



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : G06F , A61B 19/00, G06F 3/00	A2	(11) International Publication Number: WO 98/24017 (43) International Publication Date: 4 June 1998 (04.06.98)
(21) International Application Number: PCT/GB97/03166 (22) International Filing Date: 26 November 1997 (26.11.97) (30) Priority Data: 9624486.8 26 November 1996 (26.11.96) GB (71) Applicant (for all designated States except US): UNIVERSITY OF BRISTOL [GB/GB]; Senate House, Tyndale Avenue, Bristol BS1 1TH (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): GRIFFITHS, Mansel, Valmond [GB/GB]; 2 Clifton Park, Clifton, Bristol BS8 3BS (GB). BRETT, Peter, Nigel [GB/GB]; Pendragon, 3 Manor Road, Salford, Bristol BS31 3DL (GB). TRITTO, Giuseppe [IT/FR]; 25, rue des Grands Augustins, F-75006 Paris (FR). STONE, Rhodri, Simon, Watcyn [GB/GB]; Troedrhwiwer, Rhandirmwyn, Llandoverly, Dyfed SA20 0PN (GB). (74) Agent: HOGG, Jeffery, Keith; Withers & Rogers, 4 Dyer's Buildings, Holborn, London EC1N 2JT (GB).		(81) Designated States: GB, JP, KR, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>Without international search report and to be republished upon receipt of that report.</i>
(54) Title: CONTROL MEANS (57) Abstract This invention relates to control means and actuators (1) with feed-back sensors (5) suitable for use in tele-operated systems, especially surgical tools and endoscopes. A membrane (9) is provided to flex with an operator's finger, and a sensor (20) responsive to longitudinal flexing of the membrane produces an output signal dependent on the position of the finger. The membrane (9) covers the finger like a glove, and extends across the back of the hand. The sensor (20) preferably comprises an optic fibre (13). The actuator (1) is fluid-operated and comprises a corrugated tube (7) with a length-restraining member (8) along one side so that the tube curves when it is extended by internal fluid pressure. A feedback sensor (5) is responsive to the position of the tube (7) and/or lateral force experienced by the tube (7) when it engages an external object. A feedback signal from the sensor (5) operates a feedback force generator (3) in contact with the operator's finger.		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

CONTROL MEANS

This invention relates to control means and actuators with feed-back sensors suitable for use in tele-operated systems, especially surgical tools and endoscopes.

Endoscopes are used increasingly in minimally invasive surgery for the delivery of surgical tools for internal inspection and treatment of patients. Preferably, endoscopes and tools should be steerable, and should incorporate sensors to produce position and/or force feedback signals to an operator. Also, it is important that the control means provided to steer or operate endoscopes or tools should be natural and simple to operate so as to make them easier and safer to use. The steering actuators and sensors used must also be designed with safety in mind, and would preferably be fail-safe. Also, all equipment should be sterilisable, and would preferably be disposable if it would be made low cost.

According to one aspect, the invention consists in a control process and apparatus involving provision of a membrane to move with an operator's finger so as to flex with it, and a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of the finger.

This arrangement makes use of the finger's natural ability to

make precise control movements, and harnesses this ability using an associated membrane and sensor without impairing the finger's sensitivity.

Preferably, the membrane is resilient and is fitted to the finger in a longitudinally pre-tensioned state so as to closely follow bending movement of the finger. To this end, the membrane may be attached to the operator's wrist.

Preferably, the membrane covers the finger like the finger of a glove, and preferably extends from the finger across the back of the hand.

Conveniently, the control means according to the invention may be incorporated in a full glove. Multiple sensors may then be attached to the back of the glove to sense the position of one or more fingers.

In this application, the sensor preferably comprises a non-electrical sensing element. For example, an optic fibre may be arranged longitudinally to flex with the finger so that light transmitted through it is attenuated by such flexing. Alternatively, two lengths of optic fibre can be attached to the membrane with adjacent ends spaced apart in longitudinal alignment so that the spacing therebetween varies with strain in the membrane as the finger flexes, thereby attenuating the light transmitted between said ends. An advantage of this arrangement is that the optic fibres can be located remote from

the finger, for example, in an extension of the membrane on the back of the hand.

In another alternative arrangement, the sensor may comprise a non-optical form of sensor and may be adapted to sense strain in the membrane. This sensor may be located remotely from the finger.

