

Vehicle moving by reptation, propelled jointly by longitudinal and lateral undulations

The present invention concerns techniques pertaining to
5 vehicles moving by reptation, constituted by series of mutually articulated elements on which lateral undulations are imposed. It can be applied especially to the conveyance of loads on all types of terrain (hard, soft, uneven etc) in a way that is visually and acoustically discreet.

Such reptationally propelled vehicles (known as snake robots) are
10 known. An example is given in the patent FR 2 741 584 by Jean-Paul GUYVARCH, "Procédé de propulsion d'un véhicule par reptation et véhicule pour sa mise en œuvre" (Method for the propulsion of a vehicle by reptation and vehicle for its implementation). The reptation technique presented therein is exclusively that of lateral undulation. To improve operation on hard
15 ground, the use of rollers is proposed. Another known example of a vehicle propelled by lateral undulations has been made in the United States by Dr Gavin MILLER. It is demonstrated on an Internet site. This vehicle is also equipped with ventral rollers. The rollers augment propulsion efficiency on hard ground. However, on soft ground (sludge for example), grass or gravel,
20 these rollers may get clogged and jammed. Not only do they stop providing any propulsive force, but they also hamper the vehicle.

As distinct from this prior art, the propulsion of the vehicle according to the present invention is achieved by a conjunction of lateral undulations and longitudinal undulations. The lateral undulations resemble
25 the swimming motions of a fish: the lateral supporting features (the rough features of the terrain or the hydrodynamic force in a liquid medium) generate a propulsive force when the motions are coordinated in such a way that each element seeks to copy the orientation of the element preceding it (as in the motions of following a wake). The longitudinal undulations consist of a
30 sequence of motions that are propagated evenly on the ventral surface of the vehicle. The ventral surface may show directional adhesion (sliding adhesion in the direction of forward motion and clinging adhesion in the other direction) so as to further increase the propulsive force.

By its characteristics, such as those described and claimed here
35 below, the invention seeks to augment the propulsive force of a vehicle with



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successive elements propelled especially by lateral undulations, for vehicles designed to move on any type of terrain.

To meet this goal and obtain other advantages that shall be seen further below, an object of the invention is a method for the propulsion of a vehicle moving by reptation, essentially constituted by a series of mutually articulated elements, in which an orientation that varies in time is imposed on each element so as to follow the path of the preceding element, so as to give the entire vehicle a sinuous path with lateral undulations, characterized in that a motion of longitudinal undulation is also imposed on the ventral surface of at least one element, so as to produce a propulsive force complementary to the force resulting from the motion of lateral undulation.

For the implementation of the method thus defined, an object of the invention is also a vehicle moving by reptation, essentially consisting of a series of elements mutually articulated by articulation elements, the vehicle furthermore comprising:

- (a) first control means, acting especially on the articulation means, tending to impose an orientation that varies in time on each element, this orientation varying so as to follow the path of the previous element, so that the entire vehicle is given a sinuous path with lateral undulations;
- (b) second control means acting especially on the ventral surface of at least one element, tending to impose a motion of longitudinal undulation on said surface, so as to produce a propulsive force complementary to the one resulting from the motion of lateral undulation.

In the context of an advantageous embodiment aimed at improving efficiency of propulsion, the invention, in terms of method, is expressed by the fact that the motion of longitudinal undulation is imposed so that the propulsion speed resulting from this motion matches the speed resulting from the motion of lateral undulation. In terms of a device, it takes the form of a vehicle in which the second control means are set so that the propulsion speed resulting from the motion of longitudinal undulation matches the speed resulting from the motion of the lateral undulation.

In the context of the practical embodiments of the invention adapted to the world of industry, the invention, in terms of method, is expressed by the fact that the motion of longitudinal undulation is imposed by the longitudinal oscillation of points of the ventral surface, each point

describing a curve that is identical to that of its neighbor but is offset in time. In terms of a device, it then takes the form of a vehicle in which the second control means act on the ventral surface in imposing a longitudinal oscillation at points of the ventral surface, each point describing a curve identical to that of its neighbor but being offset in time.

