BIPED ROBOT WITH UNCONVENTIONAL KINEMATICS

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The article deals with the design of a robot with an unconventional kinematic structure, which is able to vertically stabilize the position of the robot base for the placement of sensors and handling superstructures. The robot concept was designed to have as few actuators as possible. The robot's kinematics was solved for the purpose of simulating the robot's movement and implementation into the robot's control system.

KEYWORDS

Gripper, robot, actuator, kinematics, simulation

1 INTRODUCTION

Conventional proposed two-legged robotic platforms usually have a kinematics analogous to humans and also perform lateral rocking movements during their movement, so that the stability of the robot during movement is achieved. There may be a problem with the application of sensors with handling superstructures during this movement [Chen 2021, Sobirin 2021, Virgala 2020b].

Bipedal robots have unstable structures due to the passive joints located at the unilateral contact between the foot and the ground [Vukobratovic 2004, Kim 2005, Park 2006].

From a control point of view, bipedal robots contain a large number of action members [Zhu 2010]. So, controlling the movement of such a robot is then more complicated. At the same time, a high number of actuators means higher energy requirements, so the robot needs a battery with a larger capacity [Fevre 2019, Gao 2021].

Bipedal robots are most often designed to interact with unknown environments and are expected to achieve a high level of autonomy. Simulation is required as a part of many control strategies for bipedal walking [Vanderborght 2008, Ficht 2021].

The aim of this work is to design the concept of a two-legged robot, which would have a stabilized base in the vertical direction so that it can be used as a transport device, sensor system carrier or as a chassis of a mechatronic assistant. At the same time, this work is an effort to create a concept with a minimum number of actuators. The two-legged concept of the robot also allows you to overcome obstacles as well as locomotion on sloping terrain [Virgala 2022].

2 ROBOT CONCEPT DESIGN

The proposed concept (Figure 1) has six degrees of freedom, so each leg of the robot can perform three independent movements using three actuators. Those movements are formed for each foot by means of a linear guide with a linear actuator, then a rotary actuator with a parallelogram mechanism, and the sole of the foot is a rotary bond with a rotary actuator.

The parallelogram consists of a foot and a rocker lever, and its movement is realized by a rotary actuator located in the ankle joint of the foot. This location is advantageous due to the lower position of the centre of gravity. The movement of the base in the vertical direction along the linear guide is realized by means of linear actuators on both legs of the robot.

The rotation of the robot during walking is realized by means of a rotating pad in the foot, which can be rotated by means of another actuator.

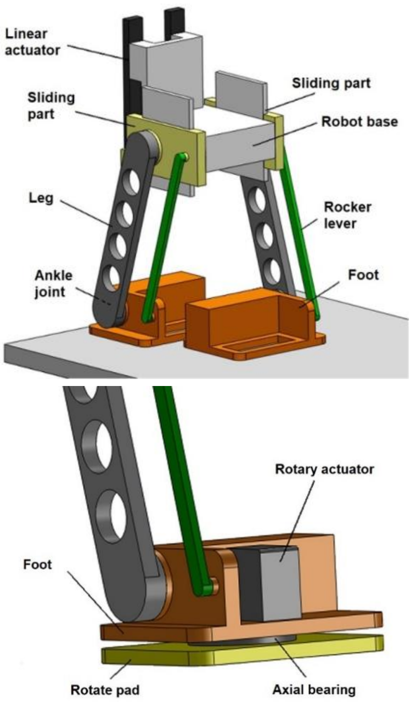


Figure 1. Robot model concept

The principle of movement (Figure 2) can be divided into several stages.

