Simulation and locomotion control for the Alicia^3 climbing robot

Domenico Longo[1], Giovanni Muscato[1], Salvatore Sessa[1]

***Abstract* — In this work simulation and implementation of the locomotion control of a single sliding suction cup robot, named Alicia^3, is described. The main purpose of this kind of system is to explore vertical walls to search for potential damages or problems on oil tanks or dams. By using this system as carrier, it will be possible to carry out a number of NDI/NDT on the wall.**

The system is mainly made of three modules linked by two arms actuated by two air pistons.

The cups can slide over a wall by mean of a special sealing that allows maintaining the vacuum inside the cup and at the same time creates the right amount of friction according to the system weight and the target wall kind.

A robot simulator implemented in Simulink® allows testing various locomotion strategies and will be described.

***Keywords* — Climbing robot, locomotion control, maintenance and inspection**

I. INTRODUCTION

Climbing robots are useful devices that can be adopted in a variety of applications such as maintenance, building, inspection and safety in the process and construction industries.

These systems are mainly adopted in places where direct access by a human operator is very expensive because of the need for scaffolding, or very dangerous due to the presence of a hostile environment.

Possible applications of these systems are inspection of external/internal surface of aboveground/underground petrochemical storage tanks, concrete walls, metallic structures and so on. This paper focuses on inspection of the external surface of aboveground petrochemical storage tanks. For this application, due to the extremely corrosive petroleum that the tanks may contain, it is very important to perform periodic inspection at different rates, as standardized by the American Petroleum Institute [1].

Among the most important factors to be inspected is the rate of corrosion, the potential risk of air or water pollution, the detection of leaks, etc. While these kinds of inspection are very useful to prevent ecological disasters and risks for the people working around the plant, they are very expensive because scaffolding is often required. Moreover, for safety reasons, plant operations must be stopped and the tank must be ventilated when human operators conduct inspections. A possible solution is to carry out automatic non-destructive inspection (NDI) on the target surface, and only when repairs are needed, a traditional or automatic way of accessing the plant applied [2], [3], [4], [5].

II. DESCRIPTION OF THE SYSTEM

The structure of the Alicia^3 module, shown in Figure 1a, currently comprises three concentric PVC rings held together by an aluminium disc. The bigger ring and the aluminium disc have a diameter of 30 cm. The sealing system is allocated in the first two external rings. The third ring (the smallest one) is responsible for semi-rigid contact between the robot and the wall, using a special kind of spherical ball bearing. An aspirator is used to depressurize the cup formed by the rings and the sealing, so the whole robot can adhere to the wall like a standard suction cup.

While the system has to move over the target surface, generally a rough metal surface or a concrete wall, the cup must not adhere with a high degree of friction, so a particular kind of sealing is required between the wall and the robot. The sealing must guarantee negative internal pressure and should allow the robot to pass over small obstacles (less than 1 cm in height) like screws or welding traces. This configuration allows the robot to climb a vertical surface with a minimum curvature radius of 1.8m. The whole structure was designed to contain two onboard wheels with two independent DC motors/gearboxes/encoders, as shown in Figure 1b.

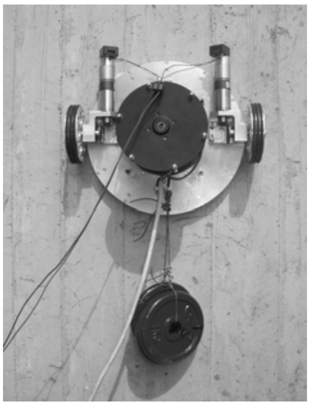

Fig. 1a - Alicia II module

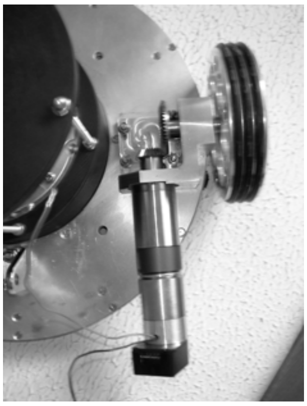

Fig. 1b - Detail of the DC motor and gearbox

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[1] Università degli Studi di Catania – DIEES V.le A. Doria 6 95125 Catania – ITALY - {dlongo, gmuscato, ssessa}@diees.unict.it

The total weight of the module is 7 kg. The DC motors/ gearboxes used in each module are able to move a mass of up to 15 kg in a vertical direction at a maximum speed of 2 m/s. The basic idea for the Alicia^3 robot (Figure 2) is to use three of these modules to allow the whole system to deal better with obstacles on the target surface. When obstacles higher than 1 cm are encountered, the base module fails to overcome them (this limitation is due to the height of the cup sealing that cannot be higher than a few centimetres). In this case, the Alicia^3 robot can pass over the obstacle in a few steps by detaching the three modules one by one, although it does so at a lower speed (Figure 3). The structure has been designed in such away that only two modules at a time can support the weight of the whole robot. The two links between the three modules will be actuated with two pneumatic pistons [6].