At the same time, in the context of an advantageous embodiment, the method is expressed by the fact that, since each point of the ventral surface oscillates longitudinally, a vertical motion having a same period as the longitudinal oscillations is furthermore imposed so as to lift up said point when it shifts in a direction not favorable to propulsion, and so as to lower said point when it shifts in a direction favorable to propulsion. In terms of a device, the invention takes the form of a vehicle in which the second control means act on the ventral surface in furthermore imposing a vertical motion on each point of the ventral surface, this vertical motion having a same period as the longitudinal oscillations, so as to lift up said point when it shifts in a direction not favorable to propulsion, and so as to lower said point when it shifts in a direction favorable to propulsion.

According to another advantageous embodiment that can be implemented independently or in combination with the other advantageous embodiments, the method is expressed by fact that, during the motion of longitudinal undulation, the ventral surface of at least one element adheres more strongly in the direction favorable to the shift than in the other direction. In terms of a device, the invention then takes the form of a vehicle in which at least one ventral surface driven by a motion of longitudinal undulation has directional adhesion that is stronger in the direction favorable to the shift than in the other direction.

The main advantages of the invention are that it allows for making a robust vehicle that uses low-cost, tested technologies, and is compact (with a diameter of five to ten cm) while maintaining a payload volume within the vehicle (about 50% of the total volume), the motions of undulation being easy to set, efficient and produced with high efficiency.

The invention shall now be described in greater detail in the context of a particular practical embodiment. In this description, reference shall be made to the appended figures, of which:

Figure 1 is a schematic top view of a vehicle with its elements driven by a motion of lateral undulation;

Figure 2 is a side view providing a schematic representation of an element of the vehicle, the ventral surface of this vehicle being driven by a motion of longitudinal undulation;

Figure 3 of the top view providing a schematic representation of a gear-based mechanical device of an element of the vehicle that can be used to obtain a motion of longitudinal undulation;

Figure 4 is a side view providing a schematic representation of the mechanical device illustrated in figure 3;

Figure 5 is a rear view providing a schematic representation of a part of the mechanical device shown in figure 3;

Figure 6 is a rear view providing a schematic representation of an alternative embodiment of the device illustrated in figure 3;

Figure 7 is a top view providing a schematic representation of a link-rod-based mechanical device of an element of the vehicle used to obtain a motion of longitudinal undulation;

Figure 8 is a side view providing a schematic representation of the mechanical device illustrated in figure 7;

Figure 9 is a side view representing an exemplary mechanical device based on sliding legs;

Figure 10 is a graph representing the paths of two points of a sliding leg;

Figure 11 is a side view representing a detail of the ventral surface of an element of the vehicle;

Figures 12 to 15 are side views representing alternative embodiments of the ventral surface illustrated in figure 11.

Reference is now made to figure 1. The vehicle takes up the general principle describing the patent FR 2 741 584 which may be referred to for further details on the making of a lateral undulation device. The vehicle consists of a chain of elements articulated along two axes (in relative bearing and in elevation). These elements may all be identical except for the head element S and the tail element. The number of elements may vary according to need from one to several tens of elements. The length of the elements

may be in the range of 10 to 20 cm. Their section may be circular or ovoid, with a diameter for example of about 5 to 10 cm.

If two successive elements A and B are considered, they are connected to each other by articulation means. The capacity of articulation
5 of these articulation means in relative bearing and in elevation may be about $\pm 25^\circ$ or more. This articulation capacity corresponds of course to an angle (in relative bearing or elevation) between two consecutive elements.

Each element is equipped with first control means that act on the articulation means. The first control means may be electro-mechanical for
10 example. Electrical accumulators, such as rechargeable batteries Nimh, may power them electrically. The first control means impose an orientation that varies in time on each element, such as the element B, so as to make it follow the path of the preceding element A, so as to give the entire vehicle is sinuous path TS with lateral undulations on either side of a mean trajectory
15 TM to be followed.