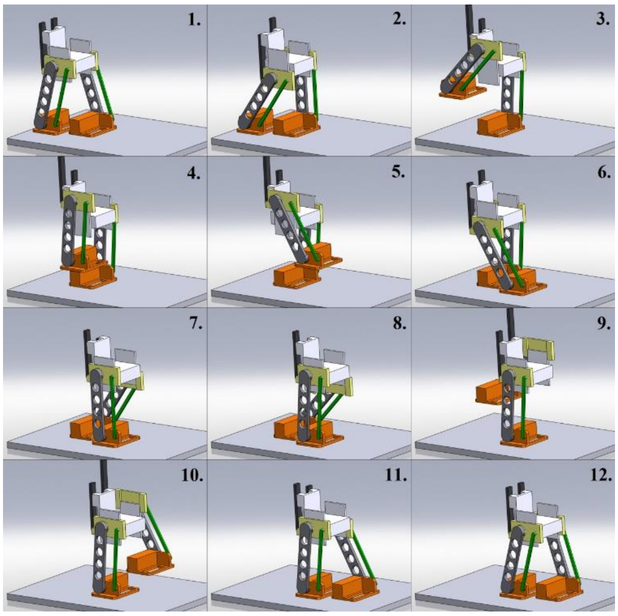


Figure 2. The movement of the robot on a flat surface

Movement of the robot to stage 2 realized by simultaneous movement of all four actuators (without rotary actuators for rotating the robot around the vertical axis).

During this movement, the platform moves forward so that the centre of gravity is transferred to the floor plan of the left foot. After transferring the weight of the robot to the left foot, the right foot can be lifted together with the entire parallelogram mechanism by inserting the linear drive of the right foot (Figure 2 - stage 3). When the right foot is sufficiently raised in stage 3, the rotation of the motor in the right ankle joint starts to move (Figure 2 - stage 4) the foot forward using the kinematic mechanism to stage 5. This mechanism also ensures the parallelism of the foot with the floor when stepped on in stage 6, which is thus realized only by extending the linear actuator of the right foot. Subsequent movement of the platform forward and thus moving the centre of gravity over the right foot (Figure 2 - stage 7, 8) repeats the cycle with the same step of the left leg of the robot. The whole course of walking is shown in the figure (Figure 2).

By an analogous sequence of movement, it is possible to overcome a step-type obstacle, while it is necessary to adjust the movements of individual actuators so as to maintain the stability of the robot's movement (Figure 3).

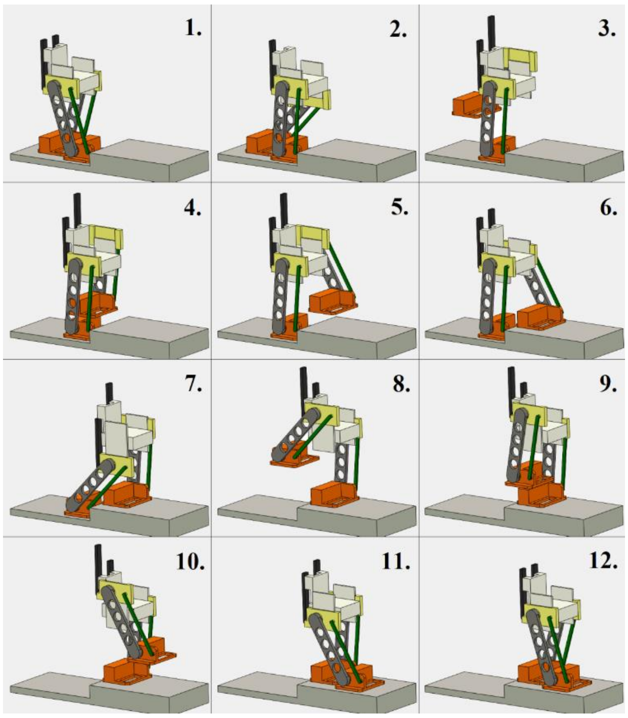


Figure 3. The concept of the movement of the robot over the obstacle shaped staircase

3 ROBOT DESIGN

The robot's leg was designed from a closed square profile to ensure sufficient rigidity. The rocker lever is located only to ensure the function of the parallelogram, i. to ensure that the foot is parallel to the pad (Figure 4).

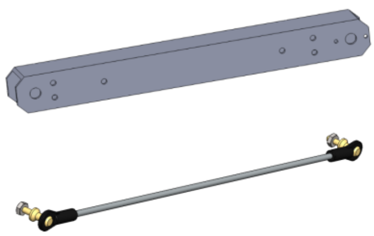


Figure 4. Designed leg and rocker lever of the robot

The shape of the foot profile is also advantageous for the possibility of hiding the wires connecting the electronics in the foot with the electronics in the base of the robot (Figure 4).

The design of the foot construction (Figure 5) uses two parallel and equally long rods mounted symmetrically on the servomotor carrier to rotate the pad. With this solution, which takes the form of a parallelogram, we obtain the distribution of the applied torque into two points (Figure 5). The resulting design of the robot layout already contains linear guides for the vertical movement of the base using linear actuators (Figure 6).