A signal processor is provided to receive the output signal from the sensor and produce an output control signal to control an actuator in accordance with the position of the finger.

The actuator may be an actuator that steers an endoscope or which operates a surgical tool.

In other embodiments of the invention, the movement of an operator's finger is used to select modes of operation of equipment and operate switch devices. This is useful where the operator is already manipulating equipment by hand control and a suitable finger is free for use in this manner. If required, two or more fingers can be used each to control a separate operation.

According to a second aspect, the invention consists in a fluid-operated actuator comprising a corrugated tube with a length-restraining member along one side so that the tube curves towards said one side when it is extended by internal fluid pressure.

An actuator may comprise a single corrugated tube to allow steering in one plane through the tube's longitudinal axis. However, multiple tubes can be combined extending alongside one another so as to allow steering in multiple different planes depending on fluid pressure applied to the tubes.

Preferably, the actuator is provided with a feedback sensor that is responsive to the position of the tube and/or lateral force experienced by the tube in engagement with an external object.

The feedback sensor may be attached to a resilient restraining member, and may comprise an optic fibre or non-optic fibre sensor responsive to strain in the restraining member. Two or more feedback sensors may be provided along the length of the restraining member to determine the position and/or force experienced by the actuator in use.

Alternatively, the feedback sensor may comprise a cover or envelope that covers the corrugated tube or tubes, and which incorporates one or more sensors that sense strain in the cover as it flexes with the tube.

A feedback processor is provided to process a feedback signal received from the feedback sensor and produce a corresponding feedback control signal which operates a feedback force generator in contact with an operator's finger controlling the actuator.

The actuator may be an actuator that steers an endoscope or which operates a surgical tool.

According to a third aspect, the invention consists in an aid for an injured hand comprising a membrane adapted to fit one finger of the hand so as to flex with it, a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of said one finger, and an actuator that stimulates an injured finger of said hand or operates a prosthetic finger so that it flexes in synchronism with said one finger.

The injured finger or prosthetic finger may have a membrane adapted to fit it so as to flex therewith, and a feedback sensor responsive to the position and/or lateral force experienced by the injured finger or prosthetic finger so as to produce a feedback signal operating a feedback force generator to apply a corresponding force to the hand or arm.

The invention may involve a glove having one finger to receive said one finger, and another finger to receive said injured finger or prosthetic finger, the finger of the glove in each case comprising the associated membrane.

The sensor associated with each of said fingers is preferably attached to the back of the glove and may comprise optic fibre sensors.

The feedback force generator may comprise a braille output transducer.

According to a fourth aspect, the invention consist in an aid for an injured limb comprising a membrane adapted to fit a finger of a patient's hand so as to flex with it, a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of said one finger, and an actuator that stimulates said injured limb or a prosthetic limb so that it flexes in accordance with movement of said one finger.

The injured limb or prosthetic limb may have a membrane adapted to fit it so as to flex therewith, and a feedback sensor responsive to the position and/or lateral force experienced by the injured limb or prosthetic limb so as to produce a feedback signal operating a feedback force generator to apply a corresponding force to the patient's hand or arm or other part of the body.

According to a fifth aspect, the invention consists in means to measure movement of a member comprising a membrane attached to said member, and a sensor responsive to flexing of the membrane so as to produce an output measuring signal dependent on the position of said member.

Said member may comprise a limb so that the measuring means serves as physiotherapy apparatus to measure movement and force

exerted by an injured limb. However, said member may comprise any member that needs monitoring.

According to a sixth aspect, the invention consists in a process and apparatus for sensing movement of a member involving provision of a membrane to move with the member so as to be strained by said movement, and two lengths of optic fibre attached to the membrane with adjacent ends spaced apart in longitudinal alignment so that the spacing therebetween varies with strain in the membrane as the member moves, thereby attenuating the light transmitted between said ends.

Preferably, the two lengths of optic fibre are guided in a closely fitting sleeve so that they are held in alignment as they move longitudinally relative to one another with flexing of the membrane. The sleeve may be the cover normally provided on optic fibres, the ends of the two fibres being stripped and inserted into a short length of the cover. The two lengths of optic fibre may conveniently be produced by cutting a length of fibre into two and rejoining the ends via the sleeve. A suitable adhesive is used to attach the sleeve and optic fibres to the membrane, the adhesive being resilient to accommodate strain in the membrane and movement of the fibres.

