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Sun follower with parallel kinematics and process for controlling such follower

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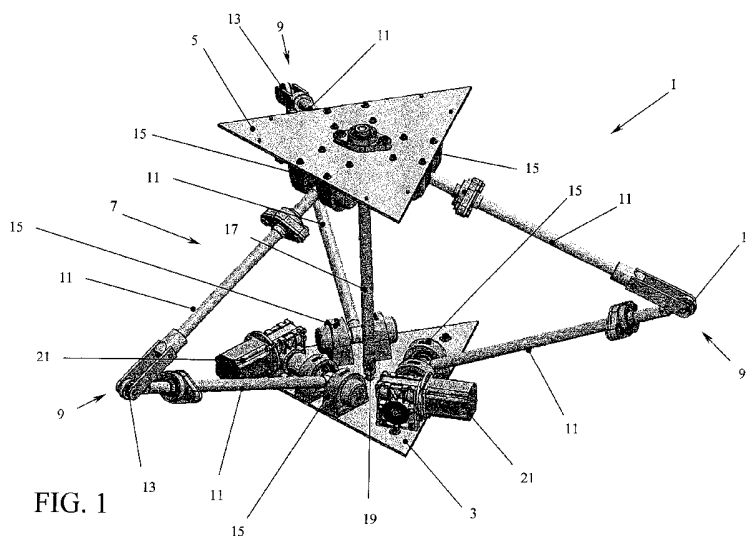
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(54) **Title:** SUN FOLLOWER WITH PARALLEL KINEMATICS AND PROCESS FOR CONTROLLING SUCH FOLLOWER



(57) **Abstract:** A sun follower (1) is described, composed of at least one fixed supporting base (3) and of at least one moving structure (5) controlled and adapted to support at least one photovoltaic module, between such fixed supporting base (3) and such moving structure (5) actuating means with parallel kinematics (7) being interposed, adapted to handle such moving structure (5). A process for controlling such sun follower (1) is also described.

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SUN FOLLOWER WITH PARALLEL KINEMATICS AND PROCESS

5 FOR CONTROLLING SUCH FOLLOWER

The present invention refers to a sun follower with parallel kinematics and to a process for controlling such follower.

10 As known, sun followers, and in particular photovoltaic followers, are structures designed for orienting one or more photovoltaic panels towards the Sun and for keeping constantly near zero the angle between the line perpendicular to the plane
15 of the photovoltaic modules and the direction from which the sun light comes.

This function is commonly performed through serial kinematic structures composed of two rotary axes, one with direction perpendicular to the
20 ground and one with direction parallel to the ground.

Arrangements with parallel kinematics are also known where two plates, one fixed and one moving, are mutually connected through some arms with
25 variable length: the adjustment of these lengths

through motors allows obtaining the orientation of the moving surface.

The sun follower, in order to be able to ensure the complete exploitation of the available sun radiation, must allow orienting the photovoltaic modules towards the Sun during the whole day. For this purpose, the azimuth angle, namely the rotation around an axis perpendicular to the ground, must be able to change in a range included between $\pm 120^\circ$, while the zenith angle, namely the rotation around the axis parallel to the ground, must be able to change from 0° to 90° .

Documents US-A1-2009/199846 and WO-A1-2009/076394 disclose a sun follower according to the preamble of Claim 1.

Therefore, object of the present invention is solving the above prior art problems by providing a follower with parallel kinematics that allows obtaining a high sighting accuracy.

Moreover, an object of the present invention is providing a sun follower with parallel kinematics that allows supporting the photovoltaic module on many abutments.

Another object of the present invention is providing a process for controlling a sun follower

with parallel kinematics that allows obtaining a high sighting accuracy.

The above and other objects and advantages of the invention, as will appear from the following description, are obtained with a sun follower with parallel kinematics as described in claim 1.

Moreover, the above and other objects and advantages of the invention are obtained with a process for controlling a sun follower with parallel kinematics as described in claim 9.

Preferred embodiments and non-trivial variations of the present invention are the subject matter of the dependent claims.

It is intended that the claims are an integral part of the present specification.

It will be immediately obvious that numerous variations and modifications (for example related to shape, sizes, arrangements and parts with equivalent functionality) can be made to what is described, without departing from the scope of the invention as appears from the enclosed claims.