The vehicle may also be equipped with a microcontroller to mechanically coordinate all the elements according to driving commands. These driving commands may be received by remote control (radio links for
20 example). The vehicle may also be equipped with sensors and, especially, with a camera to transmit images to the operator driving the vehicle.

The general principle of the driving of the vehicle may be the one described in the patent FR 2 741 584, which may be referred to for further details.

The addition of a system of propulsion by longitudinal undulation
25 greatly relaxes the constraints related to the control of angles between the elements. Since the motor activity is provided by longitudinal undulation, the values of torque to be exerted are far lower.

Reference is now made to figure 2. Each element of the vehicle is oriented by a base of vectors (x,y,z). The vector x is oriented in the
30 longitudinal direction, in the direction of the movement. The vector z is oriented in the vertical direction, upwards. The orientation and the direction of the vector y are determined so as to form a direct base. This vector therefore corresponds to a transversal direction.

Figure 2 is a side view, namely in the plane (x,z), of an element. It
35 illustrates an example of an embodiment of longitudinal undulations. This

element has a ventral surface V resting on the ground at certain places. This ventral surface V is driven by a motion of longitudinal undulation. The motion of longitudinal undulation may be imposed by the longitudinal oscillation of points of the ventral surface V , each point describing a curve identical to its neighbor but being offset in time. In practice, motive points p_1, p_2, p_3, p_4 enable the production of these oscillations, these points being fixed to the surface. In the plane (x,z) , a given motive point p_2 periodically, and as a function of time, describes a curve which, for example, is on the whole circular and more or less flat. This curve may go to the extent of being a straight-line segment along x . A motive point p_3 , neighboring p_2 , describes an identical curve in a manner that is offset in time (advanced or delayed). The points of the surface fixed to the motive points describe the same movement as the motive points .

Since the oscillations of a consecutive points p_2, p_3 are offset, the distance d between them varies with time. This is also the case for the points of the surface V . To permit these variations, the surface V may be formed by a flexible membrane (that folds when d diminishes) or by an elastic membrane (that shrinks when d diminishes). The distance d may be in the range of 3 to 4 cm on an average for example.

It can be seen that these longitudinal undulations bring many setting parameters (phase-shifting between the points, movements of the points of the ventral surface) into play.

If the motive points describe a straight-line segment (with extreme flattening), i.e. if they have a purely longitudinally motion, then it is possible to take, for example, a 180° phase between two successive points: periodically, the points approach each other and then move apart along the longitudinal direction. In this case, propulsion is obtained if the points of the surface neighboring the motive points easily slide in the positive direction x and do not slide or hardly slide in the other direction. This is the case typically if the surface V were to be covered with scales or sealskin. In other words, the ventral surface V adheres more strongly in the direction favorable to the shift than in the other direction.

If the motive points describe circles, then for example a 180° phase can be taken between two successive points. If the ventral surface V is fixed to at least four motive points, then propulsion can be obtained without

resorting to directional adhesion, through the vertical motions (the projection of the circle along z). In other words, for each point of the ventral surface V oscillating longitudinally, an additional vertical motion with the same period as the longitudinal oscillations is imposed so as to lift up said point when it moves in a direction s_2, s_4 not favorable to propulsion, and so as to lower said point when it moves in a direction s_1, s_3 favorable to propulsion.

Depending on the nature of the ventral membrane used and depending on the surface of the ground, a suitable compromise between these two motions must be found. It is therefore desirable to find a mechanical embodiment of this motion that enables the easy setting of the different parameters of the longitudinal undulation and has high mechanical efficiency.

Hereinafter in the description, we shall present examples of embodiments of mechanical devices used to obtain a longitudinal undulation, these devices equipping each element in a way that is mechanically independent of the other elements. Naturally, these examples are not exhaustive.

Advantageously, the invention uses direct-current electrical motors associated with mechanical reduction gears to move the motive points. This has the advantage especially of constituting a tested, low-cost technology.