The invention will now be described by way of example with reference to the accompanying drawings.

A schematic of a steerable endoscope is shown in Figure 1. The endoscope consists of a steering actuator 1 with integral sensing 5. The sensing requires interpretation to enable the data to be converted to indicate both position and force distribution.

The user control interface 2 has sensing to determine the position required by the user. The interface also has feedback actuation 3 to enable force feedback to be felt by the operator.

The system operates via a controller 4 which receives the position input from the user interface 2 in accordance with the position of the operator's finger. In response to a change in position, the controller 4 moves the actuator 1 to the position required.

Whilst under actuation, the endoscope tip may come into contact with an object. The position of contact and force is detected by the tactile sensor 5. This information is used by the user interface to resist the movement of the operator's finger in proportion to the measured feedback force.

The design of the actuator as incorporated in the steerable tip of the endoscope is shown in Figure 2. The actuator is manufactured from bellowed polymer tube 7 and incorporates a machined nylon insert 6. The insert is fixed in place with adhesive and forms an air-tight chamber within the bellowed

tube. The insert has a restraining strip 8 that runs up one side of the tubing. When the chamber is pressurised, the bellowed tube attempts to expand longitudinally. As one edge is restrained by the insert this has the effect instead of curling the tubing. The result is a controllable finger action that may be actuated by either pneumatic or by hydraulic pressure.

The sensor 5 is used to determine both position and force and uses the known deformation characteristics of the restraining strip 8 whilst the chamber is under pressure.

The sensor 5 may comprise a strain gauge, but is preferably an optic fibre sensor.

The use of optic fibre enables an inexpensive form of sensing to be utilised that is also electrically isolated. The fibres used are plastic and the light source and receiver are infra-red light emitting diodes and receivers. The fibres may be attached to the restraining strip 8 within the chamber of the endoscope. The sensing system relies on the attenuation of light transmitted through the fibre when bending occurs. The resulting output from the sensor is non-linear but gives a good indication of bending by varying light levels. It is possible to instrument a number of positions on the restraining strip to enable the shape of the beam to be determined.

The user interface 2 requires a method of control that is natural to the user, thus allowing control of the device to be mastered quickly and enabling the user to become skilled in its operation. This will also reduce the likelihood of an operator error occurring while using the device.

To provide such an interface, control means is proposed in the form of a "skin" that the user wears. The skin 9 is thin and is constructed from a rubber material and is worn on the operator's finger as shown in Figure 3. A sensor is attached to the skin to give accurate information about the position of the finger.

It is preferable to use an unobtrusive sensor that does not affect the user's tactile experience. This has been found possible by the use of a fibre optic sensor which gives greater potential for low cost, disposable units to be built.

The fibres are fixed to the skin in a similar arrangement to the endoscope tip. The tension created in the skin when the user's finger is flexed, generates a signal by attenuation of the light transmitted through the waveguide and detection of this by the receiving photo-transistor.

A calibration procedure allows adjustment for the size of the user's finger. This procedure enables the system to calculate the range of operation by values obtained when the finger is straight and flexed to the maximum position.

This instrumented skin also may be used in the same way to instrument the endoscope tip.

To facilitate a fully integrated system, feedback actuation 3 is provided to relay the forces measured at the endoscope tip to the user's finger. This utilises an air bag that can be inflated to preset pressure. The system operates at a very low pressure of maximum 37kpa.

The arrangement is shown in Figure 4. The air bag 10 is contained within a vessel so as to direct the force of inflation onto the user's finger.

As an alternative optic fibre sensor for use in the endoscope tip or the user control interface, a fibre 13 can be cut at a measuring point along its length, as shown in Figure 5, so that adjacent ends are spaced apart, and the distance therebetween varies with flexing of the substrate to which it is attached. An optic fibre sleeve 11 is provided as a close fit to hold the two ends of the fibre in longitudinal alignment, and the sleeve 11 and optic fibre are attached by resilient silicone adhesive 12 to the substrate. In the case of an elastic substrate, such as the membrane 9, a strain in the membrane will cause the ends of the fibre to move apart, and this is accommodated by the resilient adhesive 12.

Figure 6 illustrates an alternative form of steerable endoscope tip in which two chambers are formed at spaced sections along the length of the bellowed tube 7 to allow independent

operation of these respective sections and vary the overall curvature of the tip.

