АВТОМАТИЗАЦІЯ ТА ІНТЕЛЕКТУАЛІЗАЦІЯ ПРИЛАДОБУДУВАННЯ

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HEXAPOD MOVEMENT ALGORITHMS TO AVOID INTERFERENCE. ANGULAR MOVEMENT

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This paper considers the possibility of using a stepping robot - hexapod for research, monitoring the condition of technical dry channels, enclosed spaces and more. Compared to existing designs used today, the hexapod has a list of advantages that make it a more versatile tool, namely: autonomy, due to the power supply installed at work, design features that ensure its increased patency on uneven surfaces. Instead, this type of work requires the development of complex algorithms for movement than in the case of wheeled or tracked machines, ie. hexapod is a platform that moves the limbs, which in turn move with the help of servos. Therefore, the movement of the platform is provided by the control of each servo. In addition, environmental information is additionally processed from rangefinders, limb contact sensors with the surface, cameras, accelerometers, etc.

Particular attention is paid to robot rotation algorithms, as the proposed scope imposes restrictions on the ability to maneuver freely in space. An algorithm for rotating robots in confined spaces based on limb state matrices has been developed, which greatly simplifies the practical implementation and allows to easily change the type of stroke during the hexapod operation. It is also proposed to introduce a buffer state matrix, which allows you to remember the last position of the limbs of the robot in case of its failure, after the elimination of which, it is possible to continue moving from any last state. Or return to the starting position and change the route.

The versatility of the algorithm allows its use not only in the development of the software part of the hesapod, but also for other types of walking robots. Since the developed algorithm allows you to easily modify the types of moves at each iteration of the step.

In the future, it is planned to test this algorithm on a model of a hexapod and supplement it with the necessary components for vertical movement, which is very important for passability in this area of application.

Keywords: *walking platform; ventilation channel; technical condition control; control algorithms; hexapod; static stability; matrix; servodrives; diagnostics; quadropod; adaptive control.*

Introduction and problem statement

In recent years, the scope of use of such robots has developed quite rapidly, replenishing the arsenal of ideas and designs. This was facilitated not only by general technical progress in general, but also by the development of technical base, algorithmic component, thus it was possible to apply such machines in new areas in which these machines did not compete with classical designs based on wheel chassis or caterpillar [1-2]. . Such new areas include search operations, research tasks, civilian use, industrial applications, diagnostics and condition monitoring of various structures or premises. Today there are methods and tools used in all the above areas. such are various caterpillar works, miniature wheeled machines, multilink works for in-tube diagnostics. However, despite the availability of ready-made solutions, there are still unresolved problems related to the control and diagnosis of the condition of objects, in particular, in confined spaces. These include: in-tube diagnostics, inspection and monitoring of ventilation shafts, various tanks or technical channels, caves, tunnels, etc. Existing designs used today have shortcomings that make them highly specialized tools that do not cover the full range of possible tasks. Therefore, there is a need to develop a universal option for each case [3].

Recent research by leading manufacturers of stepping robots focuses on the use of quadropods, but such work is less stable than hexapods and requires complex control algorithms, which complicates development and makes it more expensive. This paper considers the use of hexapod for its use in the field of technical condition control in narrow or closed spaces, technical ducts, ventilation, etc.

Note that wheel or crawler works are also used for these purposes, but their passability is limited and usually in the case of such robots select a specific solution for each case, respectively, wheel / crawler structures are not universal and require a whole arsenal of different structures, which is expensive in production.

Recent work aimed at developing hexapod control algorithms is aimed primarily at the use of this class of robots in open areas, which makes them unsuitable for the proposed field. Therefore, this paper will consider hexapod control algorithms that can be used to monitor the technical condition of narrow or closed spaces, technical ducts, ventilation, and so on.

Review of literature sources

To carry out operations on flat horizontal surfaces, a lot of machines and devices have been created, but there is a problem of carrying out various operations in places, access to which is limited or difficult for any reason. This problem was especially acute in the industrial sector. As a result, walking robots of vertical movement were designed, which later became a separate class of walking robots. The main task of such robots was to gain access to hard-to-reach places located on a vertical plane. Such robots are considered in [4]. A feature of their designs is the use of vacuum suction cups for adhesion to the surface, which partly solves a whole range of problems, since it allows the robot to move vertically through ventilation shafts and channels, and thus there is no need to disassemble these structures, especially if it is difficult. But such a solution requires a vacuum unit, which in turn increases the robot's weight and dimensions. This imposes restrictions on both the investigated areas and the time of the hexapod's autonomous operation due to the additional consumption of the compressor (s).