We shall now refer to figures 3 and 4, which represent an example of a gear-based mechanical device. Figure 3 is a view along the plane (x,y) , i.e. a top view. Figure 4 is a view along the plane (x,z) , i.e. a side view. This mechanical device makes it possible to obtain the motion of longitudinal undulation illustrated in figure 2.

A driving gear e_m with a vertical axis drives secondary gears e_1 to e_8 with vertical axes. These secondary gears are distributed on either side of a median axis M (see figure 3). They have the same radius. The driving gear e_m is centered on the median axis M . The secondary gears e_1, e_3, e_5, e_7 are placed so as to be facing gears e_2, e_4, e_6, e_8 respectively. The driving gear e_m transmits a rotational motion to the gears e_3 et e_4 , which therefore rotate in the same direction. These gears e_3 and e_4 respectively transmit this movement firstly to the gears e_2 and secondly to the gears e_5 and e_6 . The gears e_5 and e_6 in turn transmit this motion of the gears e_7

and e8 respectively. The gears e1, e2, e5 and e6 therefore rotate in the same direction. The gears e3, e4, e7 and e8 rotate in the other direction.

Vertical rods t1 to t8 respectively cross the gears e1 to e8. These rods are driven in rotation by the gears. They therefore describe circular trajectories in the horizontal plane (x,y). These rods are positioned in the same way on either side of the median axis M. Thus, for example, the rods t1 and t2 rotate in phase.

Ducts g1 to g4 are placed beneath the gears e1 to e8, along the direction y, that is transversally. The bottom of the rods t1 and t2 is in contact with the duct g1. The rods t1 and t2 slide in the duct g1 along the direction y, and push it along the direction x. Thus, the circular motion in the plane (x,y) of the rods t1 and t2 is converted into a rectilinear motion of the duct g1 along the direction x. In other words, the rods t1 and t2 guide the duct g1 along the direction x, thus producing a motion of longitudinal oscillations. Similarly, the rods t3 and t4 guide the duct g2, the rods t5 and t6 guide the duct g3, and the rods t7 and t8 guide the duct g4.

These ducts g1 to g4 are fixed to the surface V. Thus, the longitudinal undulations of this surface are obtained. These ducts form motive lines (lines in the direction y). Hence it is all the more the case that they form motive points (a line being formed by points). The motive points p1 to p4 shown in figure 2 may be the midpoints of the ducts g1 to g4 respectively, i.e. they may be located on the axis M.

The fact that two gears placed facing each other (for example e1 and e2) rotate in the same direction gives rise to a lateral force on the associated duct (for example p1). If the sliding of the rods in the duct is not perfect, this gives rise to a lateral force on the duct. The ducts may be laterally stressed (this is not shown) for example by the ventral surface V or by an external sheathing. According to one alternative embodiment, the gears placed facing each other may rotate in reverse directions so as to mutually compensate for the lateral driving force.

The main advantages of this mechanical device are that it is efficient and compact in the vertical plane. This makes it possible to carry a large payload. Furthermore, all the gears e1 to e8 play a direct part in the motion of the rods, and hence that of the ducts. The fact that these ducts rotate in opposite directions does not prevent them from being all used.

Reference is now made to figure 4. It is possible in addition to apply a vertical motion to the motive points, i.e. to the ducts g1 to g4. To this end, it is possible for example to make the rods t1 to t8 slide vertically in the gears, these rods then carrying the ducts along vertically.

5 Reference is now made to figure 5, which illustrates an example of a device used to guide these rods vertically. These rods can be guided vertically by inclined surfaces placed on top of the rods. The rods slide in the plane (x,y) on these surfaces. Thus, for example, the rods t3 and t4 are guided by inclined surfaces r3 and r4. In the position corresponding for
10 example to a semi-rotation of the gears e3 and e4, the rods t3 and t4 are placed at new positions t'3 and t'4 respectively. To arrive at these positions t'3 and t'4, the rods are shifted in the plane (x,y), describing a semi-circle. In their new positions t'3 and t'4, the points of contact between the rods and the surfaces r3 and r4 are lower. The rods therefore slide downwards. They
15 then carry the duct g2 along to a new lower position g'2.

