen. In particular, linear motion of the rod (26, 28) as caused by the actuators (22, 24), causes linear translation of the nuts (30, 32). The legs (12, 14) consequently rotate on the pins (38) and slide and rotate relative to the constraining pins (40). As the constraining pins (40) are fixedly coupled to the housing, linear motion of the rod (26, 28) therefore causes the legs (12, 14) to slide and rotate within the slots (20) and relative to the housing (16). As one possibility, one or both of the nuts (30, 32) may be translated substantially parallel to the robot axis so as to cause the legs (12, 14) to be fully retracted within the housing. The legs (12, 14) may be arranged for full retraction when the nuts (30, 32) are towards both extremes of their movement substantially parallel to the robot axis, or are towards only one of the extremes. In the event that the legs (12, 14) are arranged for full retraction when the nuts (30, 32) are towards both extremes of their movement substantially parallel to the robot axis, then, when the nuts (30, 32) are moved between those two extremes, the legs (12, 14) are first retracted, the legs (12, 14) then rotate and slide within the slots (20) about the constraining pins (40), before finally being retracted within the housing (16).

In Figure 1, when the first set of legs (12) opens the robot receives a force in the backward direction. When the second set of legs (14) opens the robot receives a force in the backward direction too. Again when the first set of legs (12) closes the robot receives a force in the forward direction. When the second set of legs (14) closes the robot receives a force in the forward direction too.

Because of the hook-like structure (14e) at the front of each leg, the force received in the backward direction is smaller than that received in the forward direction. The reason here is because of the form of the legs; the legs face less resistance while opening due to the external curved edge (14g), whereas when the legs are closing the hooked end can engage the surroundings.

The closing and opening can be controlled in the following control sequences so that the robot only moves in the forward direction.

Control Sequence 1:

Cycle 1:

At the beginning of the legged locomotion, both the leg sets are closed.

Step 1: In this step front leg set (12) starts opening. During this step the robot (10) moves in the backward direction though very small.

Step 2: The rear leg set (14) starts opening and front leg set (12) starts closing. Because of the difference of the force produced by two leg-sets (12, 14) the robot (10) moves forward.

Step 3: The front leg set (12) starts opening and the rear leg set (14) starts closing. Because of the difference of the force produced by two leg-sets (12, 14) the robot (10) moves forward.

Repeated Cycle:

By repeating steps 2 and 3 the robot moves forward.

Control Sequence 2:

Cycle 1:

At the beginning of the legged locomotion, both the leg sets (12, 14) are closed.

Step 1: In this step the front leg set (12) starts opening. During this step the robot (10) moves backward direction though very small.

Step 2: The rear leg set (14) starts opening. The robot (10) experiences a backward force. But as the hook of the front leg set (12) locks the robot (10), it remains stand-still.

Step 3: The front leg set (12) starts closing. The robot (10) experiences a forward force and the robot (10) moves forward. Because of the hook structure, the opened rear leg set (14) creates very low resistance in the forward movement of the robot (10).

Step 4: The rear leg set (14) starts closing. The robot (10) experiences a forward force and the robot (10) moves forward. The closed front leg-set (12) creates no resistance in the forward movement of the robot (10).

Thus at the end of step 4 the robot (10) returns to its initial configuration i.e. both the leg sets (12, 14) are closed.

Here the robot (10) moves backward a little bit in step 1 and moves forward in steps 3 & 4.

Repeated Cycle:

By repeating steps 1 to 4 the robot moves forward

Control Sequence 3:

Cycle 1:

At the beginning of the legged locomotion, both the leg sets (12, 14) are closed.

Step 1: In this step the front leg set (12) starts opening. During this step the robot (10) moves backward direction though very small.

Step 2: The rear leg set (14) starts opening. The robot (10) experiences a backward force. But as the hook of the front leg set (12) locks the robot, it remains stand-still.

