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Synthesis of action variable for motor controllers of a mobile system with special wheels for movement on stairs☆,☆☆

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Summary The article presents a procedure of obtaining waveform of angular velocities for special segmented wheels required for smooth movement of a stair-climbing chassis on stairs. The waveform was determined for a specified velocity of the chassis using a dynamic contact analysis in the CAD system SolidWorks. The main part of the work was to verify whether real motors on a testing chassis are capable of producing the required angular velocity with its significant step changes. The values of angular velocities were sent to drive control units from a software control system of the chassis. The chassis was recorded during the movement on stairs on a video camera and the resulting video was then analyzed by a special single-purpose image processing algorithm, which detected key points in individual frames. Outcome of the algorithm are tables with positions and velocities of individual key points during time. Tests proved that with lower velocities it is possible to achieve very good results with the chassis moving almost steadily.

Introduction

On our department we have been dealing with design of a special wheel for movement on stairs (Krys et al., 2014) for a long time. A possible solution seems to be a wheel with rotary segments which is capable of smooth driving both on a flat ground and on stairs without oscillation of the chassis centre of mass. The main considered application field was transport of handicapped people and unstable loads, where typically is used a combination of wheeled and tracked chasses with stabilizers (TGR, 2015; SANO, 2015) and wheeled chasses with combined wheels (Morales et al., 2013; Quaglia et al., 2011; Le Masne de Chermont, 2004). Another potential field of application are reconnaissance

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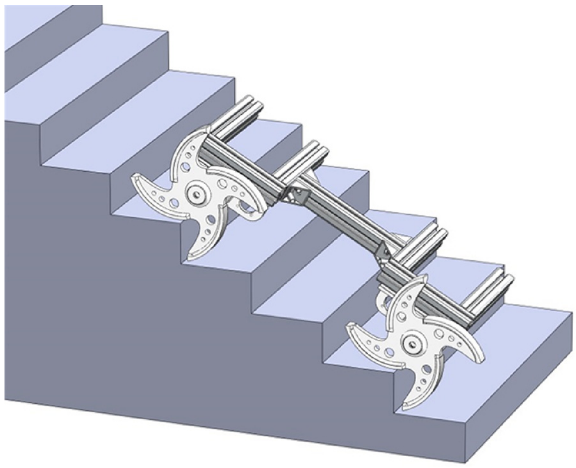

Figure 1 Simulation model in CAD system SolidWorks.

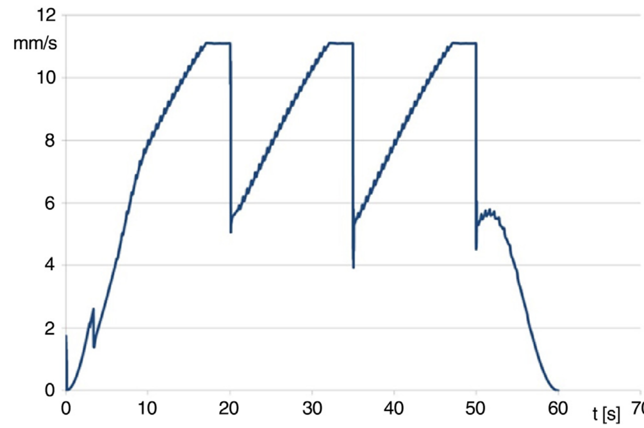

Figure 2 Velocity of the chassis in a direction parallel to the flight of stairs.

and manipulation mobile robotic systems, where are predominantly used tracked chasses in various modifications (tEODor, 2015; OSCAR, 2015; iRobot, 2015; Li et al., 2013; Liu and Liu, 2009). The principles applied for prototypes with special wheels or with rocker-bogie mechanisms do not provide movement of the chassis without oscillation of its centre of mass in vertical direction (Herbert et al., 2008; Eich et al., 2008; Hong et al., 2013; Boxerbaum et al., 2009). Our design of a wheel with rotary segments is capable of linear movement of the chassis with almost eliminated oscillation. The variable radius of contact surface of the wheel segments however causes fluctuating velocity of the chassis relatively to the stairs if the wheel rotation speed is constant. The article presents a way of elimination of this phenomenon by using variable angular velocity of wheels; and also presents verification that this is practically possible to achieve on a physical robot with real motors.

Simulation

Contact kinematic simulation in the CAD system SolidWorks 2012 was used to determine the course of wheel angular velocity required to produce constant movement velocity of the chassis when driving on stairs. The simulation model (Fig. 1) was tuned for constant angular velocity of the wheel 6°/s, cosinusoidal acceleration and deceleration with the total running time 60 s. Using this setup, velocity of the chassis relatively to the stairs was examined (Fig. 2). The simulation model was simplified to only one half of the chassis.

Afterwards the simulation model was modified so that the chassis moved with a defined velocity relatively to the stairs (constant with cosinusoidal acceleration and deceleration, Fig. 3) while preserving contact and rolling of the segments on stairs. To achieve this, a line parallel with the flight of steps was created in the simulation model. One of the translational axes of a planar kinematic constraint was oriented parallel to the created line. A drive was then defined on this translational axis with the specified values of chassis velocity (Fig. 3).

The next step was to set the maximal possible coefficients of friction in the contacts between wheels segments and the staircase to eliminate potential slipping.

Already the first tests showed a significant step change in the wheel angular velocity. For this reason the simulation of climbing up four stairs was configured for 60 s (that means a quite low translational speed), to increase the chance that real mechanism with motors will be able to accomplish the movement as accurately as possible. The subsequent simulation generated the required waveform of angular velocity of wheels for the defined speed of the chassis (Fig. 4). The step changes (peeks) mentioned above are clearly visible on the graph.

The process is analogue of inverse kinematics used for manipulators with serial kinematic structure.

Verification on a scaled prototype

The values of required angular velocities determined by the simulation were exported to a table which was then used as input for the drive control units of motors of a scaled-down chassis prototype. A special rigid version of the wheels (with the segments locked in the optimal angle) was manufactured for these tests. The wheels are made from polycarbonate PC-10 with break-away support material, supplied by STRATASYS. Previous tests showed that

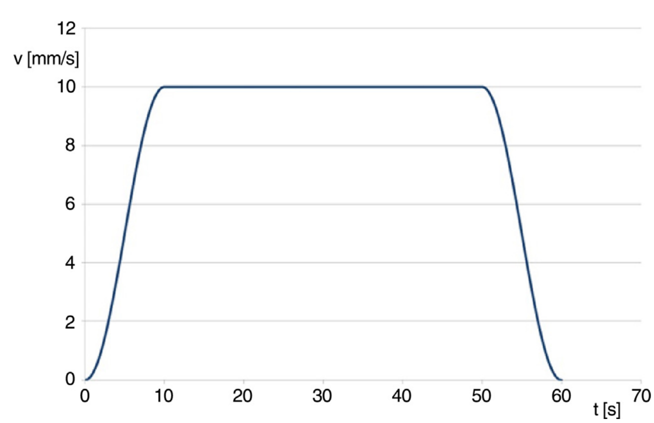

Figure 3 Required velocity of the chassis during travelling on stairs.