By modulating the inclination of the surfaces, it is possible to augment or reduce the amplitude of the vertical oscillations. These surfaces may also form a fixed roof r. In this case, the amplitude of the vertical oscillations is no longer adjustable.

20 Reference is now made to figure 6 which illustrates an alternative embodiment of the device that can be used to apply a vertical motion. The rods are fixed to the gears so as to prevent them from sliding vertically. It is the gears e1 to e8 that shift vertically, thus carrying the rods along vertically, these rods carrying along the ducts. To this end, the rotational axes e1 to e8
25 can be equipped with cams. For example, the rotational axis of the gear e3 can be equipped with a cam c3, d3. A part d3 of this cam is connected to the gear e3. The other part c3 of this cam is fixed vertically. The gear e4 is not shown in figure 6. Another position e'4 of this gear corresponding to another point in time is shown. In this other position e'4, this gear is in a lower
30 position. The rod t4 (not shown) is in a lower position t'4, thus bringing the duct g2 into a new, lower position g'2.

The advantage of this mechanical device is that it is simpler to make while at the same time having equivalent efficiency. However, it necessitates the use of gears that are positioned at a sufficiently high level so
35 that they can remain in contact despite offset vertical motions.

Reference is now made to figures 7 and 8 which represent an example of a mechanical device based on link-rods. Figure 7 is a view in the plane (x,y), i.e. a top view. Figure 8 is a view in the plane (x,z), i.e. a side view. This mechanical device can be used to obtain the motion of longitudinal undulation illustrated in figure 2.

Propulsion relative to the ground is provided by horizontal rods k1 to k5 perpendicular to the axis of a frame CH. In other words, the horizontal rods k1 to k5 are oriented along the direction y. These horizontal rods act on the surface V in the same way as the ducts of the gear-based mechanical device described here above. The rods k1 to k5 describe horizontal cylinders that are more or less flattened. In other words, the points (motive points) of the rods k1 to k5 describe more or less flattened circles.

The rods k1 to k5 are guided by link-rods b1 to b10. These link-rods are located on either side of the frame CH. The link-rods b1, b3, b5, b7, b9 are located on one side of the frame CH and the other link-rods b2, b4, b6, b8, b10 are located on the other side. Each horizontal rod k1 to k5 is connected to two link-rods, with one link-rod on each side. Thus the rod k1 is connected to the link-rods b1 and b2, the rod k2 is connected to the link-rods b3 and b4, the rod k3 is connected to the link-rods b5 and b6, the rods k4 is connected to the link-rods b7 and b8, the rods k5 is connected to the link-rods b9 and b10. The left-hand and right-hand link-rods guiding the same rods are therefore offset by one rank.

The unconnected ends (not connected to the rods k1 to k5) of the link-rods b1 to b10 are carried along by a synchronized motion of rotation about shafts a1, a2, a3, a4, a5 rotating at the same speed. The shaft a1 drives the free end of the link-rod b1. The shaft a2 drives the free end of the link-rods b2 and b3. The shaft a3 drives the free end of the link-rods b4 and b5. The shaft a4 drive the free end of the link-rods b6 and b7. The shaft a5 drives the free end of the link-rods b8 and b9. The shaft a6 drives the free end of the link-rod b10. The shafts a1 to a5 are transversal (horizontal and perpendicular to the axis of the frame CH), i.e. along the direction y. The shafts a1 to a5 can be driven by a driving systems such as a system of gears, chains or notched belts that is not shown.

The spatial periodicity (on the ground) of the longitudinal undulation can be adjusted by playing on the phase-shift between the link-

rods located on a same side of the frame CH, i.e. firstly between the link-rods b1, b3, b5, b7 and b9 and secondly between the link-rods b2, b4, b6, b8, b10.

The flattening of the cylinders described by the rods k1 to k5 can be adjusted by playing on the phase shift between left-hand and right-hand rods (b1 relative to b2, b3 relative to b4, etc...). If the phase shift is zero, the points of these rods describe circles. If the phase shift is 10° or 20° for example, the points of these rods describe flattened circles.

