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# Architectural survey and Robotics: new frontiers in study, preservation and restoration of historical sites

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## Abstract

*In this work a study of feasibility is illustrated to design and build a mobile robot for inspection and analysis of historical sites of architectonic interest. This novel application for robotic systems can be considered of great interest because nowadays the need of more and more accurate and efficient survey activity requires enhancement and even development of procedures with more reliable, innovative, and advanced characteristics. Within this expectation robots and robotic systems seem to be suitable solutions even with the purposes of: operating in environments that cannot be reached by human operators. The study of feasibility concerns with the analysis and simulation of a robotic system that can be used for operating in historical sites. Basic features of such mobile robots, either legged or wheeled, are well known, but specific requirements should be considered for the proposed applications in archaeological/architectural sites, which can be considered as a novelty in the field of Robotics. Basic features of the proposed robotic system can be summarized as follows: the robot should be able to move inside the archaeological and/or architectural sites by carrying surveying devices and by avoiding damage of the surface and other parts of the site.*
*In Cassino preliminary design considerations have been developed and a suitable simulation has been carried out in order to test a designed robotic system acting on a simulated pavement, for several operating conditions. The simulation process is of basic importance, since it is not possible to test in advance the robot on site and there are not precise information about the preservation of pavement under-study. A simulation has been carried out with different conditions and it has been also useful to test the operation of the design of a robotic system with hexapod structure. At this moment, the research in Cassino is in a final phase concerning with first applications of a robot prototype. However, a continuous review of the design work is undergoing to formulate a general problem in which the design of a suitable low-cost easy-operation robotic system is properly defined also for not expert users in the field of robotics. The prototype activity is performed with the aim to design a specific test-bed through which verifies the identified design requirements and feasible solutions even for the operation of the system.*

## 1 Introduction[1]

The work being presented is the result of collaboration between the DART (Laboratory for the Documentation, Analysis & Surveying of Land and Architecture) and the LARM (Robotics and Mechatronics Laboratory). Despite their seemingly diverse spheres of research, these two institutes have a long history of opportunities to discuss and share their knowledge, and to research issues on which to base practical, fruitful collaborations[2].

Our aim is to study characteristics and issues concerning the analysis and conservation of built heritage from the innovative standpoint of robotic systems. The design requirements and special features of the operations of an extremely wide variety of robotised systems have been fully outlined, and are now entirely familiar. However, in a specific application related to a topic such as built heritage, apparently so far removed from the more general fields of robotics and mechatronics, there are not many precedents.

The sample study presented here, i.e. the pre-Cosmatesque pavement of the basilica of Montecassino[3], is a good example not only of the flexibility of the field of mechanics, but also of the possibilities for interaction with architecture in general, and the field of surveying in particular. A study of this type focuses specifically on applying robotised systems to the research and surveying of historic pavements, although the broader aim is to study and explore robotic systems and automated procedures to develop the work and the results, not only

[1] *A first version of the paper, by M. Cigola and M. Ceccarelli has been presented to XI International Seminar Forum Unesco - University and Heritage, Florence 11-16 September 2006.*

[2] *The research team is composed by investigators from DART Laboratory for the Documentation, Analysis & Surveying of Land and Architecture, and LARM Laboratory of Robotics and Mechatronics. In particular at DART the following are involved: Michela Cigola, architect with expertise in Restoration of Monuments, full professor ICAR/17, director of DART; Assunta Pelliccio, architect, assistant professor. At LARM the following are involved: Marco Ceccarelli, engineer, full professor ING-IND/13, director of LARM, Giuseppe Carbone, engineer, assistant professor.*

[3] *Cosmatesque style started at the beginning of XII-th century and it was used mainly in Rome and Lazio region up to the end of XIV-th century. Its main characteristics can be considered the assembling aspect with square or rectangular panels that are composed of marbles parts and porphyry disks. The first Cosmatesque pavement is that one in the Basilica of Montecassino Abbey that was inspired by oriental sources and ancient Roman [1].*

during the analysis stage but also for the protection and conservation of historical buildings.

The use of robots in difficult situations is becoming increasingly common, as in the case of inspections of the innermost layers of atomic plants, space voyages and explorations of inaccessible areas of land such as the craters of volcanoes. There is good reason to suppose that a new, original example could be the study and protection of historical buildings by using self-propelled robots to carry out extremely complex tasks on various types of surface, under the supervision of a human operator.

Our idea is to develop a link between robotics and architecture, with a mechanical design that has been specially developed for architectural analysis and restoration, in an extremely innovative application in the field of robotics. It is an attempt to make a robot perform many of the operations required in architectural surveying via automations which can improve procedures and results in terms of speed, accuracy and execution.

