PERCEPTIVE ROBOT MOVING IN 3D WORLD

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Abstract. This paper reflects the state of development of multilevel control algorithms for a six-legged mobile robot. The robot has a perceptive ability and can measure distances up to points in the terrain relief to be overcome. The measurement process is coordinated with the robot's motion. DC simulation results and the analysis of the robot's moving image on the display screen make it possible to check the algorithms and to search ways for their improvement.
Key words: six-legged walking vehicle, mobile robot, control algorithm, data processing, DC simulation.

I. Introduction. The mobile robot (Fig.I)

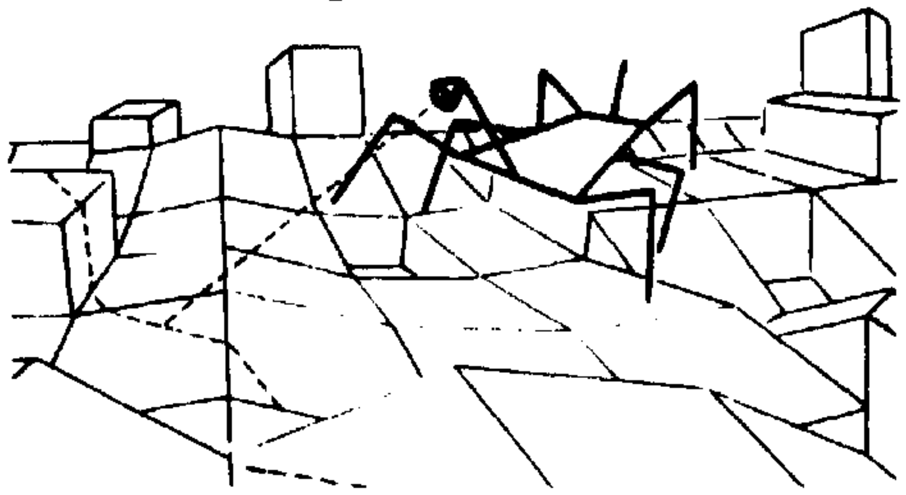

Fig. 1. Mobile robot.

is intended for roving over an unknown and rather complicated world for delivering loads or collecting information. The guidance and contol systems of such robots should have some operational modes of different degrees of autonomy .

The autonomous functioning of the robot requires development of algorithms providing both the robot's perception of the environment and the robot's motion designing ability* Some results on such problems for a robot's motion over prismatic terrain were given in papere • The motion in a 3D world of a rather general type, which is treated paper, required the development of more powerful algorithms for motion design and information back-up to ensure the robot's operation in a more sophisticated world. The investigations at the Institute of Applied Mathematics cover two problems for a six-legged mobile robot: the problem of synthesizing the control algorithms and the problem of testing the algorithms by means of DC simulation. For this purpose a display system containing two DC's was developed .

2. Information problems are complicated by the necessity to arrange the robot's perception ability using for data processing a DC with restricted memory and speed capacity. It is assumed that the robot has a measurement system to estimate distances up to terrain relief (Fig.I). Like in the case of the prismatic world , special algorithms were developed to filter the measurement data and to reduce the information flow. These algorithms make it possible to reject information which may be considered as negligible when making a decision about the robots motion.

The next phase of data processing gives the information for estimating the feasibility to place the leg tips on the support surface and to move the rouot'b body over it . The obstacles which could be overcome when walking along the prescribed route should be transmitted together with the standpoint and route data to the motion design system. If the terrain appears to be easy enough for walking, in this case it is sufficient to transmit to the motion design system only the information on the standpoints and their close confinement.

Thus we observe two stages. The first stage involves preliminary oata processing and filtering necessary for the terrain data base. The second stage covers terrain analysis which reveales the convenient places for the legs. The data base is replenished with the analysis results. The analysis is carried out by joint efforts of the route selecting and information systems. Their block-diagrams are shown in Fig. 2.