Step 3: The front leg set (12) starts closing. The robot (10) experiences a forward force from and the robot (10) moves forward. Because of the hook structure, the opened rear leg set (14) creates very low resistance in the forward movement of the robot (10).

Step 4: The rear leg set (14) starts closing and the front leg set (12) starts opening. The robot (10) experiences a forward force from the rear leg set (14) and a smaller backward force from the front leg set (12). Because of the difference of two forces the robot (10) moves forward.

Repeated Cycle:

By repeating steps 2, 3 and 4 the robot moves forward.

In other arrangements the legs may be outwardly sprung when deployed to facilitate gripping and sliding (according to rotation sense); in some, the legs may be of a resilient material.

It is preferable to avoid passing anything having spiky projections along the GI tract as such projections may snag on the tract. Furthermore, along some portions of the GI tract there may be no need for drive at all as gravity and peristalsis may move the capsule robot without need for any locomotive contribution from the capsule robot. Where a locomotive contribution from the capsule robot is required, it is preferred that the force static-friction (legless) mode of operation is employed so as to minimise the chances of damaging the lumen of the GI tract. However, when navigation in force static-friction mode is insufficient, for example when the robot needs to work against gravity, or to pass an obstruction, the legs may be extended through their slots and the grippers engaged with the bodies of the actuators so that the legged mode may be employed to push and/or pull the capsule robot along the lumen.

Whilst in the above the grippers have been described as comprising electromagnets, a person skilled in the art would appreciate that a number of alternative means could be employed to grip the moving portion of the actuator, for example the gripper could have a mechanical clutch arranged to engage/disengage the movable portion of the actuator – which may be shaped to facilitate engagement/disengagement. As other possibilities, permanent magnets, suction, electrical charges, or surface tension forces could be employed to enable the gripper to selectively engage the bodies.

Whilst the above has been described with reference to a linear motor being the actuator, a person skilled in the art will understand that alternative means may be employed to move the masses and the legs, for example, one or more rotary motors coupled to lead screws, hydraulic or pneumatic actuators, electrical charge-based actuators, piezoelectric actuators etc.

A person skilled in the art will understand that, although the above has been described with reference to an example having a pair of actuators and two corresponding sets of legs, only a single actuator and a single set of legs, or indeed a single leg, is required in order for the capsule robot to benefit from having dual proportion modes controlled by the same actuator. Accordingly, a robot having any number of actuators each with one or more associated legs is envisaged.

A person skilled in the art will appreciate that, whilst the present description has been made with reference to the gastrointestinal tract, the capsule robot described herein could equally be employed in other vessels or pipe-like structures within or without the human or animal body.

As one possibility, a plurality of the herein described capsule robots could be employed in order to create a team or chain of robots. This may be particularly advantageous when a force larger than could be provided by a single capsule robot is required in a particularly torturous vessel. For example, a plurality of the capsule robots may be inserted and moved to abut one another prior to simultaneous actuation of the actuators so as to provide an elevated pushing force.

A person skilled in the art will appreciate that the capsule robot described herein may employ a number of different permutations of legged and force static-friction propulsion. For example, multiple sets of legs may be activated at the same time or may be activated sequentially which may provide a millipede-like manner of locomotion. Similarly, actuators acting in force static-friction mode may also be activated all together or in any sequence and any combination and sequence of force static-friction mode propulsion and legged propulsion may be employed.

As one possibility, the capsule robot may carry a camera thereby enabling the robot to act as an assistant for robot assisted endoscopy.

A person skilled in the art will appreciate that, in addition to providing means for propelling the capsule robot, the legs may also be employed to open an occlusion or to widen a narrowing of a bodily vessel. The capsule robot may be equipped with cutting or biopsy means to enable one or more samples of the lumen of the vessel to be taken by the capsule robot and such means may be coupled to or incorporated in the capsule robot's legs.