The main advantages of such a system are that it is compact and easy to adjust. It is possible especially to adjust a system of this kind during operation by playing on the phase shift between the right-hand and left-hand sides to flatten the cylinders described by the rods. This makes it possible to match the undulation to the nature of the terrain.

Reference is now made to figures 9 and 10 which represent an exemplary mechanical device based on sliding legs. Figure 9 is a view in the plane (x,z), i.e. a side view, of a sliding leg. Figure 10 is a graph representing the trajectories of two points of the sliding leg in the plane (x,z).

The mechanical device comprises several propulsion legs. Each propulsion leg b has a broken segment shape forming a constant angle. The ends A and C of the leg b are respectively connected to a sliding guide (in A) and to a horizontal rod (in C). The horizontal rod is oriented along the direction y. It is fixed to the ventral surface V.

The point of the leg forming an angle, referenced B, is driven in the plane (x,z) i.e. the vertical plane, by a rotational motion with an axis O. In other words, the axis O corresponds to a drive shaft that rotationally drives the point B of the leg b. The motion described by the point C depends on the lengths AB, BC, the distance OB, and the angle (AB, BC).

An example of a curve described by the point C is illustrated in figure 10. The point B describes a circle. The point C oscillates longitudinally and vertically at the same period. The point C is lowered when it shifts in the negative direction x (the direction favorable to propulsion), and is lifted when it shifts in the positive direction x (the direction not favorable to propulsion).

Naturally, the complete device comprises several sliding legs rotationally driven by several driving shafts. These driving shafts (such as O)

may be connected by a central feed system such as a belt for example. These legs may be aligned along a longitudinal central axis for example. This is different from the link-rod-based system in which said link-rods are distributed to the right and to the left.

5 As in the case of the preceding device, the spatial periodicity (on the ground) of the undulation can be adjusted by playing on the rotational phase shift between the successive driving shafts.

Reference is now made to figure 11 which represents a side view of the ventral surface V. This ventral surface may be lined with a flexible
10 membrane (furthermore illustrated in figure 4) or an elastic membrane (furthermore illustrated in figure 2). This membrane can therefore get deformed by folding (in the case of the flexible membrane) or get contracted and shrink (in the case of the last membrane). This membrane furthermore ensures the tight sealing of the vehicle and adhesion relative to the ground.

15 To this end, this membrane may be formed firstly by adhesive parts v1, v2 and secondly by flexible or elastic parts m1, m2. The adhesive parts v1, v2 are placed facing the motive points p1, p2. These adhesive parts may be lined with scales for example, favoring adhesion in the direction favorable to the movement of the vehicle. Of course, these adhesive parts
20 v1, v2 are also tightly sealed. The flexible or elastic parts m1, m2 allow for making a tightly sealed junction between the adhering parts. The flexible or elastic parts m1, m2 of this membrane may be formed, for example, by a plasticized flexible membrane of the type having folds such as a concertina membrane or a vacuum-cleaner tube.

25 Reference is now made to figures 12 to 15. These figures illustrates alternative embodiments of the adhering parts v1, v2 of the ventral surface V. In compliance with the embodiment shown in figure 12, the adhering part v1 is covered with claws. These claws are oriented so as to present longitudinal, directional adhesion.

30 In accordance with the embodiment shown in figure 13, the adhering part v1 is lined with inclined blades. These blades have a profile with an upper part in front, used to fasten them to the part v1, and a lower part behind, serving to cling to the rough features of the ground. These blades slide longitudinally in one direction and cling in the other direction.

In accordance with the embodiment shown in figure 14, the adhering part v1 is covered with pin structures w1, with rubber-coated (adhering) surfaces placed on the rear side. These rubber-coated pin structures are particularly suited to dry terrain.

5 In accordance with the embodiment shown in figure 15, the surface v1 is coated with vertical knife blades z1, oriented longitudinally and articulated about a transversal axis of rotation z2. The axis of rotation z2 is in front of the blade. A spring z3 may act in the rear of this blade to maintain contact with the ground. This gives both lateral adhesion, which is useful for
10 motions of lateral undulation, and longitudinal, directional adhesion which is useful for motions of longitudinal adhesion.