Figure 7 illustrates a steerable endoscope or tool which is steered in more than one direction by virtue of multiple corrugated tubes that can be selectively pressurised. Four such tubes 7 are provided extending alongside one another, and a single restraining tie 8 is provided along the centre of the tubes so that the tip bends to the side in any direction depending upon the pressurisation of the four tubes 7.

In order to sense the position and force exerted by the tip in the device of Figure 7, an elastic cover 15 is provided over the four tubes 7, and multiple sensors 16 are attached to the cover to sense strain in the cover 15. The sensors are preferably optic fibre sensors shown in Figure 5. Signals derived from the sensors 16, and pressurisation values of the four tubes 7, are combined with a knowledge of the bending characteristics of the tip to determine the position of the tip and resulting applied force.

In an alternative embodiment, the tie 8 can be made of elastic material so that the tip is extensible and its length is controlled by the combined forces produced in pressurising the tubes 7.

Although the embodiments of the invention described above serve to control bending movements of a device, it is equally

applicable to control axial extension or torsional movements in a device.

The invention is applicable to a wide range of surgical operations of which the following are typical:

- *Control of flexible structures and mechanisms to maintain the position of tissues and tissue structures
- *Application of temperatures or ultrasound probes
- *Surface mapping within a human body
- *Palpation
- *Guidance along cavities or surfaces by touch
- *Control of cutting tools
- *Control of penetrating tools
- *Visual inspection through directional control of the visual envelope

Figure 8 illustrates a hand 17 fitted with a prosthetic finger 18 that is controlled according to the invention. An elastic glove 19 fits over the hand including the prosthetic finger, and multiple fibre-optic sensors 20 are attached to the back of the hand to monitor movement of a healthy finger 21 and to produce output signals which are converted by a controller 22 to a position signal in accordance with the position of the finger 21. This position signal in turn is used to control movement of the prosthetic finger 18 via an associated actuator, which may take the form shown in Figure 2. The sensors 20 are also located to produce output signals that can be processed by the controller 22 to determine the position of

the prosthetic finger 18 and/or the force experienced by it. A feedback signal is therefore generated by the controller 22 which allows closed-loop control and also allows a feedback actuator 23 to be operated to give the patient a tactile experience of the force applied by the prosthetic finger. This feedback actuator may take the form of a braille output transducer.

CLAIMS

1. Control apparatus comprising a membrane adapted to cooperate with an operator's finger so as to flex with it, and a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of the finger.
2. Apparatus as claimed in claim 1 in which the membrane is resilient and is adapted to be fitted to the finger in a longitudinally pre-tensioned state so as to closely follow bending movement of the finger.
3. Apparatus as claimed in claim 2 in which the membrane is adapted to be attached to the operator's wrist.
4. Apparatus as claimed in claim 3 in which the membrane is adapted to cover the finger like the finger of a glove, and preferably extends from the finger across the back of the hand.
5. Apparatus as claimed in claim 4 in which the membrane is incorporated in a glove.
6. Apparatus as claimed in claim 5 in which multiple sensors are attached to the back of the glove to sense the position of one or more fingers.

7. Apparatus as claimed in any of the preceding claims in which the sensor comprises a non-electrical sensing element.

8. Apparatus as claimed in claim 7 in which the sensor comprises an optic fibre arranged longitudinally to flex with the finger so that light transmitted through it is attenuated by such flexing.

9. Apparatus as claimed in claim 7 in which the sensor comprises two lengths of optic fibre attached to the membrane with adjacent ends spaced apart in longitudinal alignment so that the spacing therebetween varies with strain in the membrane as the finger flexes, thereby attenuating the light transmitted between said ends.

10. Apparatus as claimed in claim 7 in which the sensor comprises a non-optical form of sensor adapted to sense strain in the membrane.

11. Apparatus as claimed in claim 8, 9 or 10 in which the sensor is located remote from the finger in an extension of the membrane on the back of the operator's hand.

12. Apparatus as claimed in any one of the preceding claims including a signal processor to receive the output signal from the sensor and produce an output control signal in accordance with the position of the finger, and an actuator responsive to said output control signal.

13. Apparatus as claimed in claim 12 in which the actuator is an actuator that steers an endoscope or operates a surgical tool.

14. Apparatus as claimed in any one of claims 1 to 11 including means responsive to said output signal.

15. A fluid-operated actuator comprising a corrugated tube with a length-restraining member along one side so that the tube curves towards said one side when it is extended by internal fluid pressure.