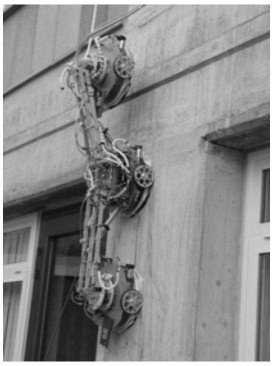
Fig. 2 - Alicia^3

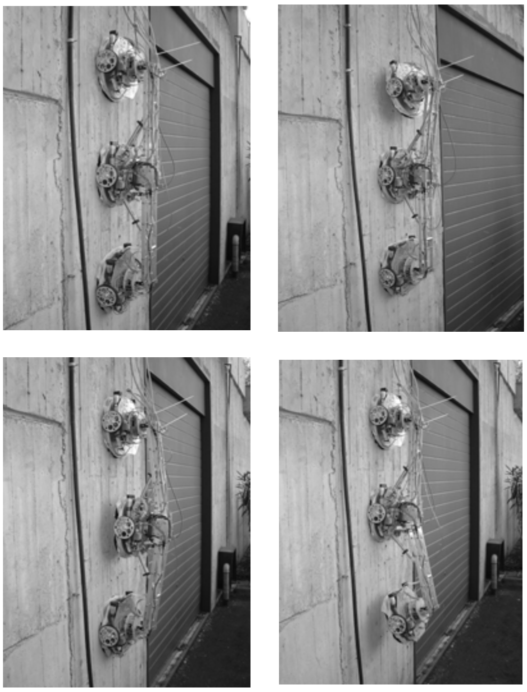
Fig. 3 - Steps for overcoming an obstacle

III. HARDWARE ARCHITECTURE

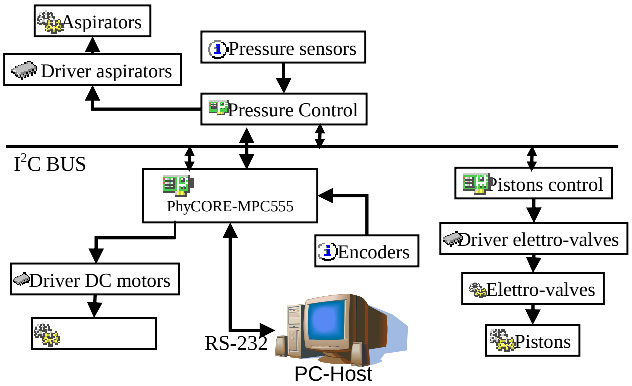

Fig. 4 – Alicia^3 hardware architecture

This section describes Alicia^3 hardware architecture and the main tasks that every module has to execute. The architecture of the final system is shown in Figure 4.

The fundamental tasks that the robot has to perform are:

- wall adhesion
- locomotion
- pass over the obstacles

The proprioceptive sensors used to accomplish these tasks are listed below:

- gage pressure sensors, based on strain gage resistor in a Wheatstone bridge
- incremental optical encoder with 200 pulse/revolution directly connect with motor axis
- inclinometer based on a Analog Devices dual axis iMEMS® accelerometer used in locomotion control.

A PhyCORE MPC555 development board is the core of the entire system; the tasks that this module has to execute are:

- Acquire inclinometer and pressure sensors with 16-bit multiplexed A/D converter
- Quadrature decode of optical encoders
- Speed/position DC motor control
- Locomotion control (modules coordinator)
- Send pressure reference to pressure control board.
- Send command to piston command board.
- Manage communication protocol for tele-operation of the robot via RS-232.

Pressure control boards are one of the most important modules of the architecture; infact these have to execute a critical task for the robot and their reliability is fundamental. The main function that pressure control board executes, is the single phase control of an universal motor with feedback control of the pressure in the cup. To optimally perform this task is necessary a correct zero-crossing detection of alternate power supply, a proper conditioning of the pressure sensor signal and an optical-galvanic protection of digital section. An ADUC842 8-bit microcontroller is the core of pressure control module.