The propulsion by longitudinal undulation taught here above does not counter lateral motion. It adds a complementary propulsion force. Advantageously, the longitudinal propulsion speed is the same on all the
15 elements. It can be determined comprehensively to match this resultant of the lateral undulation.

It is not necessary to provide for a feedback control system on the longitudinal propulsion command if also, as described in the patent FR 2 741 584, a feedback control is planned for the command of the inter-segment
20 angles.

Advantageously, a vacuum cleaner tube type of membrane may cover the link between consecutive sets. This membrane ensures high mechanical resistance and continuity of shape.

Be that as it may, in order to be particularly advantageous, the
25 particular embodiments described are nevertheless not exhaustive and a variety of alternative embodiments, especially with respect to the details given by way of examples, will remain within the context of the invention that is the subject of the patent.

For example, other motor-driven systems, especially hydraulic or
30 pneumatic systems, may replace the systems given by way of an example.

CLAIMS:

1. Method for the propulsion of a vehicle moving by reptation, essentially constituted by a series of mutually articulated elements (A,B), in which an orientation that varies in time is imposed on each element (B) so as to follow the path of the preceding element, so as to give the entire vehicle a sinuous path with lateral undulations, characterized in that a motion of longitudinal undulation is also imposed on the ventral surface (V) of at least one element, so as to produce a propulsive force complementary to the force resulting from the motion of lateral undulation.
2. Method according to claim 1, characterized in that the motion of longitudinal undulation is imposed so that the propulsion speed resulting from this motion matches the speed resulting from the motion of lateral undulation.
3. Method according to any of the above claims, characterized in that the motion of longitudinal undulation is imposed by the longitudinal oscillation of points of the ventral surface, each point describing a curve identical to that of its neighbor but being offset in time.
4. Method according to claim 3 characterized in that for each point of the ventral surface oscillating longitudinally, a vertical motion having a same period as the longitudinal oscillations is furthermore imposed so as to lift up said point when it shifts in a direction (s2, s4) not favorable to propulsion, and so as to lower said point when it shifts in a direction (s1, s3) favorable to propulsion.
5. Method according to any of the above claims characterized in that, during the motion of longitudinal undulation, the ventral surface of at least one element adheres more strongly in the direction favorable to the shift than in the other direction.
6. A vehicle moving by reptation, essentially consisting of a series of elements mutually articulated by articulation elements, the vehicle furthermore comprising:

(a) first control means, acting especially on the articulation means, tending to impose an orientation that varies in time on each element, this orientation varying so as to follow the path of the previous element, so that the entire vehicle is given a sinuous path with lateral undulations;

5 (b) second control means acting especially on the ventral surface of at least one element, tending to impose a motion of longitudinal undulation on said surface, so as to produce a propulsive force complementary to the one resulting from the motion of lateral undulation.

10 7. A vehicle according to claim 6, characterized in that a vehicle in which the second control means are set so that the propulsion speed resulting from the motion of longitudinal undulation matches the speed resulting from the motion of the lateral undulation.

15 8. A vehicle according to any of the claims 6 to 7, characterized in that the second control means act on the ventral surface in imposing a longitudinal oscillation at points of the ventral surface, each point describing a curve that is identical to that of its neighbor but is offset in time.

20 9. A vehicle according to claim 8, characterized in that the second control means act on the ventral surface in furthermore imposing a vertical motion on each point of the ventral surface, this vertical motion having a same period as the longitudinal oscillations, so as to lift up said point when it shifts in a direction not favorable to propulsion, and so as to lower said point
25 when it shifts in a direction favorable to propulsion.

30 10. A vehicle according to any of the claims 6 to 9, characterized in that a vehicle in which at least one ventral surface driven by a motion of longitudinal undulation has directional adhesion that is stronger in the direction favorable to the shift than in the other direction.