16. An actuator as claimed in claim 15 which comprises a single corrugated tube to allow steering in one plane through the tube's longitudinal axis.

17. An actuator as claimed in claim 15 comprising multiple tubes combined extending alongside one another and each with a length restraining member along one side so as to allow steering in multiple different planes depending on fluid pressure applied to the tubes.

18. An actuator as claimed in any one of claims 15 to 17 provided with a feedback sensor responsive to the position of the tube and/or lateral force experienced by the tube in engagement with an external object.

19. An actuator as claimed in claim 18 in which the feedback

sensor is attached to a resilient restraining member.

20. An actuator as claimed in claim 19 in which the feedback sensor is responsive to strain in the restraining member.

21. An actuator as claimed in any one of claims 18 to 20 comprising two or more feedback sensors provided along the length of the restraining member to determine the position and/or force experienced by the actuator in use.

22. An actuator as claimed in claim 18 in which the feedback sensor comprises a cover that covers the corrugated tube or tubes, and which incorporates one or more sensors that sense strain in the cover as it flexes with the tube.

23. An actuator as claimed in claim 18 comprising a feedback processor to process a feedback signal received from the feedback sensor and produce a corresponding feedback control signal, and a feedback force generator adapted to contact an operator's finger controlling the actuator and responsive to said feedback control signal.

24. An actuator as claimed in any one of claims 15 to 23 that steers an endoscope or operates a surgical tool.

25. An aid for an injured hand comprising a membrane adapted to fit one finger of the hand so as to flex with it, a sensor responsive to longitudinal flexing of the membrane so as to

produce an output signal dependent on the position of said one finger, and an actuator that stimulates an injured finger of said hand or operates a prosthetic finger so that it flexes in synchronism with said one finger.

26. An aid as claimed in claim 25 in which the injured finger or prosthetic finger has a membrane adapted to fit it so as to flex therewith, and a feedback sensor responsive to the position and/or lateral force experienced by the injured finger or prosthetic finger so as to produce a feedback signal operating a feedback force generator to apply a corresponding force to the hand or arm.

27. An aid as claimed in claim 25 or 26 comprising a glove having one finger to receive said one finger, and another finger to receive said injured finger or prosthetic finger, the finger of the glove in each case comprising the associated membrane.

28. An aid as claimed in claim 27 in which the sensor associated with each of said fingers is attached to the back of the glove.

29. An aid as claimed in any one of claims 25 to 28 in which the feedback force generator comprises a braille output transducer.

30. An aid for an injured limb comprising a membrane adapted

to fit a finger of a patient's hand so as to flex with it, a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of said one finger, and an actuator that stimulates said injured limb or a prosthetic limb so that it flexes in accordance with movement of said one finger.

31. An aid as claimed in claim 30 in which the injured limb or prosthetic limb has a membrane adapted to fit it so as to flex therewith, and a feedback sensor responsive to the position and/or lateral force experienced by the injured limb or prosthetic limb so as to produce a feedback signal operating a feedback force generator to apply a corresponding force to the patient's hand or arm or other part of the body.

32. Means to measure movement of a member comprising a membrane attached to said member, and a sensor responsive to flexing of the membrane so as to produce an output measuring signal dependent on the position of said member.

33. Means as claimed in claim 32 in which said member comprises a limb so that the measuring means serves as physiotherapy apparatus to measure movement and force exerted by an injured limb.

34. Apparatus for sensing movement of a member involving comprising a membrane adapted to move with the member so as to be strained by said movement, and two lengths of optic fibre

attached to the membrane with adjacent ends spaced apart in longitudinal alignment so that the spacing therebetween varies with strain in the membrane as the member moves, thereby attenuating the light transmitted between said ends.

35. Apparatus as claimed in claim 34 in which the two lengths of optic fibre are guided in a closely fitting sleeve so that they are held in alignment as they move longitudinally relative to one another with flexing of the membrane.

36. Apparatus as claimed in claim 35 in which the sleeve is the cover normally provided on optic fibres, the ends of the two fibres being stripped and inserted into a short length of the cover.

37. Apparatus as claimed in claim 36 in which a suitable adhesive is used to attach the sleeve and optic fibres to the membrane, the adhesive being resilient to accommodate strain in the membrane and movement of the fibres.