To pass over the obstacles is necessary to actuate the air pistons; this task is executed by two identical command piston boards, everyone drives four 1/1 NC fast electro-valves. An ST52F513K3B6 8-bit microcontroller receive via I^{2}C commands from MPC555 and generate signals to assign a direction and air flow (PWM signal with f=76Hz) at the piston in normal mode or to open the chamber of the piston in open mode (this configuration is useful for a better mechanical adjustment of the robot in non-flat wall).

IV. LOCOMOTION CONTROL

In this section the locomotion strategies that are implemented on microcontroller firmware will be described.

The software developed for all the closed loop controls and coordination of Alicia^3 robot is a hierarchical structure with three levels as shown in Figure 5.

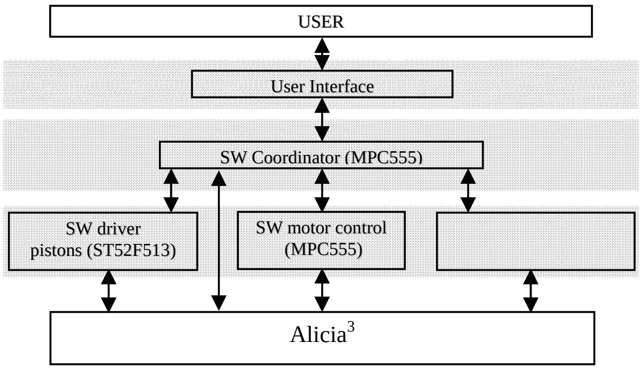

Fig. 5 – Software hierarchical structure

Also the firmware in PhyCORE MPC555 development board is organized into three layers.

As can be seen in Figure 6, *I layer* is an interface for internal peripheral of MPC555 processor (ADC, MPIOSM, PWM, PIT); *II layer* is an interface for external peripheral (Inclinometers, encoders, I^{2}C); *III layer* is the high level control that implemented the locomotion strategy using the low level interfaces.

In *III layer* there are *Alicia*, *Module* and *Wheel* sub-modules that are responsible of the locomotion strategies.

In *Wheel* sub-module is implemented speed/position control of the single wheel (classical PID controller).

The *Module* sub-module implements a control loop on the speed of the wheels and inclination of the module, which allows the robot to move along a user defined direction

In *Alicia* sub-module there are three functions:

- *Homing* function is used to re-align the robot (start condition)

- *GoAlicia* function is used to go forward the robot; in particular we implement algorithms to improve alignment of the modules. A misalignment between modules leads to mechanical stress on the structure of the robot.

- *TurnAlicia* is used for the rotation of Alicia^3; this operation is divided into two part: in the first one the external modules turns of 90° with respect to the central module; in the second one, speed reference for each wheel is determined from kinematic calculus (Figure 7).