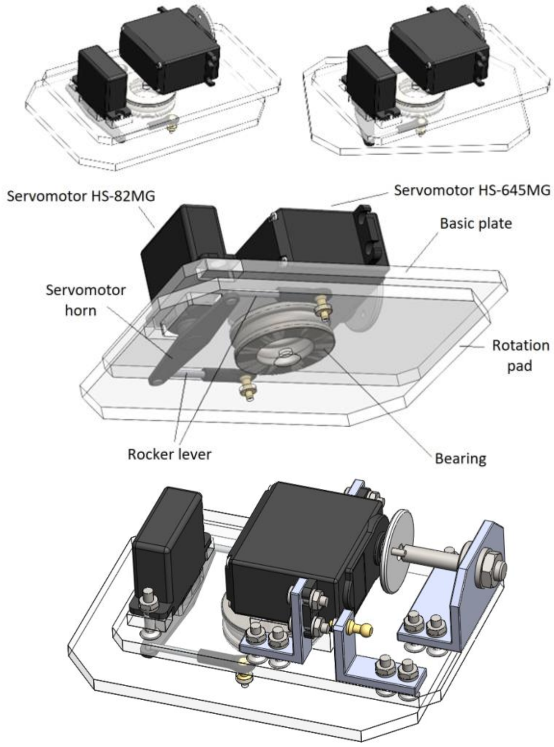


Figure 5. Designed leg and rocker lever of the robot

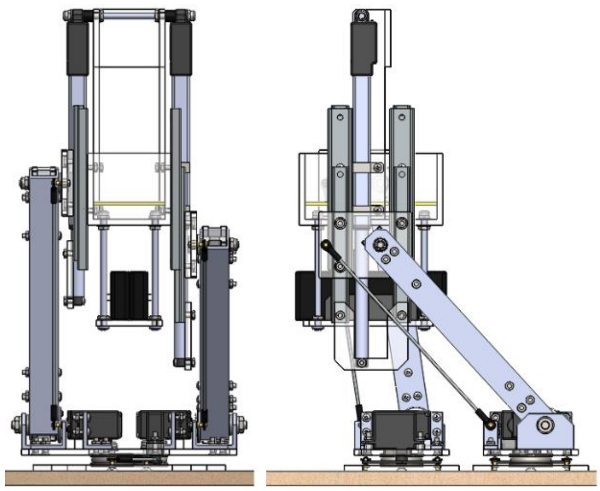


Figure 6. The final design of a two-legged walking robot

The verification of the robot's components was performed under the action of static effects, i.e. under the action of the individual weight of the individual parts of the robot. The configuration was considered when there is the greatest stress on the robot structure. This situation occurs when one foot is moved over the other, and thus the entire weight of the robot is transferred to one foot at this stage of the step. When calculating the load of the bearings forming the articulation between the robot's legs and the carrier [Cacko 2014], a loading gravitational force is created from the weight of the entire robot base, leg and foot, which is not in contact with the pad (Figures 7, 8).

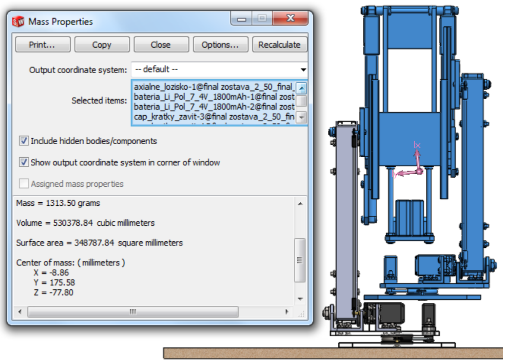


Figure 7. Determination of the weight of the transferred part of the robot and the position of the centre of gravity - upper joint

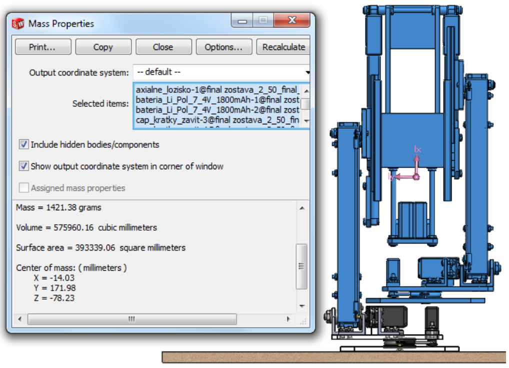


Figure 8. Determination of the required weight and position of the center of gravity - lower joint