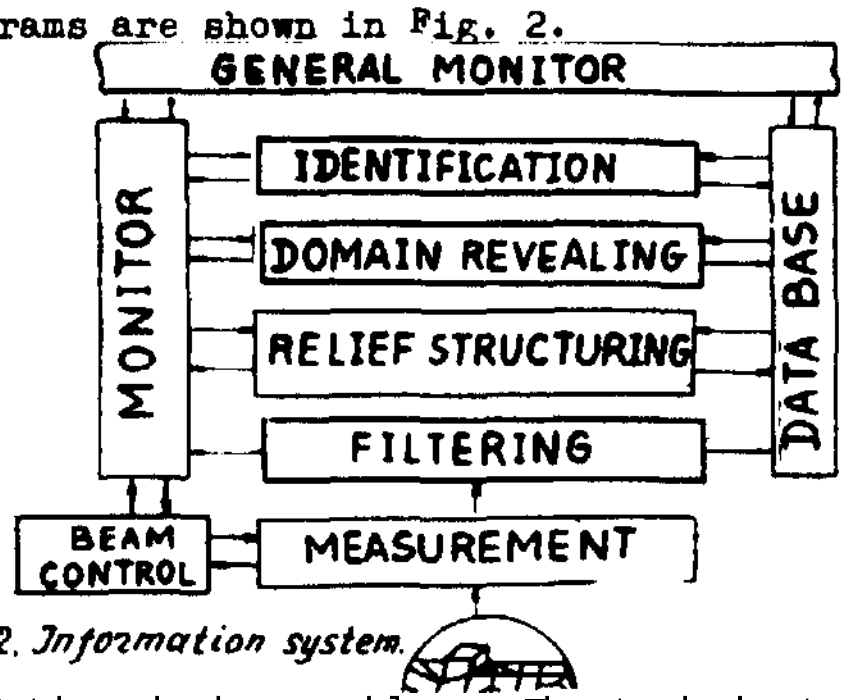

Fig.2. Information system.

3. Motion design problems. The task is to ensure stable motion of the walker along the chosen route in a rather complicated relief. The motion design problems for a rline route were considered in papers[5-8] They dealt with gait selection, stepping schedule and body motion. In the case of movement in a 3D world it is necessary to make the most efficient use of all six degrees of freedom of the body and of eighteen degrees of freedom of the legs. When the walker moves in a changable direction it is necessary to make a choice of standpoints in such a way so as to provide a margin of freedom for body motion. In order to solve this problem the method of gait description proposed by MacGhee was generalized to involve the case of irregular gait along the arbitrary route. An algorithm was developed to find the sequence of the support poligons with maximum existence time. The existence time is the minimum of two times, the first being the time when the feet can stand on the tops of the support poligon, the second being the time of the vehicle's static stability while using the poligon.

A special gait which is free of preliminary agreement on the order of functioning the legs and on the order of using the standpoint sequence, appeared to be very efficient and adequate for stable walking in difficult situations. Such "free" gait is governed by a set of rules on the calculation of the "up" times for legs. Priority should be given to the leg for which the rest of possible support time is minimum. More detailed consideration of "free" gait is given in paper[9].

The vehicle body rotation (in pitch and roll) may be unavoidable when the level differences for chosen standpoints appear ratherrffid comparable with the leg length. In this case it is necessary to calculate the corridor of possible body positions. If the vehicle body moves inside the corridor, the body will have no collisions with the terrain; the standpoints and timing for the legs can be chosen so as to ensure safe motion of the legs. Some problems of linear and nonlinear programming were solved to synthesize algorithms for calculating the corridor and the optimal body motion inside it.

The following logics was adopted to simplify the walker's motion design procedure:

1. If the route selecting system plans the route using the rough model of motion design system and the regular rules of body motion design, it is possible to use a simplified method of motion design.
2. If the previous approach cannot be applied while at the same time the feasibility of further vehicle motion cannot be rejected with certainty (due to the roughness of the model), the motion design system has to make a more detailed analysis for finding a solution. It may cause deceleration or even stoppage of the walker due to the limitations in DC capacity.

