PRINCIPLES OF MOBILE WALKING ROBOT CONTROL IN SCOPE OF TECHNICAL MONITORING TASKS

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INTRODUCTION

Modern mobile robots research shows that exist range of tasks in a limited environmental space when usage of flying robot it is energetically inefficient of impossible at all. Also there are environments where wheeled robots cannot operate efficiently because of inappropriate underlying surface. Limited environmental space is a closed industrial space of production facility, having number of obstacles, such as machines, communications and walls, so that robot cannot pass.

When solving tasks of industrial facilities technical monitoring [2] by means of the compact flying drones, it is necessary to overcome navigation difficulties and real-time obstacle avoidance in dynamical environment. Control of compact aircraft [1] in a three-dimensional space with dynamic and fast-moving obstacles is non-trivial task that depends on concrete kind of environment at production facility.

For every single limited space at facility it is necessary to provide a specify control conditions and limitations, or install more complex control algorithm and faster control unit. Complexity of navigation task, that aircraft need to solve, determines time period while aircraft still in flight but does not performing useful operations, consuming limited amount of fuel.

1. OVERVEW OF EXISTING TECHNOLOGIES

For wheeled robots [3] one of the most significant limitations is the frequent change of surface level, where robot moves. To overcome such kind of limitations, additional ramps are needed to be installed to allow robot move over stairs, doorsteps and other obstacles of this type and having different height. Proposed proof of concept for mobile walking robot, that is less demanding on power resources comparing to aircraft, and having possibility overcome obstacles with height greater than wheel radius for the same power wheeled robot.

Building of walking robots and research in scope of walking machines started in second half of previous century, because of extreme computing power grow. Nowadays exists a wide range of industrial and military walking machines, also robotic production companies are ready to achieve mass market housekeeping robots in near future, as shown in [4], [5].

As the designer of world class robotic systems can be mentioned USA based company DARPA Boston Dynamics, started early 70s at Massachusetts Institute of Technology (MIT) robotics research laboratory, presented theirs military robot carrier Big Dog in 2005 [6], that handle up to 110 kilograms of load and able to follow arm forces. Also DARPA presented range of four-legged robots such as Cheetah, modeling different stages of cheetah run and achieving speed of nineteen miles per hour that is world record for legged robots. Another one DARPA's robot is a Small Dog, equipped with bunch of sensors and designed especially research in motion algorithms over raw surface using artificial intelligence.

In 2010 Department of Robotics in Moscow State Technical University n. a. N.E. Bauman (MSTU) creates two-legged robot [7] for humanoid walking dynamic research [8].

2. ROBOT DESCRIPTION

2.1. Concept for mobile walking robot carrying

Proposed proof of concept for mobile walking robot carrying load up to sixty percepts of own robot's mass. Control system includes computing unit, seven servos, three-axis accelerometer and moving camera operating in a visible range.

Mechanical design can be described as follows: horizontal plate, where load is placed, mounded onto main baulk in the way so mass of load distributed symmetrically along roll axis of robot. Under main baulk accumulator batteries bracings are placed. Symmetrical front and rear moving baulks are connected to the front and rear sides of the main baulk via bearing joint, so they can freely rotate around corresponding vertical axes. Both front and rear moving baulks are equipped identically and symmetrically with three servos each one. On the moving baulk one servo is installed vertically for rotating relatively to the main baulk around vertical axis, two other servos are installed in orthogonal plane, equipped with pillars and allow robot positioning in vertical plane. So pair of vertical servos provides rotating of moving baulks in horizontal plane while four other servos are used for moving pillars up and down.

Camera is coupled with compact crank mechanism and servo, so stereo image processing for navigation purposes can be achieved with one single camera. Advantage of such approach is saving computing power by retrieving one image at time instead of two images at time. Disadvantage of such moving camera unit is that camera cannot be calibrated so precise as fixed stereo-camera, but exists methods such as [9] and [10], where calibration of camera is not mandatory.