The present invention will be better described by some preferred embodiments thereof, provided as a non-limiting example, with reference to the enclosed drawings, in which:

- Figure 1 shows a top perspective view of an embodiment of the sun follower with parallel kinematics according to the present invention;
- Figure 2 shows a diagram showing the preferred 5 dimensional relationships between the various components of the sun follower according to the present invention;
- Figure 3 shows a block diagram showing some steps of the control process according to the 10 present invention; and
- Figure 4 shows a block diagram showing other steps of the control process according to the present invention.

With reference to Figure 1, it is possible to 15 note that the sun follower 1 according to the present invention is composed of at least one fixed supporting base 3 and of at least one moving structure 5 controlled and adapted to support at least one photovoltaic module (not shown), between 20 such fixed supporting base 3 and such moving structure 5 actuating means with parallel kinematics 7 being interposed, adapted to handle such moving structure 5, and in particular to orient this latter structure 3 towards the Sun and 25 to keep constantly next to zero the angle between

the line perpendicular to the plane of the photovoltaic module and the direction from which the sun light comes. As known, the expression "parallel kinematics" points out the concurrence of
5 movements of the axes of the actuating means whose origin does not depend on the movement of any other axis.

In particular, the actuating means with parallel kinematics 7 of the sun follower 1
10 according to the present invention are closed-kinematics mechanisms, which have great stiffness due to the presence of many kinematic chains adapted to connect the "end-effector" to the fixed supporting base 3 in addition to reduced
15 positioning errors.

Preferably, both the fixed supporting base 3 and the moving structure 5 are made as plates substantially identical one to the other. In particular, the photovoltaic modules are assembled
20 so that they are co-planar to the plate making the moving structure 5.

According to the invention, the actuating means with parallel kinematics 7 comprise three arms 9 composed of kinematic chains having their
25 respective ends operatively connected to the fixed

supporting base 3 and to the moving structure 5,
each one of such arms 9 being composed of at least
two rods 11, preferably having the same length,
mutually connected by interposing at least one
5 first articulating means 13, preferably made as a
ball joint.

The ends of such arms 9 are operatively
connected respectively to the fixed supporting base
3 and to the moving structure 5 in fastening points
10 arranged at 120° one to the other; the ends of such
arms 9 are operatively connected to the fixed
supporting base 3 and to the moving structure 5 by
interposing second articulating means 15,
preferably composed of hinges.

15 Moreover, the fixed supporting base 3 and the
moving structure 5 are mutually connected through
at least one fourth rod 17, whose ends are
operatively and respectively connected to such
fixed supporting base 3 and to such moving
20 structure 5 by interposing respective third
articulating means 19, each one of such third
articulating means 19 being preferably composed of
a ball joint: alternatively, one of such third
articulating means 19 can be a cardan joint.

25 The above-described moving structure 5

therefore has two degrees of freedom in rotation, corresponding to the motion along the azimuth and zenith axes.

Moreover, the actuating means with parallel kinematics comprise at least two motors 21. The control of movements along such two axes can be obtained by adjusting, through such motors 21, the slant of the respective two arms 9 composing the kinematic chains. As shown in Figure 1, preferably each motor 21 can have its related drive shaft keyed onto the axis of the respective lower hinge 15. Alternatively, the motors 21 could be linear motors operating in an intermediate position on the arms 9 whose slant has to be adjusted, and suitably constrained to a frame preferably and functionally integral with the fixed base 3. Possibly, the motors could be keyed-in to the axes of the upper hinges 15.

The geometry of the structure of the actuating means with parallel kinematics 7 can synthetically be described through three dimensional parameters: the distance of the constraint points of the arms 9 of the kinematic chains from the centres of the fixed supporting base 3 and of the moving structure 5, the distance between the same constraint points

and the first articulating means 13 and the distance (fixed) between the centres of the fixed supporting base 3 and of the moving structure 5. These quantities are respectively called "base",
 5 "arm" and "central rod". The lengths of these components are mutually independent. However, so that the structure can explore the whole working space required for a sun follower, it is necessary that these quantities keep well-defined relative
 10 relationships.

