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THREE - POINT SUPPORT AND GRIP

SUPORTE E ADERÊNCIA EM TRÊS PONTOS

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Abstract
Supports are not very developed in modern robotics. It is generally accepted that robots (industrial robots) only need to be well-founded and be able to perform their tasks in their reach area. With the development of locomotion robotics, as well as with the development of the space industry, the importance of supports is gaining relevance. Nature here on Earth has shown us that supports (feet) are complex mechanisms of great importance. Revealing the importance and need for the synthesis of supports and grippers is of great importance for the development of mobile, service and space robotics. This material sheds some light on the problems related to the synthesis of support and gripper mechanisms.

Keywords: Robotics. Locomotion. Support. Grip.

Resumo
Os suportes não são muito desenvolvidos na robótica moderna. É geralmente aceito que os robôs (robôs industriais) só precisam ter uma base sólida e ser capazes de realizar suas tarefas em sua área de alcance. Com o desenvolvimento da robótica de locomoção, bem como com o desenvolvimento da indústria espacial, a importância dos suportes está ganhando relevância. A natureza aqui na Terra nos mostrou que os suportes (pés) são mecanismos complexos de grande importância. Revelar a importância e a necessidade da síntese de suportes e garras é de grande importância para o desenvolvimento da robótica móvel, de serviço e espacial. Este material lança alguma luz sobre os problemas relacionados à síntese de mecanismos de suporte e garras.

Palavras-chave: *Robótica. Locomoção. Suporte. Garra.*

1 INTRODUCTION

The kinematic system of industrial robots in theory is usually divided into a manipulation system and a wrist. The manipulation system is firmly attached (founded) to a stable base [1] and performs global movements (in most cases, these are 3 degrees of freedom), while the wrist is attached to the end link of the manipulation system and provides local, mainly orienting, movements [2]. These are usually 2D or 3D movements. A technological gripper is attached to the wrist for gripping technological elements. Thus, in the end, most industrial robots had 5-7 degrees of freedom.

With the development of technology and robotics, the need for mechanisms and robots with many degrees of freedom (more than 7) arose. These mechanisms have long kinematic chains, the length of which can reach hundreds or more degrees of freedom. Some of these mechanisms have a closed structure, others open or mixed. In biomechanics, similar kinematic structures are observed in fauna.

Robots resembling the kinematic structures of fauna in our environment have already appeared in many places [3]. There was talk of the space industry, where the use of robots is of utmost importance. All this has necessitated that the processes of *landing, support, grip, and locomotion* [4] be studied more and more in depth, both in terms of the physical phenomena arising in these processes and the types of structures necessary for their implementation. These four processes, considered in depth, necessitated the development of new types of supports and grippers that could attach different endpoints of the manipulation system to a basic base.

It is known from mechanics that when a body breaks down into separate parts, the trajectories of these parts are such that the total trajectory of their total mass remains unchanged.

When two or more bodies are combined, there is an increase in the mass of the combined body and, therefore, there is a change in the trajectory. In this material, the case of merging two bodies into one will be considered primarily. This refers to the landing of a spacecraft and a meteorite.

In locomotion [5], whether under gravity or not, some kind of impact is realized upon contact between the two bodies. From the theory of impact it is known that the impact is related to the so-called impact force exerted between the colliding bodies for a very short time. To a large extent, this impact is uncontrollable and leads to unpredictable destruction, which must be avoided.

In the present material, the situation is of interest when two bodies approach each other in outer space [6] and one (the spacecraft) captures the other (the meteorite or comet), that is, they merge into one body with a minimized impact force between them.

2 PRESENTATION

The essence of the four processes – landing, support, grip and locomotion, are basic independent processes in nature. The need for their application in robotics is imposed by the further development of robotics itself. In modern society, when talking about constructing robots (even if they are industrial), natural factors must always be taken into account, such as gravity, atmospheric pressure, magnetic field, etc. This is necessitated by the fact that more and more people are talking about the space industry, where there are many different natural conditions.