Analysis of the designs of modern robots designed to diagnose and monitor the condition, which are presented in the sources [4, 5], use for their work cable for data transmission and power. There is also a chassis with wheels, which does not allow the work to rise vertically or overcome protrusions and significant irregularities.

In the existing prototypes of walking robots, much attention is paid to the algorithms of movement, which basically use adaptive control. As shown in [6], such algorithms allow you to move in four directions, bypass obstacles and restore motion in the event of a robot overturning. However, these algorithms are presented for open traffic. Diagnosis of confined spaces and channels requires the development of new algorithms, as there is no room for maneuver, and options for overcoming obstacles are much less than in the open. Adaptive algorithms also include the method of reinforcement learning (RL), which is covered in [7], but this method was considered only for wheeled robots.

The work [8], carried out by developers from France led by Jean-Baptiste Moret, deserves special attention. Based on the results of this work, the walking robot can adapt to work with broken or lost limbs. After the loss / breakage of any limb, the robot was able to resume up to 96% of its initial speed.

The algorithms presented in the work are, of course, very useful, but only in open areas, where there is time and space for adaptation. In conditions of robot motion limitation, such algorithms are not appropriate for use for the proposed scope of the robot.

In [9], a motion algorithm is proposed with a correction for the deformable surface along which the robot moves. Deformation compensation is certainly necessary if the movement occurs on soft surfaces (sand, swamp, etc.), but for the proposed field of application of the robot, such an amendment is not necessary, since mainly in such places, reinforced concrete structures, wooden or metal structures are used. Therefore, this amendment can be neglected.

The authors from the Federal Polytechnic School of Lausanne and the University of Lausanne investigated that an algorithm that implements a bipedal gait makes movement faster on a flat surface than a tripedal algorithm used by most insects [10]. Instead, the tripedal algorithm predominates when moving vertically. Also in the course of research it was found that with poor traction bipedal gait shows the best result. In this paper, we will use the results of these studies and take into account important aspects that will become the basis for the development of our own algorithms for motion in confined spaces.

Thus, the existing developments cover the range of applications of robots only in open areas and therefore are not suitable for the proposed field of application of hexapod. Therefore, it was decided to adapt the existing algorithms for the movement of the hexapod for its operation in conditions of movement in confined spaces, technical dry ducts, ventilation shafts, pipes, etc.

Development of motion algorithms

The direct motion of the hexapod in space on a flat surface is determined and all the steps of the control algorithm are defined, and the kinematics is unchanged. In the process of monitoring the condition of technical dry ducts, ventilation shafts, pipes, etc., the use of previously specified actions in the algorithm can lead to loss of stability of the robot, lead to its fall into failure or damage to the components of the robot.

To solve this problem, it is necessary to use adaptive motion algorithms, which are aimed at analyzing the environment using sensors mounted on the hexapod, and, depending on the situation, change or correction of motion [11]. There are many such adaptive algorithms for hexapods, but they are all designed to control the robot in open areas. Operations in ventilation shafts and ducts require adjustments in the process of movement, as these objects are closed spaces and can have various obstacles, failures, etc. In general, management principles remain unchanged.

For the efficiency of the adaptive motion algorithm it is necessary to know all the components that can be determined either experimentally or in fact during the operation of the robot. From the known parameters it is possible to allocate the following: weight and dimensions of the robot, parameters of the applied sensors, on indications of these sensors the type and environment is defined. Uncertain will be: the size, curvature, length of the studied objects, as well as the presence of obstacles. So, for example, in fig. 1-a, b, d show a typical ventilation shaft, with concrete protrusions and gaps between the bricks. And in fig. 1-c shows the part of the shaft that has irregularities and variable size, descents and ascents, etc.


a b
c D

Figure 1. Possible application environments of the robot: a – standard ventilation shaft in brickwork; b – ventilation shaft with a cement barrier; c – ventilation shaft with uneven edges; d – ventilation shaft from a brick in a panel design

In such cases, the hexapod must analyze the nature of the obstacle, its size, location and be able to determine the possibility of bypassing it in a confined space. The task is complicated by the fact that for effective operation, the hexapod must maintain a given speed and balance. Summarizing the above, we can form the main class of tasks assigned to the control system, which in the general case has the form (simplified) shown in Fig. 2.

