Fig. 1

INVENTORS
VICTOR C. ANDERSON
RONALD C. HORN

BY

ERVIN F. JOHNSTON
ATTORNEY
TENSOR ARM MANIPULATOR

Victor C. Anderson, San Diego, Calif., and Ronald C. Horn, Springfield, Ill., assignors, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Filed May 10, 1968, Ser. No. 728,211
Int. Cl. B25J 9/00

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The Navy's man-in-the-sea program has become a reality with the Sealab I and Sealab II projects. These projects have been primarily directed toward testing the capability of man to work on the continental shelf areas of the oceans. The average depth of the continental shelves is approximately 600 feet which is only a small fraction of the average depth of the oceans, which is approximately 12,000 feet. Accordingly, a detailed study of the deep ocean area must be carried on by man in a high pressure diving hull or with bottom located equipment and instrumentation which can collect data either automatically or by remote control operation.

One approach for prolonged study of the ocean bottom has been the Benthic Laboratory. This laboratory, which was used in support of the Sealab II project in 1965, is a bottom located inverted dome which is filled with kerosene and has along its inner periphery a series of plug-in electronic modules. These plug-in modules provide the circuitry for the collection and dissemination of ocean bottom data. It is envisioned that the Benthic Laboratory will become a permanent fixture on the deep ocean floor and that various remotely controlled bottom vehicles, which are controlled by the laboratory, will collect ocean data such as core samples, TV viewing, and temperature and current data.

It is necessary in the Benthic Laboratory to occasionally repopulate TV cameras, operate switches, mate connectors, and remove and replace modules. Because of the permanency of the Benthic Laboratory on the ocean floor and its operation without the aid of man in attendance thereof, it has become necessary to provide a manipulator substitute for man's arms to perform the necessary work functions. The present invention provides such an arm substitute which will enable remote functions as described above. The present manipulator includes a series of plates which are interconnected by universal joints for pivotable action with respect to one another. Each of the plates has a plurality of apertures. Extending through these apertures is a plurality of tendons which are connected at one set of ends to selected plates. Accordingly, upon selectively pulling opposite ends of the tendons the plates can be pivoted to desired positions resulting in a snake-like movement of the entire arm assembly. One end of the manipulator may be provided with fingers or a tool which may also be operated by the tendons. The tendons may be selectively pulled by means including a computer which is programmed to perform work functions of the arm and fingers to achieve desired work functions.

An object of the present invention is to provide a manipulator which has dexterity similar to the human arm.

Another object is to provide an arm manipulator which can be positioned in six spatial coordinates by simply selectively tensing a series of tendons.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a side view partially in cross-section of the tensor arm manipulator shown in a partially bent position;

FIG. 2 is an exploded isometric view of one of the plates and universal joints of the tensor arm manipulator, such as plate 1; and

FIG. 3 is a vertical partial cross-section view of one of the plates, such as plate I, and universal joint portion of the tensor arm manipulator.

Referring now to the drawings wherein like reference numerals designate like or similar parts throughout the several views, there is shown in FIG. 1 a tensor arm manipulator 10 which has a series of plates 12 which will be individually referred to by letter designations A through K. Each plate has a central axis 14. The plates 12 are interconnected by universal joints 15, or the like, so that the plates may pivot with respect to one another and may be aligned along a common central axis 16.

Each of the plates 12 is provided with a plurality of apertures 18 which are simultaneously aligned with apertures of adjacent plates when the plates are aligned along their common axis 16. In FIG. 1 the apertures of plates A through D are so aligned. A plurality of tendons 20, which may be monofilament nylon cord, extend through the apertures 18 of the plates and are connected to one set of ends to selected plate locations. As shown in plate E, this connection may be made by a plug 22 bonded to the end of the tendon and fitted within a counterbore provision within the plate body. Upon selective pulling of the tendons from the left side of plate A the plates 12 can be pivoted to desired positions about the common axis 16. To the right end plate K there may be mounted a tool means 24 which may be operated by a portion of the tendons for performing work functions on various equipment. This tool will be described in more detail hereinafter.

The degree of macrodexterity of the manipulator arm 10 depends upon the number of plates utilized and the ratio of the plate diameters to the spacing therebetween. As a minimum the manipulator arm should include the two end plates A and K with a plurality of plates 12 therebetween. In one embodiment constructed I used a plate diameter to plate spacing ratio of 4.8 for plates A through E; a ratio of 4.0 for plates F through H; and a ratio of 3.0 for plates I through K. The same spacing
3,497,083

In order to obtain the desired movement of the plates the tendons 20 are connected to the plates at selected radial locations. We have obtained maximum macrodexterity of the arm 10 by connecting four tendons to each plate 12, with the exception of the left end plate A, the four tendons being at 90° intervals in the circular row about the central axis of the plate. This arrangement can be seen in plates E and H of FIG. 1. Accordingly, the plates 12, with the exception of end plate A, can be rotated within two planes of movement by selectively pulling tendons which are diametrically displaced from one another. With such an arrangement the four tendons connected to the end plate K slidably extend through the adjacent plate J and the four tendons connected to the plate J plus the four tendons connected to the end plate K slidably extend through the next adjacent plate I, and so on as the plates progress to the left of the arm manipulator 10. Accordingly, it is apparent that a total of 40 tendons will slidably pass through the end plate A. If desired, the end plate A may be mounted to fixed structure (not shown) which is in a convenient place for the operation of the manipulator arm 10.