3 THREE - POINT SUPPORT

In essence, the support is the point, spot or area of contact between two bodies that are pressed against each other by an attractive force that acts on both bodies. The support can be a point, line, plane, surface or volume (in the case of a clamped support). All types of supports are found in the fauna, the diversity is enormous. The three-point support is a planar support and it will be the subject of special attention in this material.

Before considering the grip, the three-point support will be considered, which is a geometric-mechanical element of kinematic systems. *The three-point support is practically the most stable of all known supports in mechanics and meets the minimum requirements of the geometric laws for determining a plane in space.*

By definition from geometry, *every three points in space, not lying on the same line, define a plane in space.*

When considering a three-point support, a kinematic structure (independent mechanism) must be understood. A three-point support, in addition to being an independent mechanism, is always part of a body or mechanism.

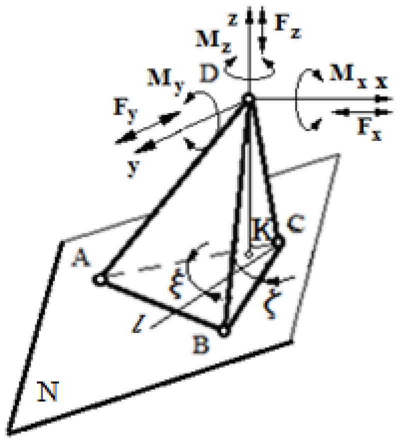
In practice, the initial data for synthesizing the support in the most general form are:

- the type of force load on the part of the body, part of which is the support itself (robot);
- the type of surface to which it will be contacted (road, surface with special characteristics, etc.). That is, here we are talking about the place of contact on the second body, which in general is not adapted for contact;
- specific manipulative movements that the support must provide, in order to optimize the manipulation process on the part of the manipulator.

In general, in mechanics, the three-point support is considered as a triangular pyramid with height *KD* (Fig. 1.), where point *D* is the top of the pyramid above the plane defined by the three contact points *A*, *B* and C, which in practice represent points of the two bodies. Point *D*, in practice represents the center of rotation of the wrist. This point can be real or unreal (theoretical). It is real when this point is from some machine element included in the kinematic chain of the support. It is unreal when point *D* is not located on any of the mechanisms of the wrist, but they are located around it.

Figure 1

Geometric representation of a three-point support on the plane ***N***



A three-point support is usually considered, but not necessarily, as a one-pointed geometric body with one vertex - the point *D*, as shown in Fig. 1. The important thing here is to determine the three support points, defining the support plane ABC in space, as well as to determine the position of other characteristic points in space.

Of great mechanical importance in the distribution of the forces of the system, the triangle *ABC* has the ability to change the sizes of its sides. This requirement is fundamental when designing a three-point support.

The geometric reality that three points in space define one plane allows for freedom in the construction of kinematic chains for supports, but ultimately the contact points, in the general case, need to be only three. Thus, these three support points define the support triangle, suitable for the future construction of the three-point support.

A characteristic feature of the task is that the load of the system is concentrated at point *D* (Fig. 1). This is a six-dimensional load, that is, there are three linear components along the three axes of the inertial coordinate system xDyz in space and mutually perpendicular components of the moments along these axes.

$$\overrightarrow{F_D^e} = \overrightarrow{F_x} + \overrightarrow{F_y} + \vec{F_z}$$
$$\overrightarrow{M_D^e} = \overrightarrow{M_x} + \overrightarrow{M_y} + \overrightarrow{M_z} \quad (1)$$

where:

$\overrightarrow{F^e}$ - the principal vector of all external forces for the system;

$\overrightarrow{M^e}$- the principal moment of all external moments for the system.

It is important to note that the forces at points *A*, *B* and *C* cause support reactions in the plane **N**, that is, in the second body.

Another feature is that the principal vector of all external forces for the system $\overrightarrow{F^e}$ and the principal moment of all external moments for the system $\overrightarrow{M^e}$ are dynamic quantities and depend on the position of the system in an absolute coordinate system xDyz and on the time *t*.

$$\overrightarrow{F_D^e} = f(\, X, Y, Z, t)$$
$$\overrightarrow{M_D^e} = f(X, Y, Z, t) \quad (2)$$

Thus, the support reactions at points A, B and C will also be functions of position and time.