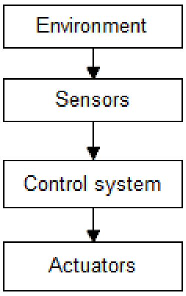

Figure 2. Simplified functional diagram of the adaptive control system

In general, the principle of operation of such a system is quite simple – receiving data from environmental sensors, as well as information about the position of the limbs, is the calculation of their further movement, and, accordingly, the robot platform.

In [12] the author uses a mathematical model of the state of the limbs, which is a vector of the state of each limb and has the following form:

$$q^i(t)=\begin{cases} 1\text{ - the limb is raised} \\ 2\text{ - the limb is lowered} \end{cases}$$

That is, the state of the *i*-th limb at time t is determined by the state function $q^i(t)$, which has two values. In [13], this model was supplemented by the third state to simplify the practical implementation of the algorithm in the computing core of the robot and on the basis of the obtained complex model developed algorithms for rectilinear motion for bipedal and tripedal gait. Since closed spaces can have rotations or curvatures in the horizon, it is necessary to implement, in addition to gait algorithms, rotation algorithms in closed spaces.

For this purpose we will use the supplemented model from work [13] and we will use it for realization of turns which can schematically look as follows (fig. 3-4).

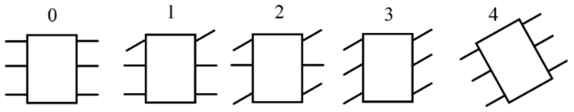

Figure 3. Iterations of the rotation process for bipedal gait

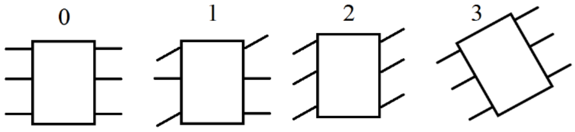

Figure 4. Iterations of the rotation process for tripedal travel

Where 0-4 and 0-3 are iterations for bipedal and tripedal gaits that need to be performed to rotate the robot. From these schemes it is seen that the rotation in the case of using a bipedal gait requires one iteration more than a similar rotation for a tripedal gait.

It is also noticeable that the iterations of 0.3.4 (bipedal) and 0.2.3 (tripedal) for both gaits are the same, so for practical implementation will differ only 1, 2 and 1 for bipedal and tripedal gaits, respectively. This approach allows you to quickly switch between types of gait, if necessary, because only the intermediate matrices of 1.2 by 1 will change and vice versa, depending on which gait was used previously.

Suppose that:

Max – the maximum angle of rotation of the drive shaft;

Mean – the average (or initial) position of the drive shaft;

Min – the minimum angle of rotation of the drive shaft.

Then, taking into account the model from [13], the drive state matrix has the form:

$$k = \begin{pmatrix} Max \\ Mean \\ Min \end{pmatrix}. \qquad (1)$$

According to the matrix (1), the position of the servo shaft will be as follows (Fig. 5).

That is, at the position of the minimum angle (Min) the shaft will rotate counterclockwise, and at (Max) - clockwise, which will bring the joint (joint) of the limb to the minimum and maximum possible position, respectively, where the position is the angle of deviation. Mean is the initial (neutral) state in which the robot stands motionless on the surface and has maximum stability. This condition takes into account the design of all servos in such a way that all their shafts at the start of the robot occupy the middle position of the entire range of the drive (for example, if the drive shaft has a range from 0° to 120°, the average position will be 60°). Consequently, the limb is in the middle position.

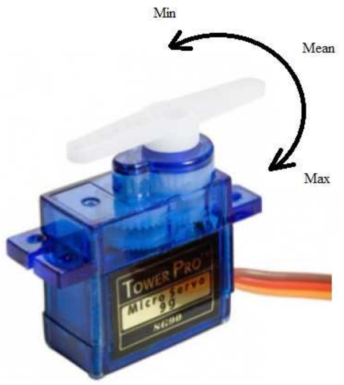

Figure 5. The position of the servo shaft according to the proposed model

And the matrices realizing turn to the left for a bipedal gait will look (tab. 1).