## 2 Architectural pavement surveys

Surveying is intended to mean a complex series of operations such as the collection, evaluation and interpretation of all possible information, not only concerning the geometrical and spatial elements of the building, but also the construction, structural and historical data.

Surveying is used most often in the fields of historical and critical analysis of architecture and restoration. There is no doubt that in order to carry out an accurate historical study of a building, accurate measurements are essential. The survey of a building is not a document on which we can work in hindsight, but it is an integral part of the process of gathering historical and critical knowledge.

A survey carried out with a view to possible restoration works must give a global picture of the building in question, which is exhaustive in terms of dimensional, structural and construction details. It must provide a snapshot of the building's state of health, its conditions of decay and static conditions. This means it must perform a historical and technical diagnosis, helping to clarify the design intentions, including the sizing and measurement aspects, orienting historical research through illustrative, bibliographical and archive sources.

The survey issues concerning protection therefore require measurements taken accurately, and graphic renderings that pinpoint the characteristics of the building and all its peculiarities, often using scales of representation larger than those normally used in the preliminary survey [2].

As far as the methods and techniques for documenting Cosmatesque pavements are concerned, we must point out that surveys of works of this type require special measurement and representation procedures, with an emphasis on the type of material and the size of the pieces used, the level and type of surface finishing, the thickness and treatment of the joints and laying surface.

Further, if the survey is carried out well, each part of the pavement should be surveyed individually and also in relation to the surface as a whole, with special emphasis on any elements which are repeated or form a series. This is because any anomalies found in these repetitions sometimes characterise the laying of the pavement.

Also, great care must be taken when measuring the irregularities of the surface as a whole (sudden changes in level, hollows, etc.) and identifying any gaps or additions made over time (fig. 1).

The overall process of measurement and the resulting graphic rendering of a Cosmatesque mosaic pavement can therefore be summarised as a series of operations, each of which must lead to a different scale of representation: survey of the entire laying of the pavement, represented as part of its architectural environment (1:100 - 1:50); a survey of its main elements (1:50 - 1:10); a detailed survey of the geometrical patterns used in the inserts which make up the largest percentage of the mosaic pavement (1:10 – 1:1) [3].

In the field of surveying historical pavements, our idea is to test this interaction between robotics and architecture, developed at the University of Cassino, in a in a project specially designed for architectural analysis and restoration, in an extremely innovative application in the field of robotics. It is an attempt to make a robot perform many of the operations related to the analysis and monitoring of historic buildings via automations which can improve procedures and results in terms of speed, accuracy and execution. To obtain this result, we need a robot with the ability to move in various directions, with “vision capacity” as it is known in the world of robotics, and obviously a high degree of versatility in order to adapt to the various sites in which it can be used.

## 3 A case study: the pre-cosmatesque pavement of Montecassino

The specific case study is the pre-Cosmatesque pavement of the basilica at the abbey of Montecassino, with the aim of testing the possibilities for applying robotic systems and automated procedures to architectural surveying.

This pavement, (there is good reason to believe it is the first example of a Cosmatesque pavement in Italy), was built by Byzantine craftsmen on the orders of the abbot Desiderius (who later became Pope Victor III) between 1066 and 1071. During the 18th century, it was replaced by another pavement with marble inlays, and for a long time was thought to have been lost.

After the monastery was totally destroyed during the Second World War, a large part of the pavement dating from Desiderius’ time, thought to have been lost, was rediscovered among the rubble. It was photographed and carefully surveyed before being consigned to oblivion once more in a cavity under the new basilica, rebuilt between 1948 and 1952 [4].

Fig.2 shows the survey of the entire pavement as it was found immediately after the basilica was destroyed in the 18th century. In particular, fig. 3, taken during the excavation and surveys carried out before rebuilding works began, clearly shows the difference in height of about a metre between the Desiderian pavement and the current surface. For any inspection or other work to the Cosmatesque mosaic, there is only a very low cavity, which is unlit and airless and therefore unsuitable for human intervention.

This is why, since the new basilica was rebuilt, the pavement has never been inspected in order to study its state of repair, or to make a stylistic analysis of the decoration.

This case study demonstrates the impossibility of using human operators, and is therefore well-suited to the experimentation of robots in this branch of studying and conservation of architectural heritage in general, and historical pavements in particular.

The interaction between the staff at DART, experts in architectural surveying, provides the main elements of the operations that the planned robot will have to perform when working inside the Cosmatesque pavement of Montecassino. These indications will be developed and made possible by the team at LARM, experts in robotised systems.

These operations can be summarised as follows: firstly, the robot will have to be able to move around inside the zone in question, carrying filming devices in order to carry out an initial study of the pavement: cameras and video cameras. These filming devices will then have to be replaced by more sophisticated instruments which can provide more precise information, such as thermo graphic machines and laser measurers.