2.2. Motivation

Redundant numbers of servo-drives requires more power for keeping all kinematics links in desired position. After performing global analysis of energy required for specific robot motion and energy actually spent for that motion, can be roughly assumed that walking robot uses just a few links for motion while other links are moving lightly or still not involved in the operation at all.

Joints of living creatures has non-trivial complex structure, comparing to robotic analogues, with number of kinematics links for achieving maximum utilization of energy for specific motion and high maneuverability of creature. Numbers of degrees of freedom for artificial walking machines usually an order of magnitude lower that for living creatures. Forces and moments in joints of robot and in joins of creature are created using fundamentally different means, so problem of energy optimization is independent topic for discussion.

Adding additional degrees of freedom with additional kinematics link and corresponding muscles for limb of creature leads to better energy utilization when performing specific motion, but this cannot be applied to artificial limb. When creature's limb moves, number of tissues are involved - muscles, tendons, fat, skin, bones and their joins, performing damping, distribution of loads and involved in forming of control forces and moments. For artificial limbs all of these functions, mainly, are performed by servo-drives attached to corresponding joint. So numbers of tasks, that are performed in a creature's limb with no energy consumption because of tissues elasticity, in artificial limb are performed with usage of electricity for positioning servo-drives.

2.3. Distinction from analogues

Basing on assumptions shown above proposed robot was designed in such way so it minimizes power consumption by excluding most of joints but still keeps walking for translation of its mass. Future minimization of power consumption requires change of moving principle that is not in scope of this article.

Main distinction of proposed robot kinematical scheme from nearest analogues having four legs is that proposed scheme uses single rotational degree of freedom for lifting and putting down legs, while analogues are designed with at least two rotational degrees of freedom for every leg, that significantly increases power consumption for every movement that robot can perform.

2.4. Robot tasks and control

Robot's scope of use can be limited to few groups such as tasks where required continuous monitoring without human and monitoring of damaged or dangerous facilities.

Control principle for such kind of object can be downscaled to control of servo-drives. Current version equipped with TowerPro MG996 servo drives, controlled by power width modulation. Working range of these servos is 0 to 180 degrees and depends on control pulse width on 50 Hz frequency.

Control system consists of main unit, responsible for servo-drives control following operator commands, or commands acquired from higher level control loop and regulator unit, responsible for adaptation of control commands respectively to sensors data. While waiting for new command, system continuously repeats last command. So when operator or higher control loop preparing control command that determines type of movement, main unit computes relations for pulses width changes in time. Next, regulator unit uses real-time data from sensors and updates computed pulses width so robot can keep on moving with no loss of efficiency.

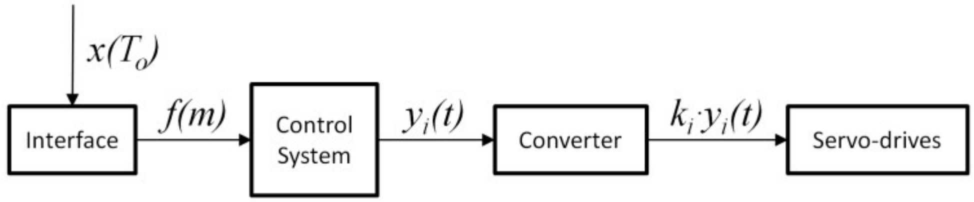

Figure 1. System structure: *$x(T_0)$ input signal in binary form, f(m) control command, $y_i(t)$ servo-drive actual control signals, k_i gain for i-th servo-drive actual control signal, i ϵ {1,2,...,7}.*

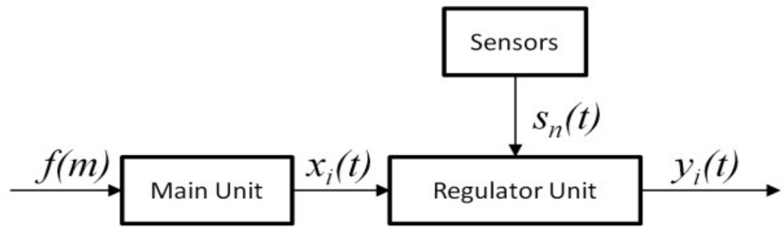

Figure 2. General schematic of control system: where: *$x_i(t)$ is a servo-drive general control signals, generated from default set of robot movements, $s_n(t)$ data from n-th sensor, n ϵ {1,2,3}.*