And for tripedal, respectively (table 2).

Based on the obtained matrices, it is convenient to implement the program code of the movement algorithm, because such a matrix determines the state of the limb and allows you to easily change it using the parameters without processing the entire program.

This makes it easy to design different gait algorithms, which facilitates and speeds up experimental studies of gait work in specific locations where it is located.

The subroutine algorithm responsible for turns can be implemented as follows (Fig. 6). Let the robot, in the process of work, use sensors to detect that it is necessary to make a turn. In this case, for both types of gait, three iterations of the turn cycle will be performed.

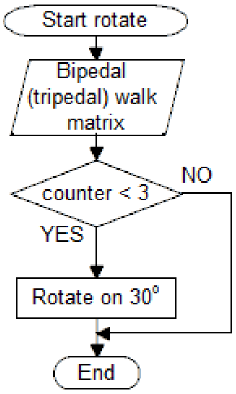

Figure 6. Simplified block diagram of a routine for rotating the robot by 90°

This number is due to the design features of the model on which the tests were carried out. As you can see in fig. 7 shows the structure of the limb of a hexapod, which consists of two servos, respectively, has two degrees of freedom, connected by a hinge.

Table 1. Matrices that implement the rotation of the robot to the left for bipedal gait

Matrix	**Iteration**
$\begin{bmatrix} Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	0
$\begin{bmatrix} Max & Mean & Mean & Min \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	1
$\begin{bmatrix} Max & Min & Min & Min \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Mean & Mean & Mean \\ Max & Mean & Mean & Min \end{bmatrix}$	2
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Mean & Mean & Mean \\ Max & Min & Min & Min \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Min & Min & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Max & Mean & Mean & Min \\ Mean & Min & Min & Mean \end{bmatrix}$	3
$\begin{bmatrix} Mean & Min & Min & Mean \\ Max & Min & Min & Min \\ Mean & Min & Min & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Min & Min & Mean \\ Mean & Min & Min & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	4

This is the order in which the images are designed to move the robot's style, so that it will ensure that everybody falls. The maximum and minimum angle of rotation of the servo drive connected to the platform body is 30º. Thus, three iterations of the loop implement a 90º rotation. For constructions other than the one shown, the values of the angles and, ultimately, the values of the iterations of the rotation cycle may differ.

Table 2. Matrices that implement the rotation of the robot to the left for tripedal gait

Matrix	**Iteration**
$\begin{bmatrix} Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	0
$\begin{bmatrix} Max & Mean & Mean & Min \\ Mean & Mean & Mean & Mean \\ Max & Mean & Mean & Mean \end{bmatrix}$	1
$\begin{bmatrix} Max & Min & Min & Min \\ Mean & Mean & Mean & Mean \\ Min & Min & Mean & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Min & Mean & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Max & Mean & Mean & Max \\ Mean & Min & Mean & Max \end{bmatrix}$	2
$\begin{bmatrix} Mean & Min & Min & Mean \\ Max & Min & Min & Max \\ Mean & Min & Min & Max \end{bmatrix}$	
$\begin{bmatrix} Mean & Min & Min & Mean \\ Mean & Min & Min & Mean \\ Mean & Min & Min & Mean \end{bmatrix}$	
$\begin{bmatrix} Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \\ Mean & Mean & Mean & Mean \end{bmatrix}$	3

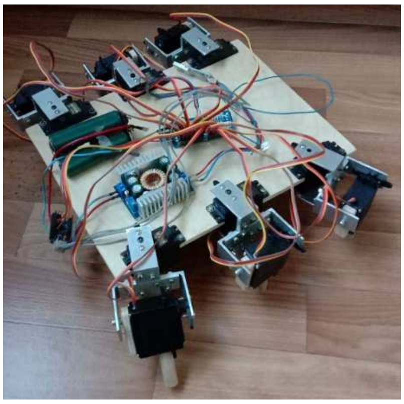

Figure 7. Design of the tested model of a walking robot-hexapod

In the process of movement of the hexapod around the object, situations may arise when it takes some time to study the environment, be it a difficult obstacle or a difficult-to-pass area. Since the use of adaptive algorithms does not guarantee an instant response to the environment, from a practical point of view it is convenient to use an additional buffer matrix that will remember the last state of the robot's limbs, which was not taken into account earlier in [13].