A simulation via Motion Analysis was created in SolidWorks to solve the strength analysis of the designed structural elements. The most unfavourable situation is simulated, when the robot is standing on one foot. After the simulation is calculated, the element load data is transferred to the appropriate files using the Import Motion Loads command. In the files of individual components themselves, analyses are created from these imported data, which investigate the stresses and deformations of individual components. The verification was performed on the parts that are most stressed, namely the robot base (Figure 9), the carrier, the designed special screw, the robot leg (Figure 10) and the rotating foot pad (Figure 11).

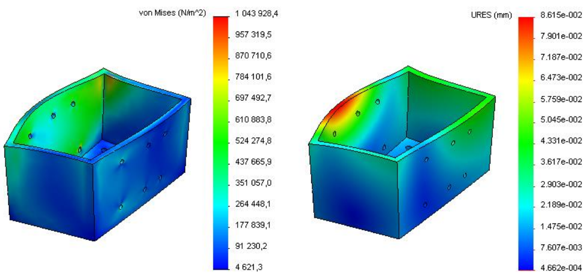


Figure 9. Stress and strain distribution - robot base

The analysis of the most stressed structural elements in the SolidWorks program did not reveal any exceedances of the yield strength of the materials used, nor did the deformations of the elements examined exceed dangerous values. For parts made of polycarbonate, the largest deformation was found to be up to 0.15 mm, and for parts made of aluminium alloy or steel, the deformations were up to 1.5 µm. The design of the two-legged robot is therefore suitable for fulfilling the functions expected of it.

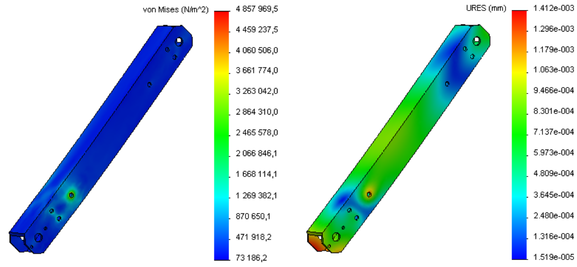


Figure 10. Stress and strain distribution - robot leg

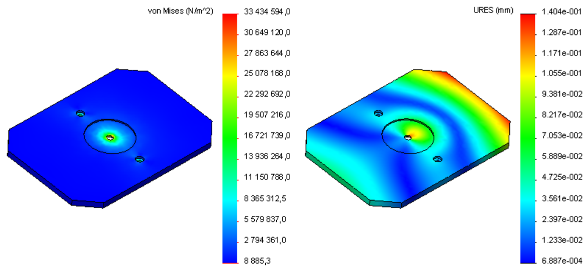
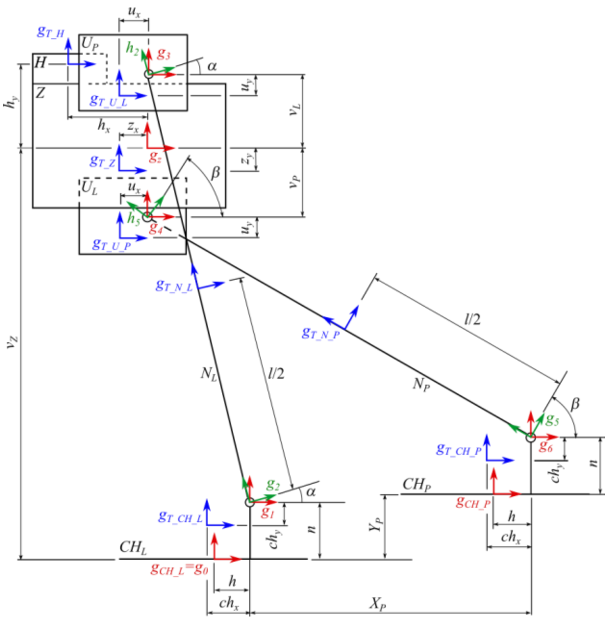


Figure 11. Stress and strain distribution - rotation foot pad

4 KINEMATIC MODEL OF A ROBOT

To create a robot locomotion control algorithm, it is necessary to know its kinematic model, based on which it will be possible to solve the problem of robot motion control [Bezak 2014, Bozek 2016, Kelemen 2018]. The individual moving members of the robot are described using Local Coordinate Systems (LCS). The position of these robot members must then be described with respect to the Global Coordinate System (GCS) (Figure 12).