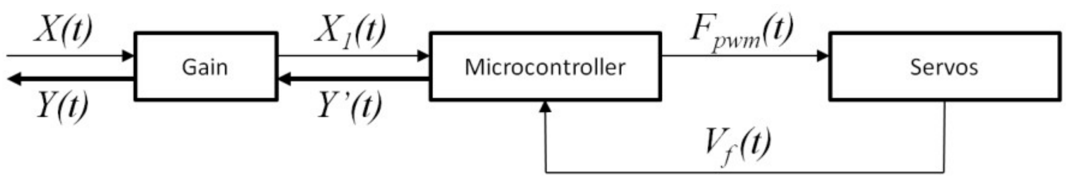

Figure 3. General structure of control unit: X(t) general control signals, $X_1(t)$ control signals for microcontroller, Y'(t) controller output signals, $F_{pwm}(t)$ control pulses for servo-derives, $F_f(t)$ feedback voltage.

Robot control algorithms computed using principle, described above - first, control command *$x(T_0)$*, that passed to the system input Interface. Next, after receiving command, values for servo-drives control, delays and control command *f(m)* are computed. Control system computes relations for servos *$x_i(t)$* using default preset of robot motions, and then retrieves data from sensors. Using sensors data Regulator Unit updates values for servos control.

When robot lose its dynamical stability while moving, say flip around roll axis because of some sort of disturbance, When robot loses its dynamical stability while moving, say flip around roll axis because of some sort of disturbance, design of robot body parts allows to arrange recovering operational condition, that means normal position of robot relative to the ground, by forming a set of special movements. First, when robot loses dynamical stability, control system performs actions to restore statically stable state of robot body. Then, robot performs set of motions to change relative position of its center of mass point in such way so body rotates around roll axis by 180 degrees. Also, while

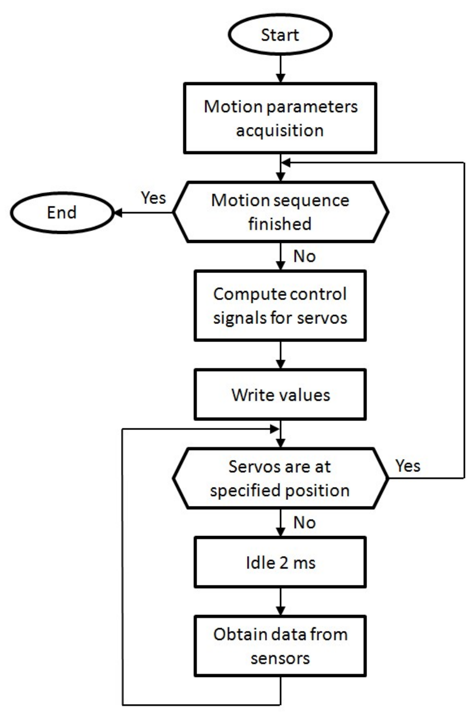

Figure 4. Generalized control algorithm.

restoring operational condition, robot body rotates by about 30 degrees around yaw axis, so additional movements are required to turn back to the robots route.

4. CONCLUSION

Shown above control principles and general schematic of control system for mobile robot can be used for the researches in a different operational conditions for the walking robots having design similar to mentioned above.

Proposed system uses only units involved in regular movement for restoring normal orientation when robot loses stability and falls down. Pairs of stereo images for the reconstruction of the observed space this system receives from a camera connected to the compact design of the crank mechanism. This way, it managed to reduce twice minimize the cost of the budget hardware required for the acquisition of stereoscopic images.

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