At the same time, since the pavement of the cavity is extremely uneven, due to the presence of architectural remains from the same period and even pre-dating the pavement, the robot will not only have to move around correctly, but also ensure that the filming devices remain parallel to the pavement.

Apart from these factors, since the knowledge of the pavement in its current state is extremely important for the purposes of analysis and conservation, as it moves forward the robot must be able to memorise and transmit to an external unit any changes in the length of its legs along the way, to provide, in real time, the changes in the x-coordinate that will also give a section of the pavement as well as the route [5].

In order to begin testing the validity of the proposed ideas, experiments are being conducted in a virtual environment, with a simulation of the cavity and the pavement. Both can be recreated since photos and precise surveys were carried out during reconstruction of the monastery (fig. 4).

This type of evaluation, carried out in a three-dimensional virtual environment recreated on the computer, is proving to be extremely useful as it reduces not only the time, but also the cost of the design stage, since it is possible to assess and test the model in depth, right from the early design phase, working within an environment which provides an excellent simulation of the area in which the robot will be working. It allows modifications, fine-tuning and changes that would be expensive and difficult even if carried out only on the prototype.

## 4 Preliminary prototypes and laboratory tests

A historical pavement can be seen as a difficult terrain that includes features that could cause robot entrapment or loss of stability. Indeed, the architecture analysis for restoration of ancient pavements should be performed by a robotic system that is capable to overcome obstacles and move easily on flat surfaces with high stability.

The task can be recognized in the acquisition of measurements along the ancient pavement. Basic survey measurements that can be carried out are based on panoramic images of the site, which can be taken by a camera installed on the robot, and local pavement slope through servo-inclinometers. These operation can require a mobile robot with an inertial system to locate the robot in a world fixed frame, and proximity sensors to avoid collisions.

A good robotic solution can be based on the use of anthropomorphic legs with wheels such as the one that is shown in fig. 5. In fact, one can use the wheels for fast movements on flat surfaces and the legs for walking in an anthropomorphic manner to avoid or climb over obstacles and steps.

An hexapod robot is a feasible solution with a large platform for carrying equipment for inspection but operations of restoration. The hexapod robot has capability of keeping horizontal posture of the platform during the walking, as shown in the simulation of fig. 4. The number of legs is higher than three in order to guarantee stability. The use of six legs can be seen as a good compromise between flexibility and complexity of the system. In fact, hexapod robots have been already successfully used for example in space exploration, in-pipe inspection, mine detection, service robotics .

The robot's six-leg structure was chosen by taking into account the considerable irregularities in the pavement, with holes of a size that make wheeled robotic vehicles unsuitable, as they are generally more suited to interaction with contact. For this purpose, an initial prototype of an articulated leg and foot has been built, created by means of an actuated wheel in order to control the force in contact with the ground, in order to limit the possibility of causing further damage to the pavement.

The robotic system was designed with six legs in order to allow movements that, if programmed and adjusted correctly, ensure that three legs will remain in contact with the ground at the same time, to give the required mechanical stability and precision needed to direct the body onto which the architectural survey devices are installed.

In particular, the design has been created to give remarkable availability of space on the body of the six-leg robot, even on the surface facing the ground. Another special feature being dealt with at the prototype stage concerns the management and planning of strategies for moving the robot. With an adequate and relatively simple control system, this can give agility and flexibility of action, even to those without great experience in robotics [6].

## 5 Conclusions

We are currently finalising the design and the construction of the robot (fig. 6), which is being developed by the two laboratories LARM and DART, and are constantly reviewing the requirements deriving from the architectural application and inspections carried out in the field of mechanics and mechatronics.

Our aim is to test the possibilities of designing robots and/or robotic systems which are specifically dedicated to the field of Built Heritage, and to historical buildings in particular, and therefore to work in a completely new field for this kind of application.

At the same time, we cannot ignore the objectives regarding the medieval pavement of Montecassino. This not only requires more detailed study to improve the knowledge of this type of work, as yet not widely studied, but there is also the aspect of studying the techniques of documentation, analysis, and therefore protection and conservation, of stone surfaces in general and in particular the pavement of the historic abbey at Montecassino, which lies hidden and unexplored beneath the current basilica.