CH_L, CH_P, N_L, N_P, U_L, U_P, Z, H – main parts of a two-legged robot,

ch_X, ch_Y, u_X, u_Y, z_X, z_Y, h_X. h_Y – constants defining the position of the centers of gravity of individual parts,

α, β, v_L, v_P – generalized coordinates,

n, h, l – dimensional constants,

g.. , $\underline{h}$.. – local coordinate systems of the main points of the kinematic chain,

g_T ... – local coordinate systems of the centers of gravity of individual robot parts,

v_Z, X_P, Y_P – base height and position of the robot's right foot position.

Figure 12. Kinematic scheme of the 3rd variant gripper solution

A special Euclidean group SE (2) is used to calculate the kinematic chain of the robot, which contains rotation and translation. An example is the element g with components (x, y, φ) belonging to SE (2), which is represented by a homogeneous matrix:

$$g(x,y,\phi) = \begin{bmatrix} \cos\phi & -\sin\phi & x \\ \sin\phi & \cos\phi & y \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

The solution is to gradually add more members of the mechanism to the original systems. The following rules were used from the properties of Lie group operations and their actions to perform such a subsequent coordinate transformation:

a. $g_{1,h} = h^{-1} \cdot g_1$
b. $g \cdot h_g = g \cdot g^{-1} \cdot h = h$
c. $g_{1,g_0} \cdot h_{g_1} = g_0^{-1} \cdot (g_1 \cdot g_1^{-1}) = g_0^{-1} \cdot h = h_{g_0}$ (2)

The inverse kinematics problem determines the individual motion coordinates for each actuator to achieve the final robot motion. The resulting mathematical models can then be implemented in a control system to control the individual actuators.

The inverse transformation method was used to solve this problem. From this task it is then possible to determine the resulting generalized coordinates α and β, which represent the rotation of the rotary actuators for the movement of the feet:

$$\alpha = \arcsin\frac{x_P - l\sin\beta}{l} \tag{3}$$

$$\beta = \arcsin\frac{x_P + l\sin\alpha}{l} \tag{4}$$

Then it is possible to determine the values of the generalized coordinates v_L and v_P, which represent the extensions of the linear actuators for both legs:

$$v_L = l\cos\alpha + n - v_Z \tag{5}$$

$$v_P = l\cos\beta + n - v_Z + y_P \tag{6}$$

Where x_p is the length of the foot step, l is the length of the foot, n is the height of the foot.

5 ROBOT WALKING SIMULATIONS

Based on the knowledge of the kinematic model, it is possible to create a robot motion simulation using the SolidWorks Motion tool in co-simulation with the Matlab / Simulink environment, and thus it is possible to display stable robot positions when performing robot motion (Fig. 13).

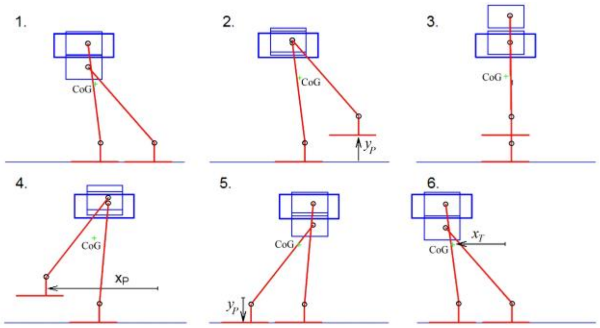


Figure 13. Simulation of walking of a designed robot

At the same time, it is possible to determine the graphical courses of individual monitored quantities of the robot (Fig. 14). From this simulation it is possible to obtain a virtual model of the robot's walk using the CAD model of the robot (Fig. 15).