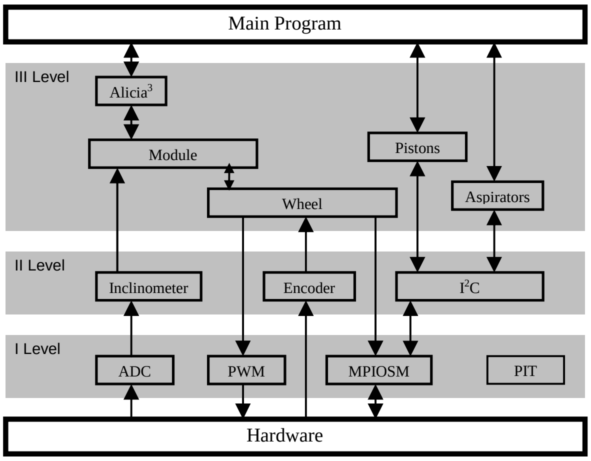

Fig. 6 – MPC555 Firmware block diagram

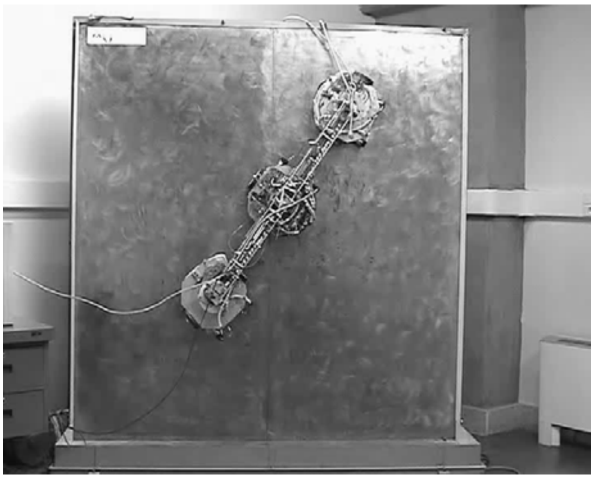

Fig. 7 – Alicia^3 during rotation

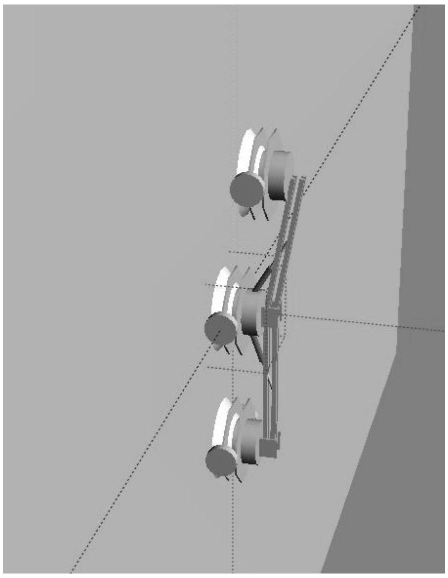

Fig. 8 – Graphical 3D viewer

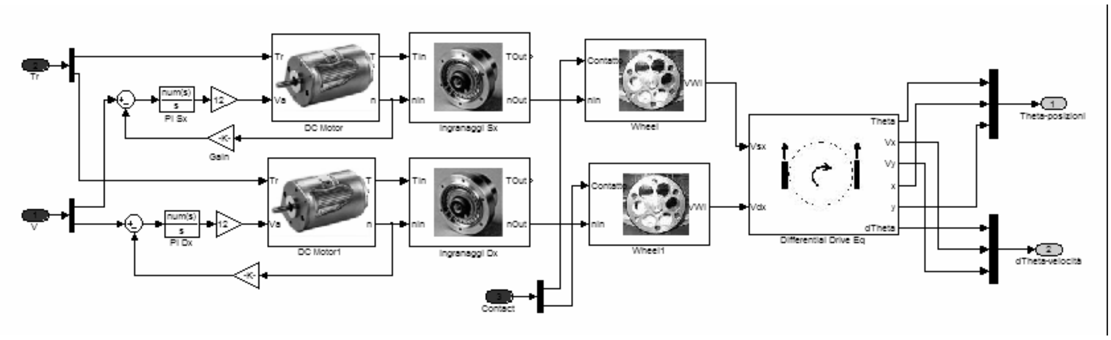

Fig. 9 – Simulink® representation of the Alicia II system model

V. SIMULATOR

The Alicia^3 simulator developed in Simulink® not only allows testing locomotion strategies but also is used to tune PID parameters for locomotion control (speed/position control loop of the wheels).

A graphical 3D viewer, developed in Delphi™ 7 using Mex-function to integrate it in Simulink®, is used to visualize Alicia^3 sequence of operations (Figure 8).

We realized basic blocks model that represent a realistic model of the Alicia^3 robot behaviour.

The basic blocks model used are listed below:

- DC motor;
- Gearboxes;
- Differential drive;
- Wheel;
- Wheel-wall contact.

For each block a set of parameters as been defined and can be adjusted according to system components. These parameters can be easy modified from the Simulink® diagram.

The control algorithms implemented in the simulator are the same of that of the real robot.

Each Alicia II module is composed by two motor with gearbox and two wheels in differential drive configuration, so the link between subsystems is shown in Figure 9.

This model is useful for the determination of the PID parameters control for turn and go-forward of the module.

A Simulink® block named Alicia^3, built by putting together three of the module block, represent the entire model of the robot and the locomotion strategies implemented for turn, go forward or overcome the obstacles.

CONCLUSION

A modular approach has been used to design mechanical, electronic and software components of the Alicia^3 robot.

Mechanic modularity simplifies the kinematics study and system simulation (it is possible to implements system model by using basic modules). Hardware modularity improves system reliability; in fact a modular hardware makes an easy components replacement and maintenance.

General software architecture and locomotion firmware implemented in MPC555 processor are also modular. Every software block implement a specific task (e.g. peripheral wrapper or control function); these blocks are then linked together to compose the whole system software. The advantage of this kind of software structure is that the code reuse and readability is improved.

A robot simulator has been developed to allow parameter tuning, system and control performance test and mission trajectory planning. For example is possible to simulate robot movement in a certain environment before to perform the real mission. It can be used during training phase for technical staff that have to tele-operate the robot.

Also in building the simulator, a modular approach as been used, each basic block of the robot as been modelled and tested separately. The global system model is then built by putting together these basic block model.

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