***Fig. 1 Rome, cosmatesque pavement of St. Crisogono (1146/1150)***

***Fig. 2 Left side of the antique pavement before the reconstruction of the closed space in 1952 [8].***

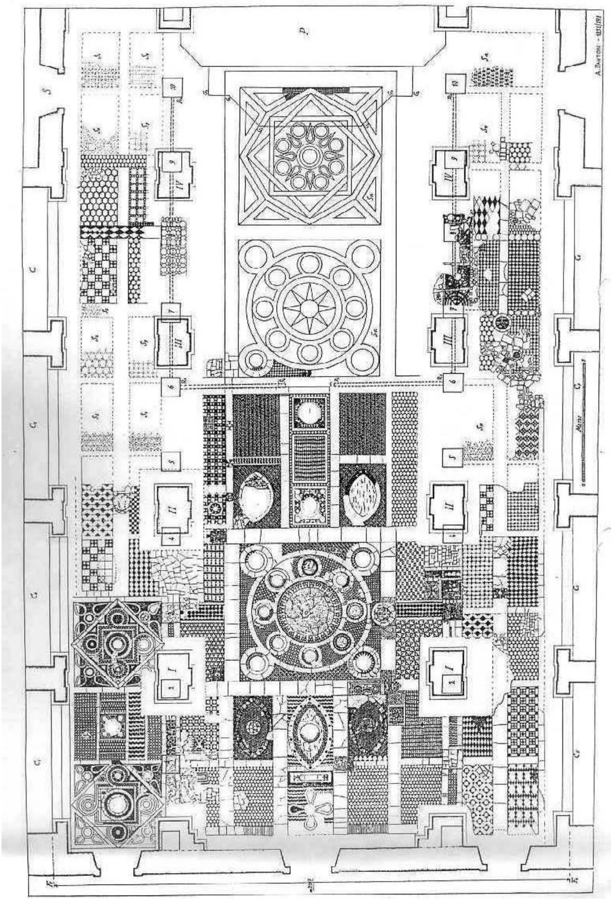

***Fig. 1 Montecassino, ancient pavement of basilica (1066/1071) beneath current in a survey of 1951-52 [7]***

***Fig. 3 A simulation example of operation of a hexapod robot on historical pavement of Montecassino.***

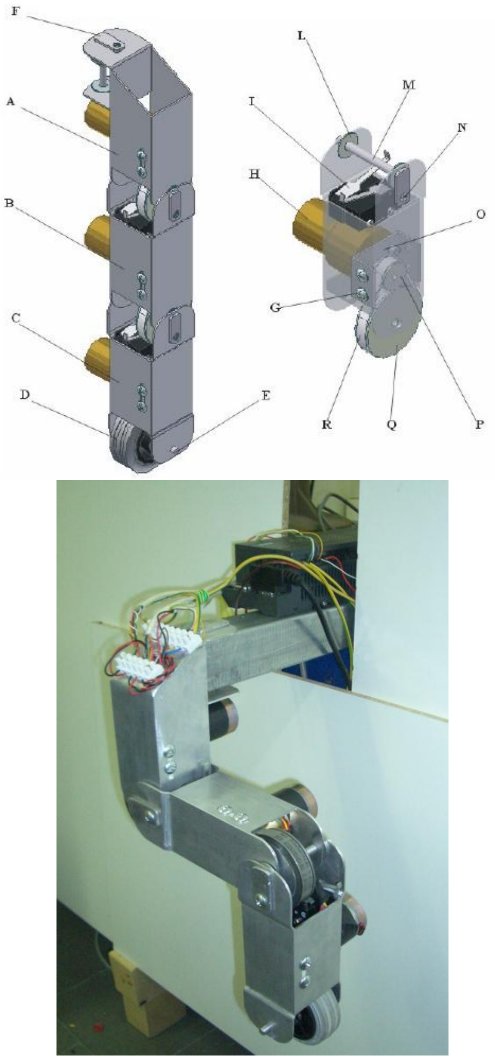


***Fig. 4 Built prototype of an anthropomorphic wheeled leg as developed at LARM,***

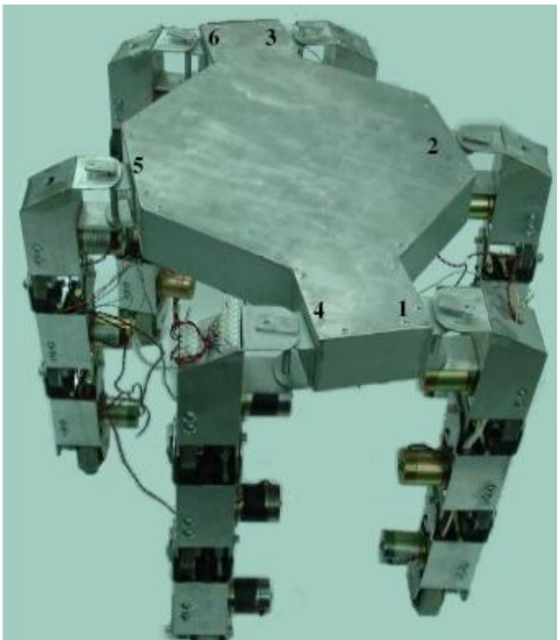


***Fig. 5 Prototype of robot developed at LARM,***

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