Figure 2 shows a diagram that includes the two-dimensional space defined by the quantities $\frac{\text{length_base}}{\text{length_arm}}$ and $\frac{\text{length_central_rod}}{\text{length_arm}}$; the darker space of the diagram of Figure 2 therefore points out a
 15 region so that a follower built with parameters that fall therein allows exploring a working space that comprises an azimuth excursion of at least 240° and a zenith excursion of at least 90°. The abscissa axis contains the value of parameter
 20 $\frac{\text{length_base}}{\text{length_arm}}$, while the ordinate axis contains the values of parameter $\frac{\text{length_central_rod}}{\text{length_arm}}$.

Consequently, from the diagram in Figure 2, it is possible to note that, preferably, the relationship $\frac{\text{length_base}}{\text{length_arm}}$ computed between the distance of the constraint points of the arms 9 of the kinematic chains from the centres of the fixed supporting base 3 and of the moving structure 5 and the distance between the same constraint point and the first articulating means 13 is included between 0.05 and 0.55, while the relationship $\frac{\text{length_central_rod}}{\text{length_arm}}$ computed between the distance between the centres of the fixed supporting base 3 and of the moving structure 5 and the distance between the constraint points of the arms 9 of the kinematic chains and the first articulating means 13 is included between 0.6 and 1.8.

Obviously, the sun follower 1 according to the present invention can work only if managed by suitable sensors and by a specific control process based on a dedicated algorithm, implemented by suitable processing means acting on the motors 21.

The sun follower 1 according to the present invention therefore comprises at least one sun alignment sensor and two sensors for detecting the

angular positions of the two arms 9, such sensors obviously cooperating with the above processing means.

The sun alignment sensor can be composed of
5 four co-planar photo-diodes, mutually separated by two baffles that are perpendicular one to the other and to the plane of the photo-diodes. In general, the baffles shadow at least one of the photo-diodes: only if the plane on which they lie is
10 perfectly aligned with respect to the Sun, all four photo-diodes are lighted and each one of them provides an active output signal. The alignment error allowed so that all photo-diodes are lighted is determined by the geometric characteristics of
15 the sensor. When at least one of the photo-diodes is lighted and provides a signal, it is possible to determine the direction along which it is necessary to move the sensor to align it with the Sun.

The present invention also deals with a
20 process for controlling the above-described sun follower 1, in particular suitable to orient the structure 3 towards the Sun and to keep constantly next to zero the angle between the line perpendicular to the plane of the photovoltaic
25 module and the direction from which the sun light

comes.

In particular, the control process according to the present invention comprises a step of actively following the sun.

5 The step of actively following the sun requires the use of an expressly-devised algorithm whose scheme is included in Figure 3.

In particular, with reference to Figure 3, it is possible to note that the step of actively following the sun is composed of a closed-loop orientation control that allows, through control signals (m_1 and m_2) to the motors 21, to orient the moving structure 5 as desired, due to the feedback of the position signals (angles β_1 and β_2) coming from the two arms 9 composing the kinematic chains actuated by such motors 21 and by the sun alignment sensor (sun).

In order to describe the step of actively following the sun, it is suitable to point out that the actual position of the moving structure 5 can be described univocally through the value of the azimuth and zenith angles, namely through the position assumed by the two arms 9 actuated (space of joints) by the motors 21.

25 In particular, with reference to Figure 4, it

is possible to note that the step of actively following the sun comprises a sub-step in which, through a suitable forward kinematic (FWD KIN) function, per se known, the values of azimuth and zenith angles are determined depending on the position β_1 , β_2 of the actuated arms 9 and a sub-step in which, through a suitable inverse kinematic (INV KIN) function, per se known, the positions β_1 , β_2 are determined, that the actuated arms 9 must reach so that the azimuth and zenith angles assume certain values.

Moreover, always with reference to Figure 4, it is possible to note that the step of actively following the sun comprises a sub-step that processes, through a suitable function G per se known, the signal ls coming from the sun alignment sensor to determine the direction Δ Azimuth, Δ Zenith along which the la moving structure 5 must be moved in order to be oriented perpendicular to the line joining the Sun and compute the related displacements. This function G obviously depends on the type of sun alignment sensor being used.