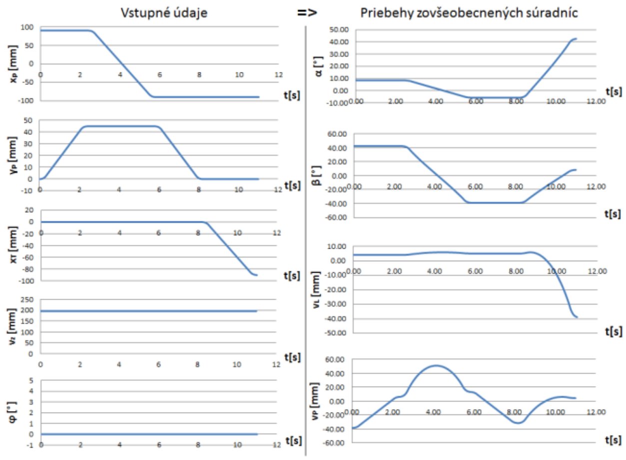


Figure 14. Robot simulation monitored variables

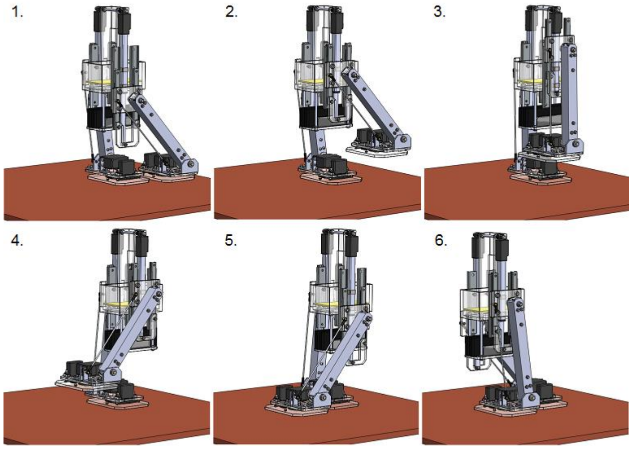


Figure 15. Simulation of robot walking using CAD model

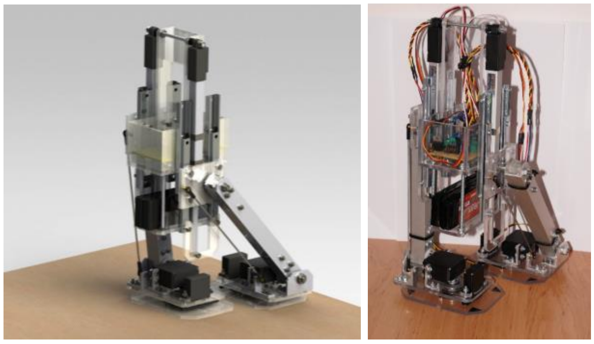


Figure 16. Final implementation of the robot

6 CONCLUSIONS

In this work, the construction of a two-legged walking robot was designed based on the presented concept, which envisages the use of six actuators. Two rotary and two linear servomotors are designed to implement the robot's walking and the other two rotary actuators are used to change the direction of movement.

The kinematics was solved in the work with the help of the created kinematic model of the robot, where the main point of the chain and the centres of gravity of the individual parts were assigned local coordinate systems. A possible accessory on a robot platform was also included in the proposed kinematic chain. Subsequently, the inverse kinematics equations were derived using the vector inverse transform method. The obtained data were further the basis for the design of static walking of the robot on a flat surface. The recalculation of the stable configuration of the robot during the individual phases of the step is provided by programs created in the Matlab environment, which also serve to recalculate the courses of generalized coordinates needed to create a walking simulation. In SolidWorks Motion, a step on a flat surface was simulated.

In connection with the design of robots, it is necessary to solve other related problems with sensor equipment [Kelemen 2021, Kelemenova 2021, Panda 2016, Peterka 2020, Zidek 2018], control systems [Kelemen 2014, Sapietova 2018], handling equipment [Mikova 2014] and effectors [Bulej 2018, Trojanova 2021, Virgala 2012, Virgala 2014], design of parts production [Jakubowski 2014], drive systems [Bozek 2021a,b, Peterka 2020, Nikitin 2020], and other relevant systems [Jakubowski 2014]. It is also necessary to address issues of energy balance and system efficiency [Kelemen 2012, Liptak 2018, Ostertag 2014, Pavlasek 2018, Pastor 2021, Pivarciova 2018, Pivarciova 2022, Saga 2020, Suder 2021, Virgala 2014, Virgala 2020a]. The robots can use information and landmarks from environment for navigation and such information may be provided by QR Codes or Data Matrix Codes [Karrach 2020].

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