38. A control process comprising provision of a membrane to move with an operator's finger so as to flex with it, and a sensor responsive to longitudinal flexing of the membrane so as to produce an output signal dependent on the position of the finger.

39. A control process as claimed in claim 38 in which a signal processor is provided to receive the output signal from the

sensor and produce an output control signal to control an actuator in accordance with the position of the finger.

40. A control process as claimed in claim 39 in which the actuator is an actuator that steers an endoscope or which operates a surgical tool.

41. A control process as claimed in claim 38 in which the movement of the operator's finger is used to select modes of operation of equipment or operate switch devices.

42. A control process as claimed in claim 41 where the operator is manipulating equipment by hand control and a finger is free for position of said membrane.

43. A control process as claimed in claim 39 or 40 in which the actuator is provided with a feedback sensor that is responsive to the position of the tube and/or lateral force experienced by the tube in engagement with an external object.

44. A control process as claimed in claim 43 in which a feedback processor is provided to process a feedback signal received from the feedback sensor and produce a corresponding feedback control signal which operates a feedback force generator in contact with an operator's finger controlling the actuator.

45. A process for sensing movement of a member involving

provision of a membrane to move with the member so as to be strained by said movement, and two lengths of optic fibre attached to the membrane with adjacent ends spaced apart in longitudinal alignment so that the spacing therebetween varies with strain in the membrane as the member moves, thereby attenuating the light transmitted between said ends.