The values processed by the function G in the sub-step related to the step of actively following the sun are displacement values along the zenith

and azimuth direction, that can be positive or negative according to the required direction. Their modulus is determined depending on the characteristics of the sun alignment sensor.

5 In the step of actively following the sun, the computed displacements are therefore added to the actual zenith and azimuth positions (Zenith, Azimuth), determined through the forward kinematic function depending on the measured values of the
10 actuated angles β_1 , β_2 , thereby obtaining the new reference azimuth and zenith positions (Azimuth ref, Zenith ref).

By processing the reference azimuth and zenith position values (Azimuth ref, Zenith ref), it is
15 possible to compute, through the inverse kinematic function, the new reference values for the actuated angles and, by difference with the measured values, the angular displacement $\Delta\beta_1$, $\Delta\beta_2$ to be obtained, By dividing this value by the amplitude of the
20 single motor-reducer pitch, the number of control signals (m_1 , m_2) is computed, to be sent to the driver of each motor 21, in addition to the motion direction (dir_1 , dir_2).

After having performed the desired
25 displacement, the step of actively following the

sun starts again.

In addition, the process according to the present invention could further comprise other steps common to control processes of prior art sun followers, such as, for example, the following steps:

- a) sighting;
- b) waiting;
- c) safety.

10 In the sighting step, the process according to the present invention takes care of orienting the moving structure 5 approximately depending on the expected Sun position, determined depending on time, date and geographic location.

15 In the waiting step, the process according to the present invention placed the sun follower 1 according to the present invention in a "stand-by" position is the Sun is covered.

20 In the safety step, the process according to the present invention takes care of orienting the moving structure 5 in a parallel position to the ground to provide the minimum resistance, for example during the night or in strong wind situations.

25 Possible variations are obviously determined

by using continuous motors, namely by using alignment sensors of a different type, without thereby departing from the scope of the present invention.

5 In any way, it is fundamental that the necessary movement to reach the alignment conditions determined depending on the signal provided by the alignment sensor in the azimuth-zenith space is composed with the actual position
10 in the same space, determined by the forward kinematic function depending on angular position values of the actuated arms, in order to determine a new reference position, still in the azimuth-zenith coordinates. It is also fundamental that
15 this reference value is referred to two new reference values in the space of the actuated joints through the inverse kinematic function.

CLAIMS

1. Sun follower (1) composed of at least one fixed supporting base (3) and of at least one moving structure (5) controlled and adapted to support at least one photovoltaic module, between said fixed supporting base (3) and said moving structure (5) actuating means with parallel kinematics (7) being interposed, adapted to handle said moving structure (5), characterised in that said actuating means with parallel kinematics (7) comprise three arms (9) composed of kinematic chains having respective ends operatively connected to said fixed supporting base (3) and to said moving structure (5), each one of said arms (9) being composed of at least two rods (11) mutually connected by interposing at least one first articulating means (13), said ends of said arms (9) being operatively connected to said fixed supporting base (3) and to said moving structure (5) by interposing second articulating means (15), and in that said fixed supporting base (3) and said moving structure (5) are mutually connected through at least one fourth rod (17), which ends of said fourth rod (17) are operatively and respectively connected to said fixed supporting base (3) and to said moving structure (5) by

interposing a pair of third articulating means (19).

2. Sun follower (1) according to claim 1, characterised in that said actuating means with
5 parallel kinematics (7) are closed-kinematics mechanisms.

3. Sun follower (1) according to claim 1, characterised in that said fixed supporting base (3) and said moving structure (5) are substantially
10 mutually identical plates, said photovoltaic modules being co-planar to said plate that makes said moving structure (5).

4. Sun follower (1) according to claim 1, characterised in that said first articulating means
15 (13) are a ball joint, said second articulating means (15) are hinges and said third articulating means (19) are two ball joints or a ball joint and a cardan joint.

5. Sun follower (1) according to claim 1,
20 characterised in that a relationship between a distance of the constraint points of said arms (9) of said kinematic chains from the centres of said fixed supporting base (3) and of said moving structure (5) and a distance between said
25 constraint point and said first articulating means

(13) is included between 0.05 and 0.55, while a relationship between a distance between the centres of said fixed supporting base (3) and of said moving structure (5) and a distance between said constraint points of said arms (9) of said kinematic chains and said first articulating means (13) is included between 0.6 and 1.8.