Thus we can see that the functioning of the motion design system is based on the data received from the information and route selecting systems. The rough models make it possible to simplify calculations and to save the DC processor time. Pig.3 shows the block-diaexam of the motion design system.

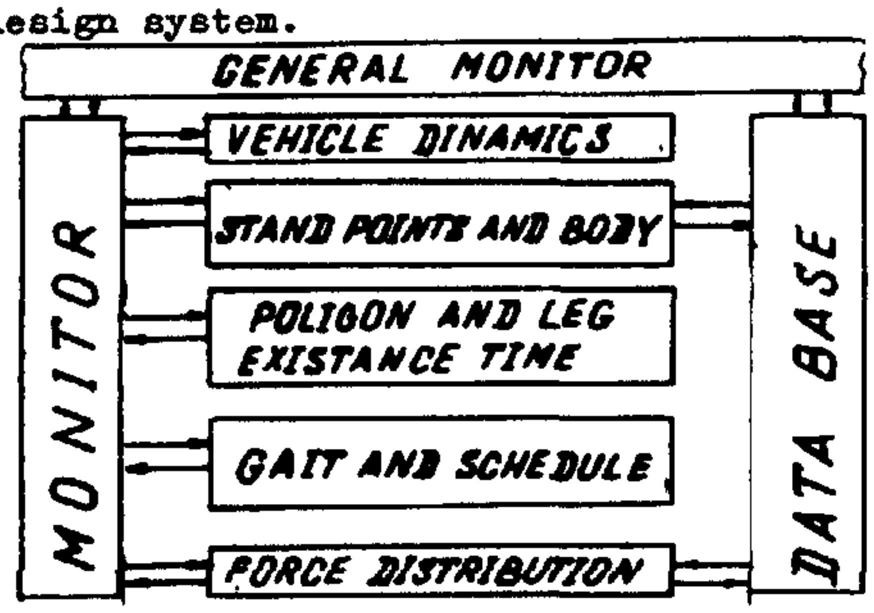

Fig-3, Motion ctestgn system (MDS).

4. Execution problems. The motion design system generates the walker's kinematics. Its realization raises the problem of reasonable force distibution in the statically indeterminable supporting system of the walker, and also the problem of motion stabilization and compensating the execution errors.

The problem of reasonable force distribution and the calculation of the appropriate torques in the leg joints was investigated in paper • The principles that were used were the following:

1. The maximal value of the normal reaction forces in the supporting points (for the legs in contact with the ground) should be kept minimum all the time.
2. The maximal angle between the direction of the reaction force and the axis of the friction cone schould be kept minimum.

Both principles were realized by solving two problems of linear programming with rather moderate searching. The first principle provides some evenese in the support force distribution, while the second one provides an increase in the friction margin.

In ordinary cases, when the required normal and tangent components of the rcc. ction forces might be chosen deep inside the domain of the tolerable values, it appeared to be reasonable to use a simplified method of force distribution based on the rough model of the walker's dynamics and on the information about the terrain inclination (Pig.4).

