A RIG FOR TESTING THE LEG OF A WHEEL-LEGGED ROBOT

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Abstract: The paper describes a rig specially constructed for testing a single leg of the wheel-legged robot being designed and presents exemplary test results. The aim of the tests was to verify the mechanical structure and control system operation in laboratory conditions. The operation of the control, communication and data transmission modules was verified. Also tests aimed at selecting proper parameters for the drive controllers were carried out on the test rig.

Key words: Mobile Robot, Suspension, Control System

1. INTRODUCTION

Mobile robots on a wheeled chassis are capable of considerable speeds, but only on level ground. Walking robots are capable of negotiating obstacles, but their speed on flat ground is very low. Wheel-legged robots combine the advantages of both the above designs. In favourable conditions they can travel on wheels at a high speed and when they encounter an obstacle they negotiate it by walking (Guccione, 2003; Grand, 2002; Halme, 2000). This means that walking is used only in cases when the obstacle cannot be negotiated by driving or when it cannot be avoided. The suspension system of such wheel-legged systems has a special kinematic structure (Gronowicz, 2009a; Szrek, 2009) whereby it is more universal and suitable for performing complicated tasks, such as climbing stairs (Gonzales, 2009).

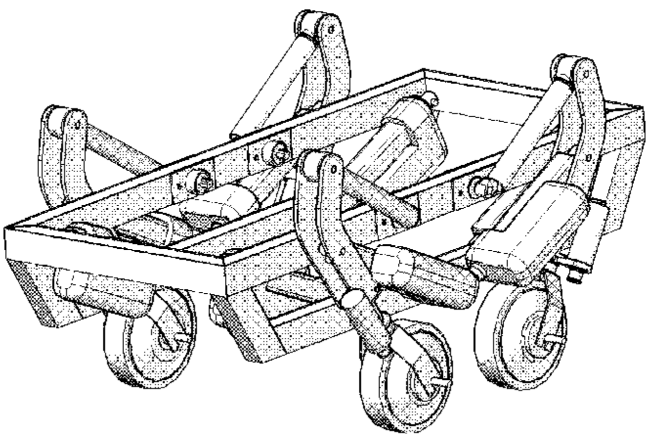

Fig. 1. 3D model of wheel-legged robot being designed

The peculiar feature of the wheel-legged robot considered here (Fig. 1) is the behaviour of its horizontal platform during travel on bumpy terrain. When the robot encounters an obstacle it surmounts it by walking. The kinematic structure of the leg was so designed as to effect the lifting of the platform by means of only one drive (a servomotor). The walking motion is effected by the simultaneous operation of two linear drives. In addition, the leg incorporates a road wheel and a turn executing drive.

Before a prototype of the robot was built, a rig for testing a single robot leg had been constructed whereby a series of preliminary tests could be carried out.

2. DESIGN OF TEST RIG

The basic dimensions of the wheel-legged robot leg were determined through a geometric synthesis based on created numerical models. A kinematic scheme of a single robot leg is shown in Fig. 2.

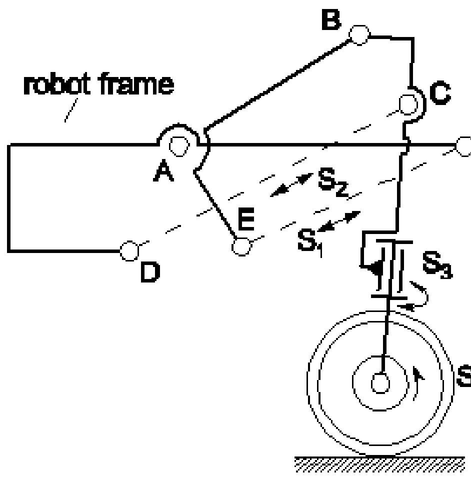

Fig. 2. Kinematic scheme of robot leg (in scale)

Concurrently the test rig was being constructed. This required close integration of simulation studies with construction work. For the preliminary design the kinematic and dynamic parameters of the system and the driving forces for different robot leg motion variants were determined through repeated simulations. Any alterations (e.g. introduction of drive units) to the design required additional simulation studies. As a result, the dimensions of the particular components and their mass parameters were specified more precisely, proper drive units and construction materials were selected, the mechanism's nodes were designed and an algorithm for controlling the drives was developed. The whole construction process was carried out interactively.

In order to determine the actual mechanical properties of the robot's leg and to test the control system it was decided to build a rig for testing a single robot leg. First of all it was necessary to build a stationary structure replacing the function of the other three legs and mimicking the motion and loads of the leg attached to the robot frame. A kinematic scheme of the rig for testing the robot leg is shown in Fig. 3.