Finding the support reactions at the support points is a classic problem for finding support reactions as functions of position and time. The most important thing here is to investigate these support reaction functions for the existence of regions of the parameter intervals in which any of the components of the support reactions are zero or acquire a negative value. In these intervals, the support reactions actually repel the second body. *So, when these components are zero or become negative, the physical phenomenon of support cannot be realized.*

4 TREE-POINT GRIP

In the previous section, we considered a three-point support loaded at point D along the axes of an inertial coordinate system centered at point D. The component of the support reactions perpendicular to plane **N** plays an important role. This component ensures the pressing of the support triangle ABC to plane **N**.

If the components of the support reactions that press the three-point support to the plane N are zeroed or become negative, the support phenomenon cannot be realized, in this case, a three-point grip is synthesized. *During the grip, the support reactions can acquire different values, without limitation, whether they are positive, negative or zeroed.*

Figure 2

Normal dynamic system load.

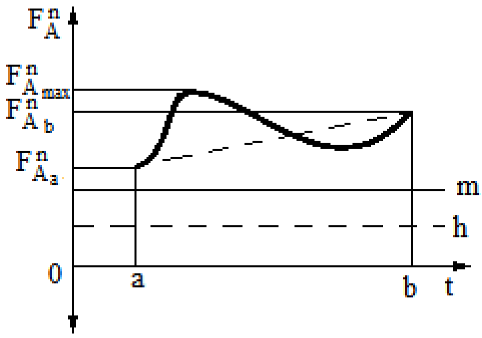
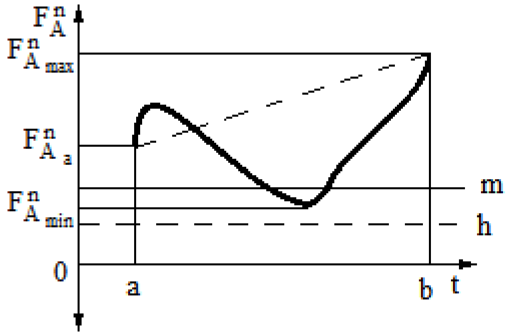


Fig. 2 shows how the force $\overrightarrow{F_A^n}(t)_{min}$ changes in the interval (a, b) above the line m, which shows the static load, due to the external compressive force between the two bodies. It is clearly seen that due to the dynamic processes they additionally load the system.

Figure 3

Increased system load.



In Fig. 3, another dynamic process of the force $\overrightarrow{F_A^n}(t)_{min}$ is observed, whose value is between the lines m and h (the line h is a constructive limiting line in the diagram, reaching which is a critical state for the supporting process). The state shown in the second graph is still normal operation but is approaching the critical minimum of operation.

Figure 4

Critical system load.

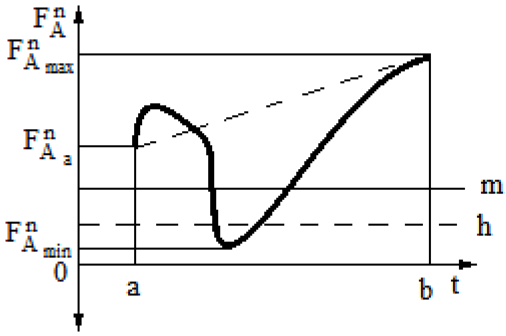


Fig. 4 shows the support process of the force $\overrightarrow{F_A^n}(t)_{min}$, the minimum of which is below the critical minimum of the line h. This shows that the support process at point A is threatened with collapse. That is, the force $\overrightarrow{F_A^n}(t)_{min}$ acquires critically low values at certain moments and the pressing of point A against the plane N may at some point be zeroed.

Figure 5

Disintegration of the supporting process.

