A Legged Robotic System for Remote Monitoring

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Cosmatesque pavement in Montecassino Abbey
built between 1066 and 1071.
beneath pavement of current Basilica rebuilt as in 17 century
after the destruction during the II world war
Basic step for robotics application in survey activity

1. Definition of design requirements and operation
2. Development of methodologies and Survey
3. Design of robotic systems
4. Development of methodologies and Survey strategies for operation of robotic systems
5. Construction of prototypes and test-bed applications
6. Test and validation

Table 1. Main size of basic obstacles

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<th>Crest (a)</th>
<th>Ditch (b)</th>
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Possible design solutions

Fig. 1) Robot Body shape

LEGES TYPES

BIOINSPIRED LEGS
- MAMMALS
- ARACNID
- REPTILES

NON ZOOMICRPHIC LEGS
- UNDER ACTUATED
- TELESCOPIC
- HYBRID
- WHEELED

LEGES ORIENTATION
- FRONTAL
- SAGGITAL
- CIRCULAR

JOINTS CONFIGURATION
- KNEE OUTWARDS
- SAME ORIENTATION
- KNEE INWARDS
Cassino Hexapod robot  
(vers 1 and 2)

VERS 1  (2001-2006)
Size: 600mmx500mmx500mm  
Weight: 200 N (20 kgp)  
Payload capability: 20N  
Step high: max 200 mm  
Control mode: PLC (Siemens S7) & switches  
Commanding mode: via subroutines and joysticks based on Ladder or graphical programming  
Other: umbilical cord for power supply and control  
• Low-cost market components

VERS 2  (2010-2013)
Size: 400mmx300mmx250mm  
Weight: 30 N (3kgp)  
Payload capability: 5N  
Step high: max 60 mm  
Control mode: arduino with wifi connection  
Commanding mode: panel buttons and gesture commands based on customized Java programming  
Other: on board battery and control hardware  
• Cost lower than 1.000 Euros
CASSINO HEXAPOD ROBOT version I
Kinematics

Fig. 7 One leg workspace

\[
\begin{align*}
  p_x &= l_1 \sin(\theta_1) + \left(l_2 + \frac{D}{2}\right) \sin(\theta_{12}) = l_1 \sin(\theta_1) + l_2 \cos(\theta_{12}) \\
  p_y &= -l_1 \cos(\theta_1) - \left(l_2 + \frac{D}{2}\right) \cos(\theta_{12}) = -l_1 \cos(\theta_1) - l_2 \cos(\theta_{12})
\end{align*}
\]  

(1)

\[
\begin{align*}
  \theta_2 &= A \tan \left( 2 \left( \frac{p_x^2 + p_y^2 - l_1^2 - l_2^2}{2l_2} \right) \right) \\
  \theta_1 &= A \tan \left( \frac{p_x (l_1 + l_2 \cos \theta_2) + p_y l_2 \sin \theta_2}{l_1^2 + 2l_2 \cos \theta_2 + l_2^2} \right)
\end{align*}
\]  

(2)
Dynamics

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = \tau_i \quad i = 1, 2 \ldots n \tag{3} \]

\[ \begin{aligned}
x_1 &= l_1 \sin \theta_1 \\
y_1 &= -l_1 \sin \theta_1 \tag{4} \\
x_2 &= l_1 \sin \theta_1 + l_2 \sin \theta_2 \\
y_2 &= -l_1 \sin \theta_1 - l_2 \sin \theta_2 \tag{5}
\end{aligned} \]

\[ L = T - U \tag{6} \]

\[ U = m_1 g y_1 + m_2 g y_2 = m_1 g l_1 \cos \theta_1 - m_1 g (l_1 \cos \theta_1 + l_2 \cos \theta_2) \tag{7} \]

\[ T = \frac{1}{2} m v^2 = \frac{1}{2} m (x^2 + y^2) = \frac{1}{2} m_1 (x_1^2 + y_1^2) + \frac{1}{2} m_2 (x_2^2 + y_2^2) \tag{8} \]

\[ L = T - U = \frac{1}{2} (m_1 + m_2) l_1^2 \dot{\theta}_1^2 + \frac{1}{2} m_2 l_2^2 \dot{\theta}_2^2 + m_2 l_1 l_2 \dot{\theta}_1 \dot{\theta}_2 \cos (\theta_1 - \theta_2) + (m_1 + m_2) g l_1 \cos \theta_1 + m_2 l_2 \cos \theta_2 \tag{9} \]

\[ \tau_1 = (m_1 + m_2) l_1^2 \dot{\theta}_1 + m_2 l_1 l_2 \dot{\theta}_2 \cos (\theta_1 - \theta_2) + m_2 l_1 l_2 \dot{\theta}_2 \sin (\theta_1 - \theta_2) + g l_1 (m_1 + m_2) \sin \theta_1 \tag{10} \]

\[ \tau_2 = m_2 l_2^2 \dot{\theta}_2 + m_2 l_1 l_2 \dot{\theta}_1 \cos (\theta_1 - \theta_2) - m_2 l_1 l_2 \dot{\theta}_1 \sin (\theta_1 - \theta_2) + l_2 m_2 g \sin \theta_2 \tag{11} \]
Dynamic model in SimMechanics

Fig. 14 Simulazione in ambiente SimMechanics

Fig. 16 Output della simulazione per attuatore più sollecitato
Path planning

Leg joints angular position

Leg joints angular speed

Leg joints angular acceleration

Leg end-point trajectory
Dynamic simulation of the full robot

Fig. 19) Modello dinamico del Cassino Hexapod II

Fig. 20) Simulazione MSC.Adams andatura su ruote

Fig. 21) Simulazione MSC.Adams movimentazione arti
Cassino Hexapod III

VERS 3 (2014-)
Size: 300mmx300mmx400mm
Weight: 30 N (3kgp)
Payload capability: 15N
Step high: max 100 mm
Control mode: arduino with wifi connection
Commanding mode: Java interface
Other: on board battery and control hardware
omniwheels
Cassino Hexapod III

Arm with laser tool

Digital Servo
Max torque 1.5Nm
Weight: 0.060kg

Servo RC
Max torque: 0.27Nm
Weight: 0.043kg
Max speed: 50 RPM
Control Architecture

- a) Arduino Yun; b) Arduino Mega 2560; c) Servo Interface; d) voltage regulator; e) IMU; f) Wi-Fi camera; g) 3D Laser Scanner; h) servomotors; i) PC; l) smartphone

Detail of the control hardware inside the Cassino Hexapod III: a) Battery LIPO; b) Arduino Yun; c) IMU; d) Servo Interface with Arduino Mega 2560;
Operating Strategies

A sample cyclogram for obstacle climbing

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A sample cyclogram for obstacle climbing
Tripod gait

A sample cyclogram for a tripod gait
Fig. 11 Main frames related to the obstacle overcome strategy.
Preliminary tests
Ongoing work

Installing Mecanum Omniwheels

Inclined Plane

Installing Mecanum Omniwheels
Ongoing work
Conclusions

• Outlines the evolution of the robotics series “Cassino Hexapod” for inspection/survey of cultural heritage goods.

• Design and prototypes have been described.

• Preliminary results confirm the possibility of operations in the architectural survey and monitoring of sites of historical interest.
Motion and Operation Planning of Robotic Systems
Background and Practical Approaches