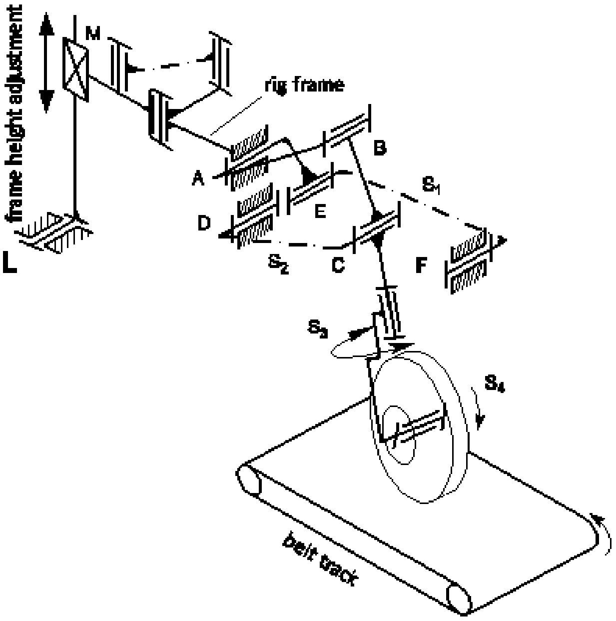

Fig. 3. Kinematic scheme of rig for testing wheel-legged leg

It was assumed that the robot vehicle's frame would always remain horizontal. This is effected through proper changes in the extension of each leg's levelling servomotors (S1). This means that the frame performs vertical motion while maintaining a constant orientation. For technical reasons (possible locking of sliding pair M) on the test rig the motion of the robot frame was replaced by the rotational motion of the rig's frame around point L. As a result, the motion of the levelling servomotor forces the rotation of the frame whereby the axle of the road wheel moves horizontally (rotates or slides relative to the base). Such coordinates of pair L were selected as to make it possible to exclude this motion from the tests. This means that the maximum change of the frame angle during levelling results in a wheel axis displacement not larger than 7 mm. The rig also makes possible stepwise adjustment of frame elevation (H) from the ground. Robot travelling motion in the rig is executed by means of a belt track. Thanks to this solution the robot's travelling properties, such as travelling speed under different working loads, possible accelerations, etc., can be tested. The wheel load (on the track) as a function of time is measured using tensometric scales. Crank AE is a tensometric beam correlating the servomotor force with the wheel load via the control system.

During obstacle negotiation each of the legs is raised in turn (losing contact with the ground) and executes the walking motion while the robot frame remains supported by the other three legs. In order to study the walking mode, the rotary motion of the frame is locked by means of an additional support. Then the leg can move freely in the air. The test rig makes it possible to test the wheel-legged robot leg in its two main operating modes and to integrate the mechanical system with the control system.

3. RIG FOR TESTING ROBOT LEG

A photograph of the rig for testing a single robot leg is shown in Fig. 4. The rig comprises: a frame made from hollow sections, a set of servomotors with controllers, a supervising computer with communication interfaces, and a measuring system.

Fig. 4. Rig for testing robot leg

3.1. Robot leg drive units

The choice of drive units is largely determined by the input system operation assumptions. The electric drive system comprises two electric servomotors LA36 made by LINAK (leg lifting and walking), a HUB-24M drive wheel and an ARE4568 drive effecting its turn. Each of the drives effects the movement of a different motion unit of the leg gear. The selected robot leg drives are characterized by:

- high reliability,
- operability in difficult conditions,
- overload protection,
- high operating speed,
- an ability to work with different speeds at the maximum torque,
- an ability of being frequently start/stop switched,
- ease of assembly,
- an ability to operate in any position.

The adopted servomotors are shown in Fig. 5 and their specifications are given in Tab. 1.

Typical drives and generally available components were considered during the design stage. All the motors are mass-produced, but some of the components had to be slightly modified. A position sensor had to be mounted on the drive wheel motor. Since the motor has no axle extending outside its housing it was necessary to make alterations inside: an additional rack was introduced and a sensor with a resolution of 512 pulse/rev. was mounted on it. A schematic showing the place where the position sensor was installed is shown in Fig. 6. Originally there was a brake in the drive, introducing axial clearance which translated into a protrusion clearance of 8 mm. Since this is not allowable in the robot leg structure the brake was removed and replaced with a flexible coupling. The original servomotors have encoders inside and the latter were used to determine the size of protrusion.