6. Sun follower (1) according to claim 1, characterised in that said ends of said arms (9) are operatively and respectively connected to said fixed supporting base (3) and to said moving structure (5) in fastening points mutually arranged at 120°.

7. Sun follower (1) according to claim 1, characterised in that said actuating means with parallel kinematics (7) comprise at least two motors (21), each one of said motors being adapted to control a slant of a respective one of said arms (9) composing the kinematic chains.

8. Sun follower (1) according to any one of the previous claims, characterised in that it comprises at least one sun alignment sensor and two sensors for detecting the angular positions of two of said arms (9), said sensors cooperating with processing means acting on said motors (21).

9. Process for controlling a sun follower (1), preferably according to any one of claims 1 to 8, adapted to orient said structure (3) towards the Sun and keep constantly next to zero the angle
5 between a line perpendicular to the plane of said photovoltaic module and the direction from which the sun light comes, characterised in that it comprises at least one step of actively following the sun comprising a closed-loop orientation
10 control to orient said moving structure (5) through control signals (m1, m2) to said motors (21) through feedback of signals (β_1 , β_2) coming from the two arms (9) and from said sun alignment sensor (sun).

15 10. Process according to claim 9, characterised in that it comprises the sub-step (FWD KIN) in which values of azimuth and zenith angles are determined depending on the position (β_1 , β_2) of said actuated arms (9) and the sub-step (INV KIN) in which the
20 positions (β_1 , β_2) are determined that the actuated arms (9) must reach so that the azimuth and zenith angles assume certain values, and in that it comprises the sub-step (G) of processing the signal (ls) coming from said sun alignment sensor to
25 determine the direction (Δ Azimuth, Δ Zenith) along

which said moving structure (5) must be moved in order to be oriented perpendicular to the line joining the Sun and compute the related movements, said computed movements being added to the actual
5 zenith and azimuth positions (Zenith, Azimuth) to obtain the new reference azimuth and zenith positions (Azimuth ref, Zenith ref), the angular displacement ($\Delta\beta_1$, $\Delta\beta_2$) to be made being computed and the control signals (m1, m2) to be sent to each
10 one of said motors (21) and the motion direction (dir1, dir2) being determined.