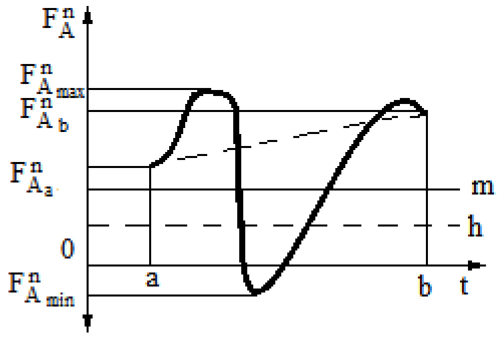


Fig. 5 shows the process in which the force $\overrightarrow{F_A^n}(t)_{min}$ becomes negative. That is, at this moment there is a separation of the point A from the plane N. This process interrupts the support process in the interval (a, b) .

The three-point grip does not differ kinematically from the three-point support, the differences are that at the support points A, B and C the three-point grip has additional kinematic units (mechanisms) that implement additional clamping forces, i.e. support reactions. In biomechanics, such additional elements (mechanisms) are the claws of the limbs. In some representatives of the fauna, they are only one element - a claw, while in others (some insects), they are separate small kinematic mechanisms.

In the conditions of outer space, a distinction can be made between griping and *docking*. In docking, both bodies have designated places for coupling with other objects in outer space. Docking is observed between space modules in weightlessness that have precisely designated sections of the outer hull for this purpose.

Griping is present when only one body has facilities with which it can stably join the other body. This is the case when a spacecraft couples to a meteorite.

It should be immediately clarified that capture, as a phenomenon, has four phases of action:

1. Contact phase – this is the first moment of contact between the two bodies (the meteorite and the spacecraft). This is the moment when the physical phenomenon of impact is realized (which is highly negative for the capture process). In this phase, there are subphases that will be briefly discussed below;

2. Capture phase – this is the phase in which a monolithic connection is realized between the three-point capture and the second body. Forces appear, which are considered by mechanics as jamming forces;
3. Capture removal phase. This is the phase in which the capture ceases to exist and all jamming forces of the capture are reset;
4. Repulsion phase or other impact between the two bodies. In this phase, forces acting after phase 3 are observed, which are for one body (the spacecraft) motive, and for the other body (the meteorite) are external.

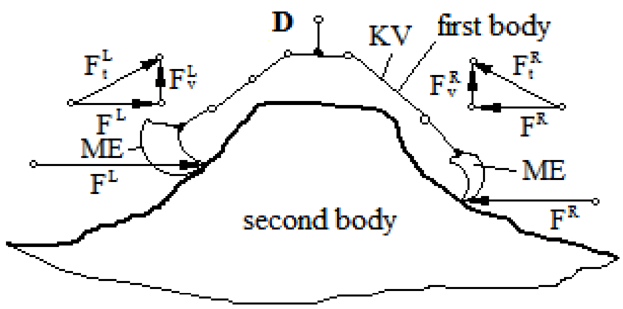
5 BLOW

The four physical phenomena - landing, support, grip and locomotion, in their action are accompanied by the phenomenon of impact at a certain moment. From the theory of impact, it is known that this phenomenon affects in a very short time interval, with the impact force taking on very high values.

Since impact forces can be destructive, through the synthesis of the kinematic chains of the three-point support, the three-point grip and locomotion, as well as the technology of action, these impact forces should be minimized or zeroed, if possible.

Figure 6

Possibility of a grip in which the impact forces are minimized due to their opposite direction.



The gripping scheme shown in Fig. 6 minimizes impact forces. As can be seen, this approach can be implemented with a convexity or concaveness on the surface of the second body.

$$F^L = F_t^L - F_v^L$$
$$F^R = F_t^R - F_v^R \quad (3)$$

In order to implement a three-point grip, a third machine element is added in addition to the two machine elements ME with the corresponding kinematic chain from Fig. 2. The third machine element completes the geometric definition of the contact points with the meteorite, forming a support triangle similar to the support triangle ABC of the three-point support.

6 CONCLUSION

The development of mechanics in the direction of synthesis of three-point supports and three-point grips, gives the opportunity for the development of landing and locomotion. This is especially important in the development of the space industry, where contact with space bodies is inevitable.

Here on Earth in the biomechanics of animals (insects, birds, etc.), which land on flowers, trees, climb them, have limbs ending in hybrid supports. This shows the accuracy of the conceptual approach for the constructive synthesis of supports and grips.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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