46. Apparatus substantially as herein described with reference to the accompanying drawings.

47. A process substantially as herein described with reference to the accompanying drawings.

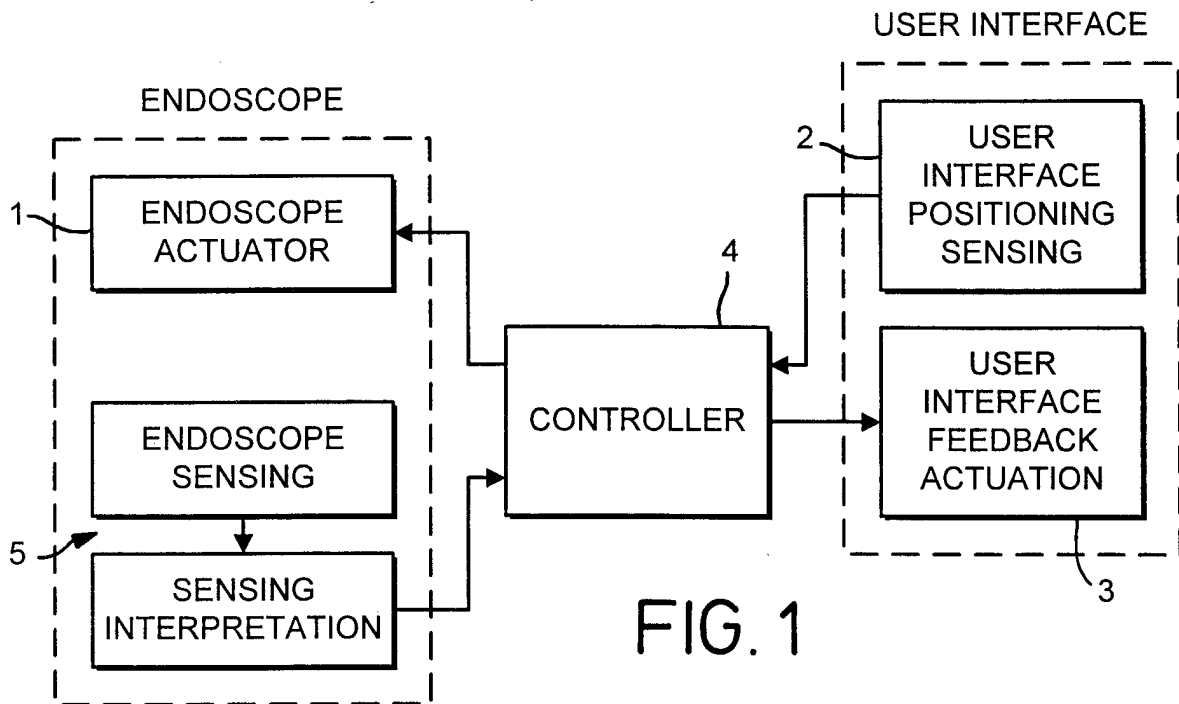


FIG. 1

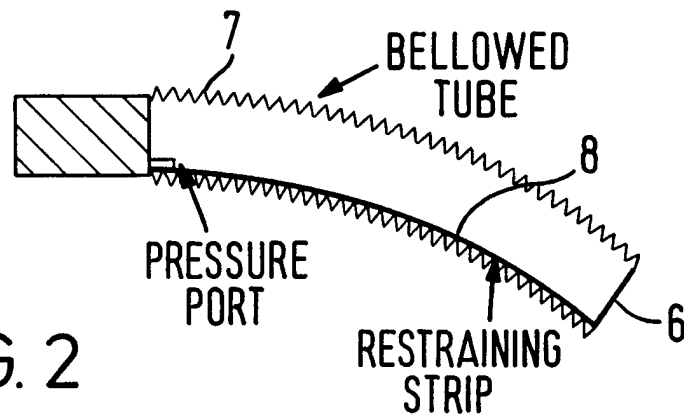


FIG. 2

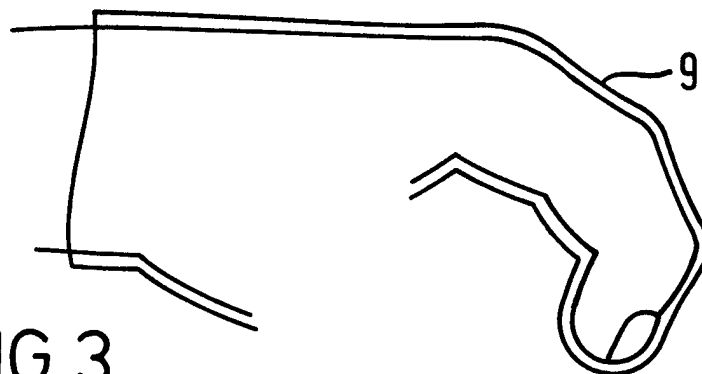
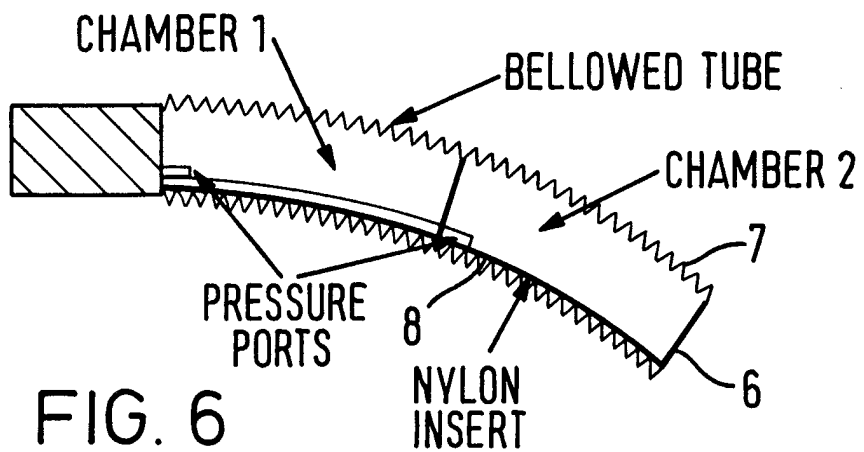
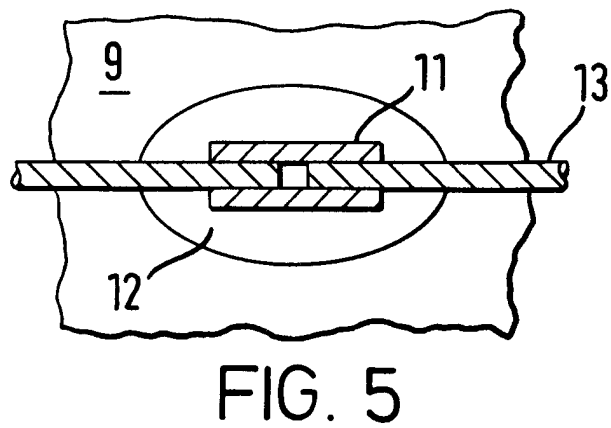
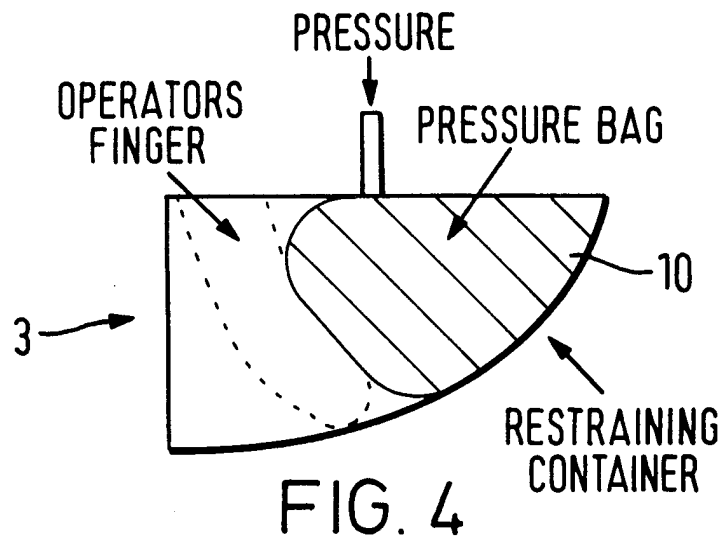