Thus, after analyzing and making a decision, the robot can continue the route from the last saved state in space or, in the case of an impassable obstacle, using the buffer matrix, return to its original state.

Next, it is planned to test the proposed rotation algorithm on a mock-up sample. And also to supplement the existing one for vertical movement and rotation in spaces with complex branches.

Conclusion

This paper proposes the use of a walking robot - hexapod for tasks of technical condition control and diagnostics of narrow enclosed spaces, technical channels, ventilation, etc.

The analysis of the robot motion algorithm showed that most of the existing solutions are aimed at the use of robots in open spaces, which does not fully satisfy the tasks. The shortcomings of previous work have also been identified, and a new motion algorithm has been developed that implements the angular turns of a six-legged robot in a confined space for bipedal and tripedal gait.

For this purpose, using the matrix of positions of the limb states from [13], rotation matrices were formed. In addition, it is proposed to use an additional matrix to saving the state of the limb in space. In the event of an emergency, this will allow you to continue moving from any stable position.

Literature

[1] Official site Boston Dynamics URL: https://www.bostondynamics.com/

[2] Робот-паук Hexa «выгуливает» комнатные растения на солнце [Електронний ресурс]. Доступно: https://gagadget.com/science/38806-robot-pauk-hexa-vyigulivaet-komnatnyie-rasteniya-na-solntse/#!

[3] Краулеры, роботы ВТД [Електронний ресурс]. Доступно: http://robotrends.ru/robopedia/kraulery-polzayushie-roboty

[4] В. Г. Градецкий, М. Ю. Рачков, *Роботы вертикального перемещения*. Москва, РФ: Тип. Мин. Образования РФ, 1997.

[5] B. B. V. L. Deepak, M. V. A. R. Bahubalendruni, & B. B. Biswal, «Development of in-pipe robots for inspection and cleaning tasks», *International Journal of Intelligent Unmanned Systems*, vol. 4, no. 3, pp. 182–210, 2016.

[6] S. Krenich, M. Urbanczyk, “Six-legged walking robot for inspection tasks”, *Solid State Phenomena*, Vol. 180, pp. 137-144, 2012.

[7] С. Г. Удовенко, «Нечеткое управление автономным мобильным роботом с подкрепляемым обучением», *Системи обробки інформації*, № 8(145), с. 56-62, 2016.

[8] Cully, J. Clune, D. Tarapore, et al. «Robots that can adapt like animals», *Nature,* vol. 521, pp. 503–507, 2015. DOI: 10.1038/nature14422

[9] Е. В. Поезжаева, «Алгоритм управления шагающего робота при диагностике и ремонте труднодоступных участков жилых и производственных помещений», *Молодой ученый*, № 1 (105), с. 203-205, 2016.

[10] P. Ramdya, R. Thandiackal, R. Cherney, et al. «Climbing favours the tripod gait over alternative faster insect gaits», *Nat Commun,* vol. 8, 14494, 2017. DOI:10.1038/ncomms14494

[11] С. И. Савин, Л. Ю. Ворочаева, «Методы управления движением шагающих внутритрубных роботов», *Cloud of Science,* Т. 5, № 1, с. 163–195, 2018.

[12] В. В. Лапшин, *Механика и управление движением шагающих машин*, Москва, РФ: МГТУ им. Н. Э. Баумана, 2012.

[13] І. Платов, & О. Павловський, “Алгоритм руху автономного робота – гексапода для переміщення у вузьких замкнутих просторах”, *Вісник Київського політехнічного інституту. Серія Приладобудування*, Вип. 61(1), с. 61–68, 2021. DOI:10.20535/1970.61(1).2021.237103