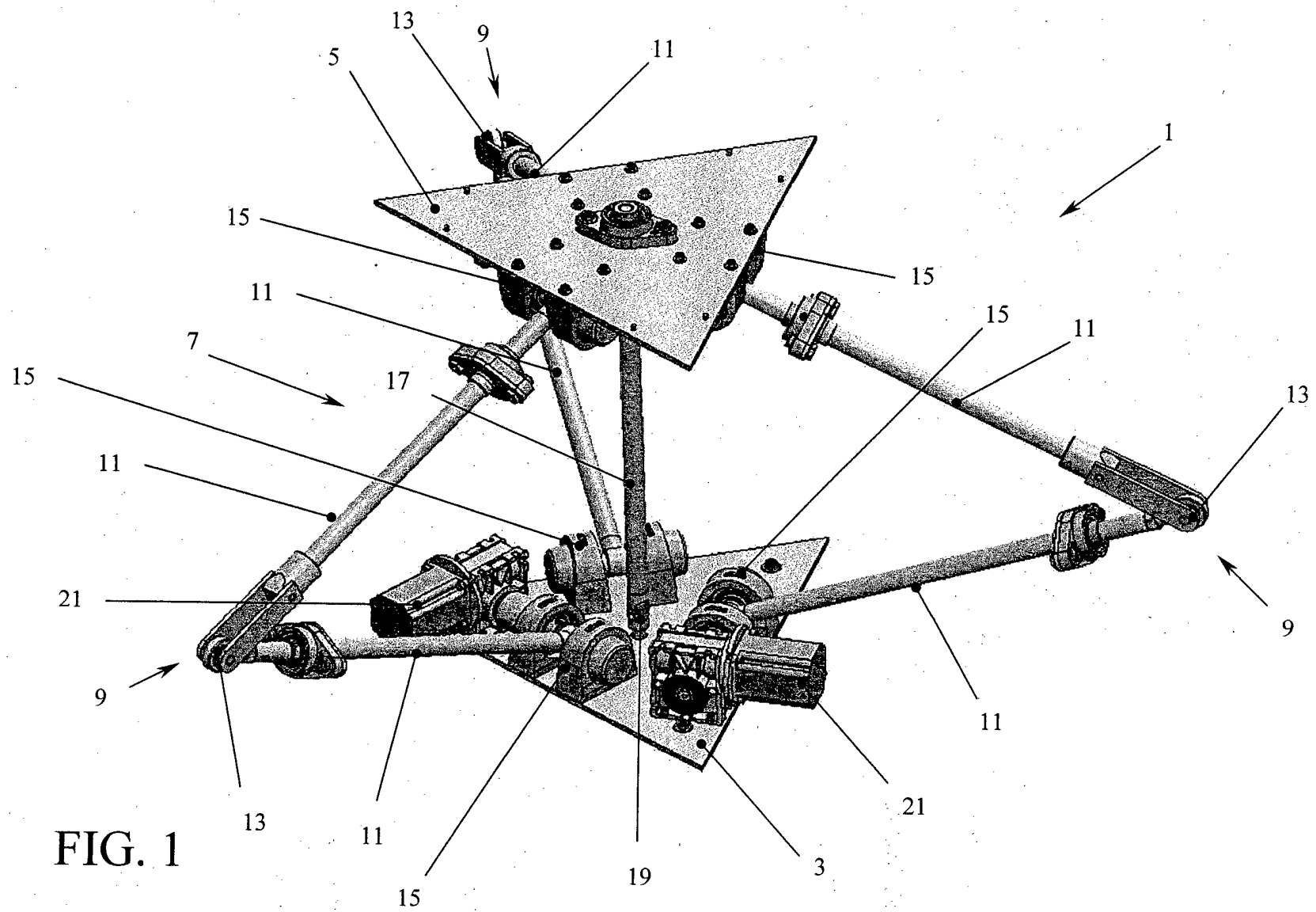


FIG. 1

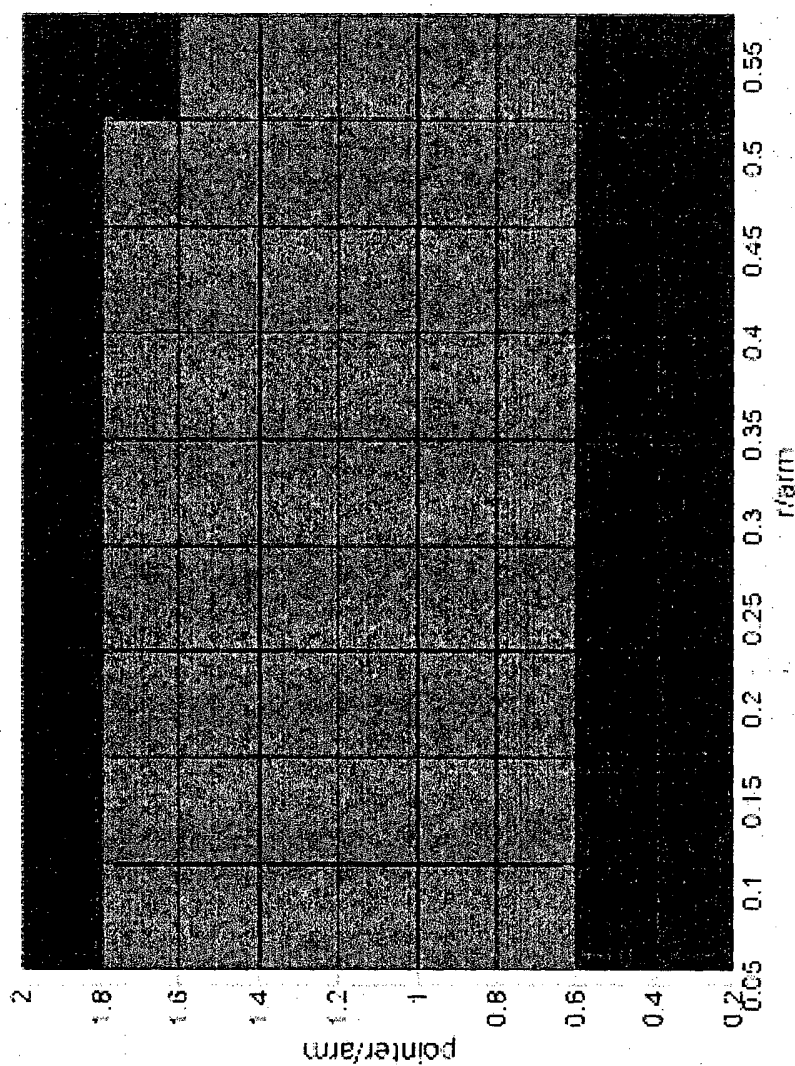


FIG. 2

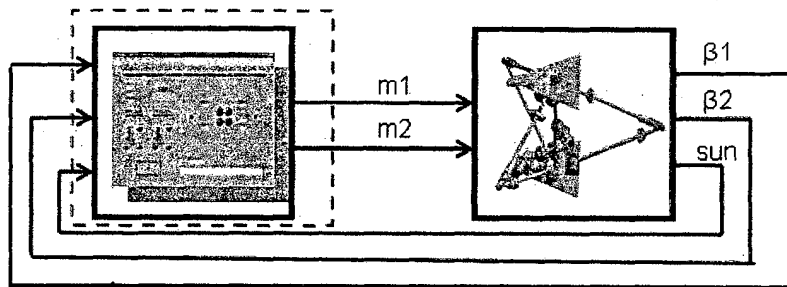


FIG. 3

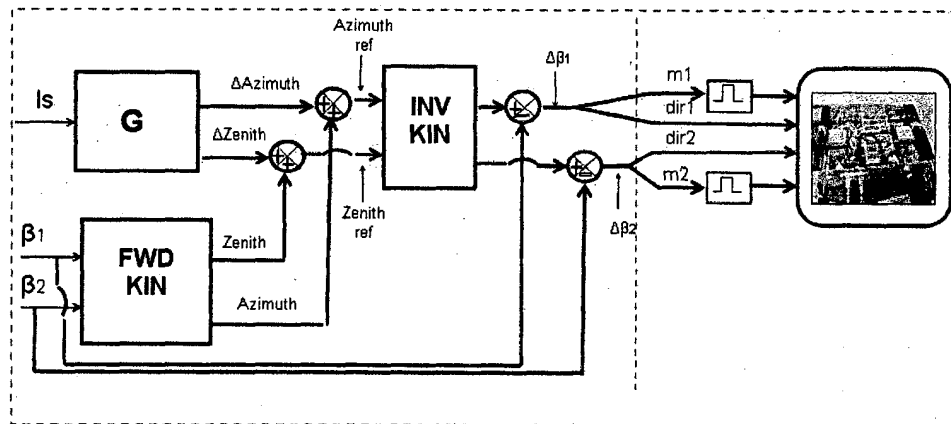


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2012/000084

A. CLASSIFICATION OF SUBJECT MATTER INV. F24J2/38 F24J2/54 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) F24J		
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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/199846 A1 (COLLINS KENNETH D [US] ET AL) 13 August 2009 (2009-08-13) paragraph [0058] - paragraph [0061]; figures 13-19 -----	1,2
A	WO 2009/076394 A1 (MOSER MARK K [US]) 18 June 2009 (2009-06-18) paragraph [0036] - paragraph [0038]; figures 1,2 -----	1,2
A	FR 2 535 033 A1 (EUROP PROPULSION [FR]) 27 April 1984 (1984-04-27) figures 1-3 -----	1-10
A	US 4 063 543 A (HEDGER JOHN HENRY) 20 December 1977 (1977-12-20) figure 2 -----	1-10
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"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
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INTERNATIONAL SEARCH REPORT

International application No

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	DE 10 2007 051714 A1 (KETTERER SOEHNE GMBH & CO KG B [DE]) 7 May 2009 (2009-05-07) paragraph [0009] - paragraph [0020]; figure 1 -----	1-10
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Information on patent family members

International application No

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