Advantageously, when the actual robot is employed for biopsy purposes, instead of the two percutaneous access ports that are conventionally required to perform a biopsy - one for the camera and another for the biopsy tool - the capsule robot may carry both a camera and biopsy means – for example an aspiration needle or a core needle. Such a capsule robot may be inserted into and removed from the abdominal via a single laparoscopic port thereby avoiding the need for a second percutaneous port and the patient trauma associated therewith.

As one possibility, the capsule robot described herein may be carried and/or deployed by non-medical professionals at a site of an injury (i.e. on a battlefield or at a place of natural or manmade disaster) and then operated by a remotely-located surgeon so as to provide diagnostic, and/or surgical capabilities very quickly after the injury.

As one possibility, the hybrid propulsion system described herein may be employed for semi-autonomous robots providing medical support during long space missions.

Capsule robots having two or more actuators may be employed in a double hybrid motion mode wherein, in addition to employing a first set of one or more legs to push or pull the capsule robot by way of a first actuator, a second actuator is employed in force static-friction mode to provide a 'hammer blow' to the capsule robot to assist in the negotiation of obstacles.

The capsule robot described herein may be arranged so that, not only the force friction mode, but also the legged mode is operable to reverse the capsule robot along a passage. For example a capsule robot carrying a camera may pass by a feature that is of interest to an operator of the robot – for example a clinician- and the clinician may wish to review that feature by reversing the robot back to that feature. In the event that the capsule robot is required to reverse along a passage in the opposite direction to that of gravity, it is envisaged that a legged mode of operation could be employed.

A person skilled in the art will understand that the amount of force required to overcome the frictional forces acting against the outer surface of the capsule robot will depend upon the outer shape and texture of the capsule robot, the surface in which the capsule robot is in contact, and any other forces acting upon the capsule robot – for example gravity and any bodily forces such as peristalsis. Furthermore, as the capsule robot encounters different terrain, the frictional forces would be expected to change accordingly. When choosing the amount of force required to overcome those frictional forces, an empirically determined force may be employed, or the force employed may be increased from a low level until the capsule robot moves. A person skilled in the art would understand a number of ways of both empirically determining the required force (for example cadaver studies) and assessing whether an employed amount of force was sufficient to move the capsule robot (for example observation of a change in scene seen by a camera of the robot, or movement when the capsule robot is viewed under X-ray or ultrasound).

A person skilled in the art will appreciate that the stator and the movable portion of the linear actuator could be swapped over so that either: i) the stator could be coupled to the housing of the capsule robot and the movable portion of the linear actuator could be selectively engaged with the gripper, or ii) the movable portion of the linear actuator could be coupled to the housing of the capsule robot and the stator could be selectively engaged with the gripper. Furthermore, the stator or the moving portion of the linear actuator may be integral with, or form part or all of the housing.

Preferably, the capsule robot described herein is arranged for wireless operation and carries its own power supply. A person skilled in the art will understand how to implement a wireless control mechanism to control capsule robot operating within a bodily vessel and so the particulars of such a mechanism will not be detailed herein. As one possibility, the capsule robot's power supply is one or more batteries positioned in one or both of the end caps (18) - see Figure 9a, 9b. By positioning batteries in each of the end caps (18), movement of the legs of the capsule robot is not impeded and the weight distribution of the capsule robot may be regulated – for example so as to coincide the capsule robot's centre of gravity with the capsule robot's long axis of rotational symmetry.

Referring to Figure 9a, showing a schematic example of a forward end cap, this may contain a light source, for example an LED, a camera, a battery supply and telemetry for transferring information. An example of a rear cap shown in Fig 9b shows another LED and camera, a battery power source and a robot controller.

A person skilled in the art will appreciate that a model of a 2D capsule motion may be employed for system design, analysis, simulation, and controller design.

Those skilled in the art will appreciate that the various features of each example described herein may be employed either alone or in any combination.

Reference is made to the following publications

[1] H. Yu, M. N. Huda and S. O.Wane, "A novel acceleration profile for the motion control of capsubots," in IEEE International Conference on Robotics and Automation, 2011, pp. 2437-2442.