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АЛГОРИТМИ РУХУ ГЕКСАПОДА ДЛЯ ОМИНАННЯ ПЕРЕШКОД. КУТОВИЙ РУХ

В даній роботі розглядається можливість застосування крокуючого робота - гексапода для досліджень, контролю стану технічних сухих каналів, замкнутих просторів тощо. Порівняно з існуючими конструкціями, що застосовуються сьогодні, гексапод має перелік переваг, що робить його більш універсальним засобом, а саме: автономність, за рахунок джерела живлення, встановленого на роботі, конструктивні особливості, що забезпечують його підвищену прохідність по нерівним поверхням. Натомість, такий тип робота вимагає розробку більш складних алгоритмів руху, ніж у випадку з колісними або гусеничними машинами, так як гексапод представляє собою платформу із, рухомими кінцівками, які у свою чергу рухаються за допомогою сервоприводів. Тому рух платформи забезпечується керуванням кожного сервопривода. Окрім цього, додатково обробляється інформація про навколишнє середовище з датчиків-далекомірів, датчиків дотику кінцівки з поверхнею, камерами, акселерометрами і т.п.

Особливу увагу приділено алгоритмам повороту робота, оскільки запропонована сфера застосування накладає обмеження на можливість вільно маневрувати у просторі. Розроблено алгоритм повороту робота в замкнутих просторах на базі матриць стану кінцівок, що значно спрощує практичну реалізацію та дозволяє легко змінювати тип ходи у процесі роботи гексапода. Також запропоновано введення буферної матриці стану, яка дозволяє запам'ятовувати останнє положення кінцівок робота у випадку його поломки, після ліквідації якої, є можливість продовжити рух із довільного останнього стану. Або повернутися у початкове положення та змінити маршрут.

Універсальність алгоритму дозволяє використовувати його не лише при розробці програмної частини гесапода, а й для інших видів крокуючих роботів. Так як розроблений алгоритм дозволяє легко модифікувати типи ходи на кожній ітерації кроку.

У подальшому планується протестувати даний алгоритм на макеті гексапода та доповнити його необхідними складовими для вертикального переміщення, що є дуже важливим для прохідності в даній сфері застосування.

Ключові слова: крокуюча платформа; вентиляційний канал; контроль технічного стану; алгоритми керування; гексапод; статична стійкість; матриця; сервоприводи; діагностика; квадропод; адаптивне керування.

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АЛГОРИТМЫ ДВИЖЕНИЯ ГЕКСАПОДА ДЛЯ ОБХОДА ПОМЕХ. УГЛОВОЕ ДВИЖЕНИЕ

В данной работе рассматривается возможность применения шагающего робота – гексапода для исследований, контроля состояния технических сухих каналов, замкнутых пространств и т.п. По сравнению с существующими конструкциями, применяемыми сегодня, гексапод имеет ряд преимуществ, что делает его более универсальным средством, а именно: автономность, за счет источника питания, установленного на работе, конструктивные особенности, обеспечивающие его повышенную проходимость по неровным поверхностям. В свою очередь, такой тип робота требует разработки более сложных алгоритмов движения, чем в случае с колесными или гусеничными машинами, т.к. гексапод представляет собой платформу с движущимися конечностями, которые в свою очередь двигаются с помощью сервоприводов. Поэтому движение платформы осуществляется управлением каждого сервопривода. Кроме этого, дополнительно обрабатывается информация об окружающей среде из датчиков-дальномеров, датчиков соприкосновения конечности с поверхностью, камерами, акселерометрами и т.п.

Особое внимание уделено алгоритмам поворота робота, поскольку предлагаемая область применения накладывает ограничения на возможность свободно маневрировать в пространстве. Разработан алгоритм поворота работы в замкнутых пространствах на базе матриц состояния конечностей, что значительно упрощает практическую реализацию и позволяет легко изменять тип походки в процессе работы гексапода. Также предложено введение буферной матрицы состояния, позволяющей запоминать последнее положение конечностей работа в случае его поломки, после ликвидации которой есть возможность продолжить движение из произвольного последнего состояния. Или возвратиться в исходное положение и изменить маршрут.

Универсальность алгоритма позволяет использовать его не только при разработке программной части гесапода, но и для других видов шагающих роботов. Так как разработанный алгоритм позволяет легко модифицировать типы походки на каждой итерации шага.

В дальнейшем планируется протестировать данный алгоритм на макете гексапода и дополнить его необходимыми составляющими для вертикального перемещения, что очень важно для проходимости в данной области применения.

Ключевые слова: шагающая платформа; вентиляционный канал; контроль технического состояния; алгоритмы управления; гексапод; статическая устойчивость; матрица; сервоприводы; диагностика; квадропод; адаптивное управление.

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