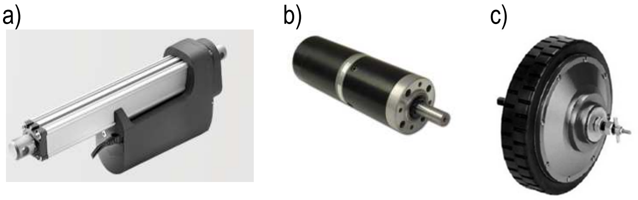

Fig. 5. Robot leg drives: a) servomotor LINAK - LA-36 (levelling and walking), b) wheel turn motor ARE4568, c) drive wheel HUB-24M

Tab. 1. Specifications of drives

Levelling and walking servomotor Linak - LA-36			
stroke	150 mm	power	140W
initial length	350mm	supply voltage	24V
push force	1700N		
Turn effecting drive ARE-24V-4568-3000-R14-EN			
transmission ratio	1:14	supply voltage	24V
rpm	171 rpm	torque	0.81 Nm
belt-toothed gear ratio	1:3		
Road wheel drive			
wheel radius	105 mm	supply voltage	24V
rpm	125 rpm	torque	13.5 Nm
current	10 A	speed	4.9 km/h

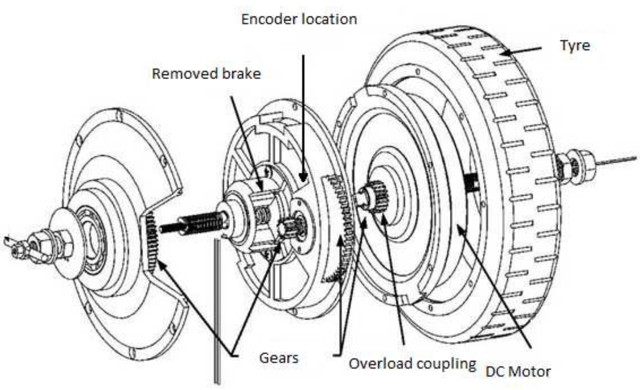

Fig. 6. Place where position sensor was installed

4. CONTROL SYSTEM WITH MEASURING SYSTEM

Before it could be installed in the robot, the control measuring system had to be tested. Controller modules, motor executing system modules, data processing system modules and measuring system modules were designed and made.

The individual modules were integrated into the overall control system and subjected to testing. The measuring and control system structure is shown in Fig. 7. The design of the controller is such that it can be used in mobile objects with many degrees of freedom. Special care was taken to ensure small dimensions, easy expandability and universal communication.

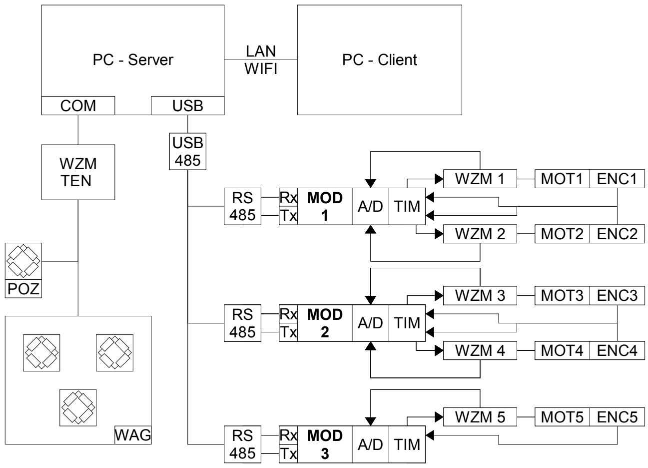

Fig. 7. Structure of control system

The particular components of the measuring and control system are described below:

The local drive controller modules (MOD) are based on the STM32F103RbT6 microcontroller with the ARM Cortex core. The system is in a 64-pin enclosure and it has all the resources and peripherals necessary to control the motors. The control system incorporates a timer block (TIM), an a/d converter block (A/D) and a serial communication block.

Position and speed are measured by incremental encoders mounted on the axle of each of the drives. The position and rotational speed of the motor can be determined on the basis of pulse counts. Moreover, having a leg kinematics model one can easily determine the leg's configuration and kinematic parameters. The (quadrature) signal from the encoder is supplied to the timer inputs where it is counted.

Fig. 8. Lifting drive with measuring beam

A tensometric beam was employed to measure wheel load (Fig. 8). The beam also serves as a crank transforming servomotor protrusion into the rotational motion of the leg for the lifting function. Owing to the fact that the sensor is part of the leg and is located on the crank it is possible to read the force directly connected with the degree of pressure exerted by the leg on the ground and the force is not disturbed by any other components.