[2] M. N. Huda, H. Yu, and S. O. Wane, "Self-contained capsubot propulsion mechanism," International Journal of Automation and Computing, 2011.

[3] M. N. Huda and H. Yu, "Modelling and motion control of a novel double parallel mass capsubot," in 18^{th} World Congress of the International Federation of Automatic ·ol (IFAC), 2011,

[4] M. Quirini, R. J. Webster, A. Menciassi, and P. Dario, "Teleoperated endoscopic capsule," PCT Patent IT2007/000 259, 2007.

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[6] H. Li and K. Furuta, " Small robot without movable parts at the outside ", Japan Patent Publication Number JP2006-305695, 2006.

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[8]H. Li, K. Furuta, and F. Chernousko, "Motion generation of the capsubot using internal force and static friction," in *2006 45th IEEE Conference on Decision and Control*, pp. 6575–6580, December 2006.

[9] P. Valdastri, R. Webster III, C. Quaglia, M. Quirini, A. Menciassi, and P. Dario, "A new mechanism for mesoscale legged locomotion in compliant tubular environments," *IEEE Transactions on Robotics*, vol. 25, no. 5, pp. 1047–1057, 2009.

[10] Y. Liu, H. Yu, and T. Yang, "Analysis and Control of a Capsubot," in Proceedings of the 17th World Congress the International Federation of Automatic Control, July 2008.

Claims

1. A device for medical use comprising a capsule body having an inertial mass and means for selectively moving the inertial mass so that the capsule body is urged to move, and further comprising outwardly deployable engagement means for engaging with an external surface and means for moving the engagement means for translation of the capsule body.

2. A device according to claim 1, wherein the means for selectively moving the inertial mass comprises an actuator, wherein the outwardly deployable engagement means comprise plural legs, said legs being mounted to the capsule body to be rotatable with respect thereto and further comprising gripping means selectively operable in a first (legless) mode to allow said inertial mass to be moved on its own and in a second (legged) mode to cause movement of the inertial mass to rotate said legs with respect to the capsule body.

3. A device according to claim 2, having two actuators, each with an associated inertial mass, two sets of legs, each set having associated gripping means.

4. A device according to claim 2 or 3, wherein the or each gripping means has an associated electromagnetic means operable to cause it to grip the associated inertial mass.

5. A device according to any preceding claim, wherein the or each means for selectively moving the inertial mass comprises a solenoid or linear motor, and the inertial mass is the rod of the solenoid or linear motor.

6. A device according to any preceding claim having at least one battery for supply of power to on board components.

7. A device according to claim 6, further comprising a wireless control device.

8. A device according to any preceding claim wherein the capsule body carries one or both of a camera and biopsy means.

9 A method of moving a capsule body within the channel of a tubular structure comprising selectively moving an inertial mass within the capsule body to urge the body to translate with respect to the channel and selectively outwardly deploying engagement means into engagement with the wall of the channel, and causing the engaged engagement means to move with respect to the capsule body whereby the capsule body moves with respect to the channel.

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Application No:	GB1121367.5	**Examiner:**	Andrew Hughes
Claims searched:	1-9	**Date of search:**	19 March 2012

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1,5-9	HUDA et al., "Self-contained capsubot propulsion mechanism", International Journal of Automation and Computing 8(3), pp348-356, August 2011 XP019938380; DOI 10.1007/s11633-011-0591-3; ISSN 1751-8520.
Y	1,5-9	RO 126268 A2 (INSTITUTUL DE MECANICA SOLIDELOR AL ACADEMIEI ROMANE)
Y	1,5-9	JP 2006280638 A (GAKUEN)
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Y	1,5-9	GB 2437339 A (NASIROV et al.)

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A	1,5-9	SU 1169765 A1 (MAMAI et al.)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

A61B; F16L

The following online and other databases have been used in the preparation of this search report

EPODOC & WPI

International Classification:

Subclass	Subgroup	Valid From
A61B	0001/00	01/01/2006
F16L	0055/34	01/01/2006