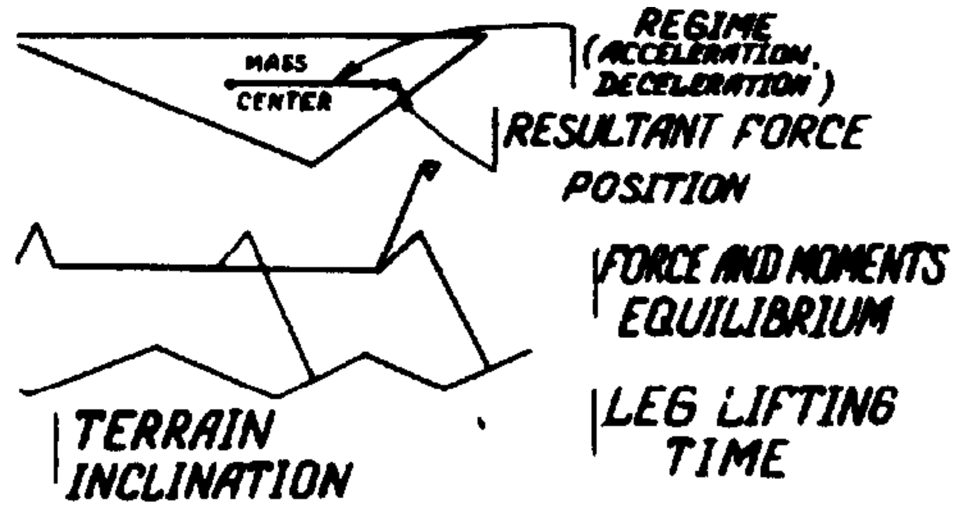

Fig.4. Factors affecting force distribution.

The motion design system sends the numbers of three "main" legs of the walker to the execution dynamic level. The three legs may be considered as the "main" ones providing they have contact with the support poligon and have a maximum rest of the support time. This rule provided a rather smooth loading the actiators of the driving legs. At the same time it diminished the amount of switchings of the regime - the moments of changing the support legs - in comparison with the solution derived from the exact optimization algorithm in[10].

According to the simplified method the vertical components of the reaction forces were calculated at the execution level using the kinetostatic equations. The accelerating or decelerating horizontal components were distributed among the main legs of the right and left side of the walker. The terrain inclination was taken into account when choosing the optimal alternative for the horizontal component distribution between the main legs of the same side.

The motion design system together with the route selecting system and information system ensured the planning of the standpoints with advantageous local inclination of the terrain. This made it possible to raise the reliability margin when implementing the walker's acceleration or deceleration.

If the executing level could not eolve the force distribution problem for the main legs fixed by the simplified method mentioned above, the linear programming problem had to be carried out according to the algorithm from[10]. In this case the slowing down of the walker's motion may be take place due to the processor overloading.

The problem of compensating the execution errors was presented in papers " • It was treated as the problem of syntesizing the follow-up system for implementation the step cycle which was composed from portions of specially chosen basic functions. The basic functions for describing the step cycle and programming the follow-up system may chosen in the form of portions of rectilinear motion of the leg tip relative to the body (with indication of the motion velocity). A rather simple stabilization algorithm described in paper was based on some principles of terminal control and was governed by the navigation system.

Thus we have that the execution level responsible for the reasonable force distribution, torques calculation and the walker's stabilization, works in close cooperation with the navigation system and the motion design system of the walker,

5. System interaction involves two aspects: the content of interaction and the methods of its realization.

The interaction includes the following processes:

1. Scanning over some terrain spots by request of the route selection and motion design.

2. Changing the mode of motion:

- upon reception of the signals from the route selection and information systems,

- upon shortage of information for the motion design system,

- upon processor overloading.

The interaction of the systems and subsystems was implemented through the set of the local monitors (of each system) headed by the general monitor. Each system consists of some independent modules (subsystems) operating in accordance with the signals received from the local monitor of the system. Each module sends to the local monitor signals upon successful termination of a task or upon the impossibility of fulfilling the tast (with the indication of the cause). The information flow between the modules was organized through a common information base.

The idea of stick memory loaded with the help of "situation-action" lists was carried into being when implementing the monitors. The situation names were calculated from the modules signals according to the procedure described in paper . The idea of this approach is similar to the idea of classification rules described in paper

The general monitor coordinates the functioning of the local monitors and provides the flow of data and signals from one local monitor to another.

6. DC Simulation. The mathematical model of walker's control system was programmed using the FORTRAN language and the assambler BEMSH. The prograrums were also implemented which simulated the walker itself and the world where the walker had to operate. The programme run in DC BESM-6. The results were reflected on the display screen in the form of the image of the walker moving over the simulated terrain. A motion picture made from the display screen gives an idea of the effectiveness of the developed algorithms.

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