Furthermore, thanks to this solution no additional measuring system needs to be introduced into the system and the sensor is not exposed to damage (from torsion, lateral forces, etc.). Besides measuring the pressure exerted by the wheel on the ground (monitoring ensuring robot stability), the tensometric beam supplies information about wheel/ground contact loss instants. This information is useful for negotiating obstacles by walking.

The signal from the strain gauge (operating in the Wheatstone bridge circuit) is amplified and read by the robot's central computer. The ADT4U sensor made by Wobit was used as the amplifier and processing circuit. Communication with the module is via a serial interface using the Modbus protocol.

The pressure exerted on the ground was additionally registered by the tensometric scales shown in Fig. 9.

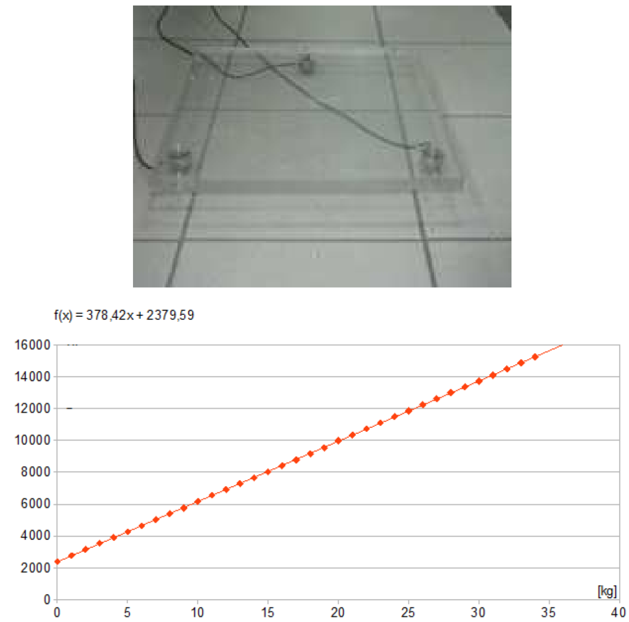

Fig. 9. Tensometric scales and their characteristics with regression function

The driving motors are controlled by the PWM signal generated in the timer block (MOD). The PWM signal is appropriately amplified by power amplification systems (WZM). Additional digital signals are used to change direction. The WZM modules also incorporate a circuit measuring the current which is read by the analog-to-digital converters.

5. TESTS ON RIG

In order to verify the leg's mechanical part and its measuring, control and communication systems tests were carried out on the test rig. During the tests the motions of the leg drives were executed for different speeds and all the measuring data were recorded. Among other things, the following were checked:

– the general functionality – to verify whether all the modules performed the functions for which they were designed;
– the communication functionality – to verify whether the particular units supplied information about the particular modules and drives in the leg (the control instructions, their implementations and performance were tested);
– the control parameters – the drive controllers perform control using the PID algorithm; the task value is sent from the supervising computer level and a local module carries out the request; the control parameters were matched experimentally by carrying out a series of tests for different settings in order to check the system dynamics and the accuracy of the control;
– the measuring path and data interpretation – to verify the whole flow of data in the leg control system being a part of the global robot control system.

Exemplary data (Fig. 10) supplied by the measuring system are: servomotor position (protrusion), speed, motor current, and wheel load (POZ sensor). The data are parameterized with time (ms). The tests showed the data readings to be correct and provided a basis for developing robot control algorithms. The tests were carried out for several cycles at different motions speeds. Conditions very similar to the ones characteristic of obstacle negotiation (the wheel is in contact with the ground and then is lifted) were reproduced in the test rig.

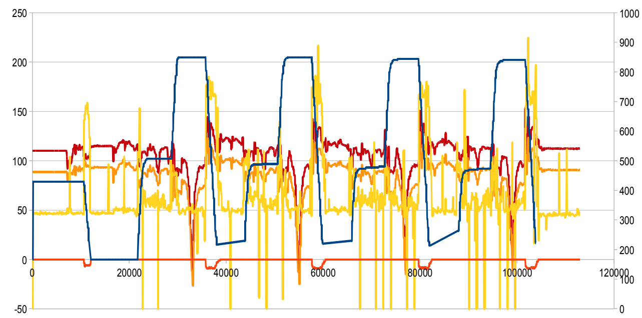

Fig. 10. Exemplary measurement data obtained from leg test rig

The diagram in Fig. 11 shows the servomotor protrusion and the force measured by the tensometric beam. A change in the sign of the force value represents an instant when the wheel loses contact with the ground. It appears from the data that the measuring system works correctly and the data can be used for the autonomous determination of the robot parameters. However, the data are not ideal. For example, at 25s (25000 ms) a considerable drop in the force level was registered, which was caused by the coming to a sudden stop when the limit switched was reached.