FIG. 3

2 / 3



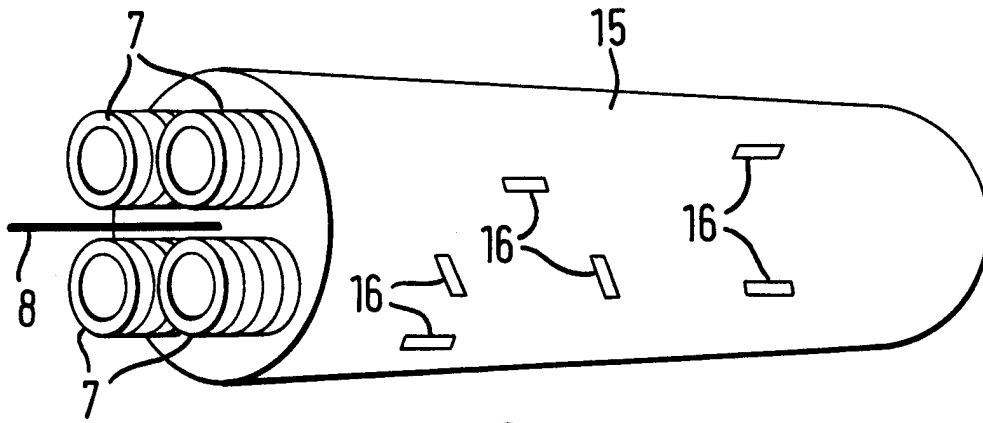


FIG. 7

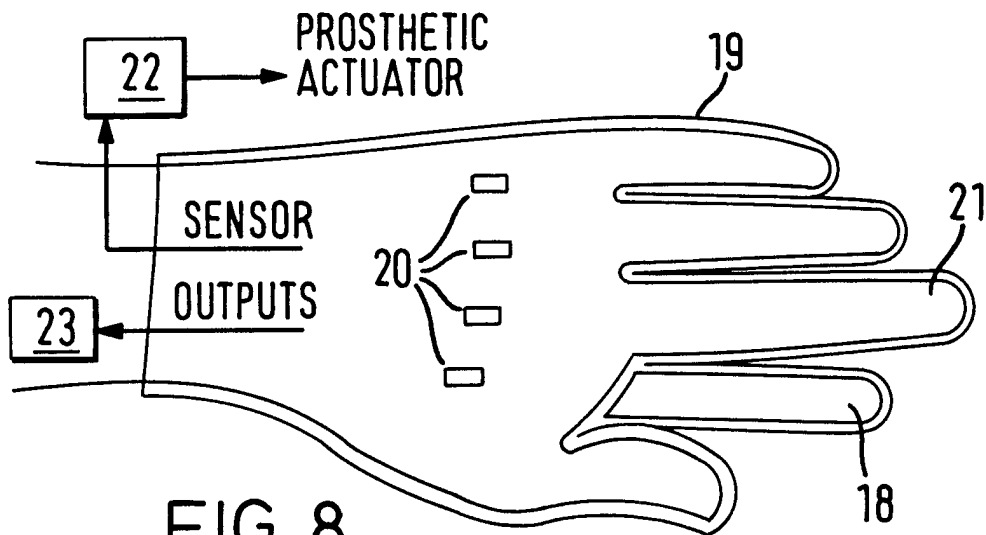


FIG. 8