In order to ensure good slidable action between the tendons 20 and the plates 12 each had inserted sleeves 30 at the plate locations where the tendons pass through. These sleeves, which may be constructed of Teflon, may be slightly inwardly rounded within their inner bore to prevent edge abrasion with the tendons. Further, we have found it desirable to construct each plate 12 of two plates like sections 32 which are held in tight engagement with one another by frictional engagement with the sleeves 30. Accordingly, the sleeves 30 are slightly force fitted in each of the plate sections 32 to retain the sections 32 together for forming a plate 12. The purpose of these plate sections will be described in detail hereinafter. In order to prevent longitudinal movement of the sleeves 30 within the plate sections 32, the sleeves may have necked down portions, as shown in FIG. 2.

The universal joints 15 may comprise body portions 34 and spiders 36. Each body portion 34 may have a pair of diametrically opposed yokes 38 and 40, and the spiders 36 may have a central body portion to which there are connected radially extending pins 42 at 90° intervals thereabout. The yokes 38 and 40 are journaled to pivot on respective pairs of pins 42 and Teflon sleeve bearings 44 may be slip fitted on the pins 42 for ensuring smooth pivoting action. Each plate section 32 may have a large central aperture 46 which slidably receives the universal joint body 34 and is counterbored to slidably receive an annular flange 48 which is located on the joint body between the yoke portions 38 and 40. A ring bearing 50, which may be made of Teflon, may be placed between the annular flange 48 and the counterbores of the plate sections 32 so as to ensure smooth rotative action of the joint body 34 within the plate sections. When the plate sections 32 are brought together on each side of the annular flange 48 with the sleeves 30 in place, the joint body 34 is retained for smooth rotative action about the central axis of each plate 12.

The tool means 24 may be actuated by a portion of the tendons 20. For this purpose, we have found it desirable to provide a series of apertures in each of the body portions of the spiders 36 for slidably receiving tendons which are connected to the tool means 24 and extend out through the left end plate A. Accordingly, by selectively pulling these centrally located tendons the tool means 24 can be actuated to perform desired work functions.

As shown in FIG. 1, the tool means 24 may include a pair of fingers 52 which extend through an opening 54 of a cylindrical housing 56, the housing 56 being mounted to the outer side of plate K. In order to mount the housing 56 to plate K the housing 56 may have a flange 58 at its inner end which is received in the counterbore of the plate sections 32 of plate K. The fingers 52 have tabs 60 which are pivotally connected to the housing 56 by pins 62 which extend through the housing walls. Connected to the fingers 52 opposite the tabs 60 is the portion of the tendons 20 which extends through the spider bodies so that upon pulling these tendons the fingers 52 are pressed together. The tendons may be connected to the fingers 52 by any suitable means such as a bonded plug (not shown). The fingers may have oppositely displaced bores with compression spring 64 disposed therein for returning the fingers to the position shown in FIG. 1.

In the operation of the tensor arm manipulator 10 the tendons 20 to the left of the plate A are selectively pulled to the left to obtain desired movements of the arm and desired work functions by the tool means 24. With selective pulling of the tendons the arm can be moved in a snake-like manner. In FIG. 1 the arm is shown bent between plates D and E and between plates G and H. In order to accomplish this only the bottom tendon which is respectively connected to plates E and H has been pulled. In order to obtain an opposite rotative movement only the top tendon connected respectively to each of these plates need be pulled. If rotation in a plane perpendicular to the drawing is desired the respective tendons 30 from the top and bottom tendons would be pulled. If desired, certain movements of the arm can be programmed into a computer which can in turn be used to operate servos which will selectively pull the tendons 20. By such programming the arm can be operated to travel to various predetermined locations to perform various work functions.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that the invention may be practiced otherwise than as specifically described.

We claim:

1. A tensor arm manipulator comprising: a series of plates spaced one from the other a distance less than the radius of any single plate, each plate having a central axis, and said series of plates normally being aligned with their central axes along a common axis, and a universally jointed spider and yoke assembly connecting adjacent plates one to the other for pivotal action with respect to one another about their common axis;

each of said plates having a plurality of apertures wherein the apertures are simultaneously aligned when the plates are aligned along the common axis; and

a plurality of sets of tendons extending in axial parallel disposition through the apertures of said plates, each of said plates being coupled to a separate set of tendons and each of said separate sets of tendons extending through said apertures of the plates preceding each plate of said plate series.

2. A tensor arm manipulator as claimed in claim 1 wherein:
said plates are equidistant from one another and are of reduced diameter with respect to one another along said common axis.

3. A tensor arm manipulator as claimed in claim 2 wherein:
two sets of tendons are axially fixedly connected to each plate with the locations of fixation being at 90° intervals about the respective central axis.

4. A tensor arm manipulator as claimed in claim 1 wherein:
each universally jointed assembly is formed with at
least one aperture aligned with said common axis; said manipulator further including:
tool means mounted on one end of said series of
plates; and
tendons extending through said universal assembly
apertures and operatively coupled to said tool
means.
5. A tensor arm manipulator as claimed in claim 1
wherein:
each plate is divided into two plate-like sections having
said apertures; and
a plurality of sleeves snugly engage the plate-like sec-
tions within said apertures to retain the sections in
place to form said plates.
6. A tensor arm manipulator as claimed in claim 4
wherein:
each universally coupled assembly comprises a spider
and a pair of yokes pivotable thereon;
each plate-like section having a central aperture which
is counterbored; and
each yoke being journalled between a pair of plate-like
sections for slidable rotatable action about a respec-
tive central axis.

References Cited
UNITED STATES PATENTS
627,203 6/1899 Priest ------------------ 64—2
3,190,286 6/1965 Stokes ------------------ 128—6
3,266,059 8/1966 Stelle.

ROBERT G. SHERIDAN, Primary Examiner
G. F. ABRAHAM, Assistant Examiner

U.S. Cl. X.R.
3—12.3; 46—40, 163; 64—2; 138—120; 287—85