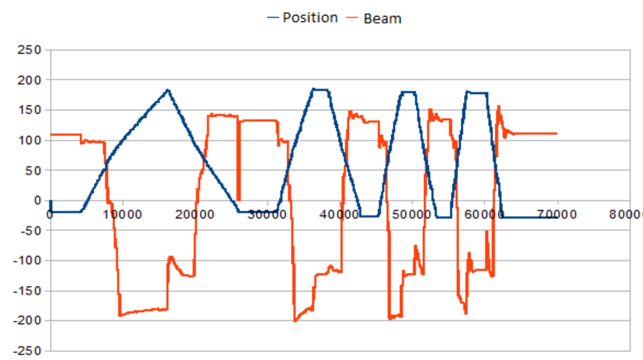

Fig. 11. The servomotor protrusion and the force measured by the tensometric beam

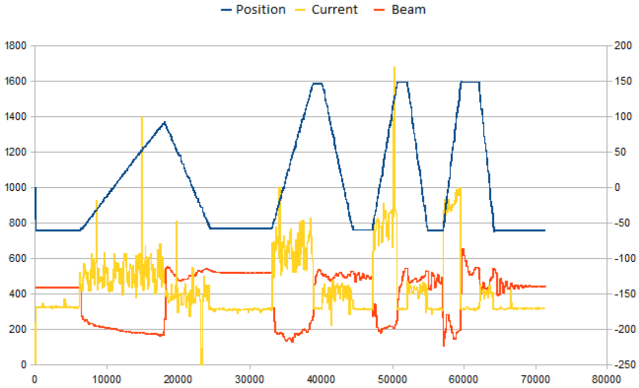

Fig. 12. Current, force, position

Moreover, the drive current referred to the force in the beam and the servomotor protrusion was measured (Fig. 12). Also in this case the obtained data agree with the intuition – the current is higher during leg raising than during leg lowering.

6. CONCLUSION

The tests on the leg testing rig were the first experimental verification in the whole wheel-legged robot design process. The operation of the leg was tested and the perceived shortcomings were eliminated. The control and measuring system of the leg (and so that of the robot) was thoroughly tested. The control, communication and data transmission modules were found to operate properly. Also tests aimed at selecting proper parameters for the drive controllers were carried out on the test rig.

Moreover, the results of the robot leg tests were used to preliminarily verify the control software whereby the design process significantly accelerated. Guidelines for developing robot control algorithms, which will ensure the autonomous operation of the robot, were formulated on the basis of the test data.

REFERENCES

1. **Gonzalez A., Ottaviano E., Ceccarelli M.** (2009), On the kinematic functionality of a four-bar based mechanism for guiding wheels in climbing steps and obstacles, *Mechanism and Machine Theory*, Vol. 44, 1507–1523.
2. **Grand Ch., BenAmar F., Plumet F., Bidaud Ph.** (2002), Stability control of a wheel-legged mini-rover, *Proceedings of the CLAWAR Conference.*
3. **Gronowicz A., Szrek J.** (2009a), Idea of a quadruped wheel-legged robot, *Archive of Mechanical Engineering*, Vol. 56, nr 3, 263-278.
4. **Gronowicz A., Szrek J.** (2009b), Design of LegVan wheel-legged robot's mechanical and control system, in: SYROM 2009: *proceedings of the 10th IFToMM International Symposium on Science of Mechanisms and Machines*, held in Brasov, Romania, October 12-15, Springer.
5. **Guccione S., Muscato S.** (2003), The wheeleg robot, *IEEE Robotics & Automation Magazine*, December.
6. **Halme, A., Leppänen I., Salmi S., Ylönen S.** (2000), Hybrid locomotion of wheel- legged machine, *Proceedings of the CLAWAR Conference.*
7. **Szrek J.** (2009), *Synthesis of the kinematic and control system of a quadruped wheel-legged robot* (*Synteza układu kinematycznego i sterowania czworonożnego robota kołowo-kroczącego*), PhD Thesis, Wroclaw (in Polish).

This research, under project no. N502 271037, was funded from the resources for science in the years 2009-2012 in Poland.