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11th INTERNATIONAL WORKSHOP ON ROBOTICS IN ALPE-ADRIA-DANUBE REGION

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Welcome to RAAD´02

Welcome to RAAD 2002 in Balatonfüred, Hungary. This series of annual workshops now having the 11th event was initiated in 1992 in Slovenia (Portoroz) by a relatively small community of approximately 25 members active in the Alpe-Adria Region. Consecutive events were organized in 1993 in Krems (Austria), 1994 Bled (Slovenia), 1995 Pörtschach (Austria), 1996 Budapest (Hungary), 1997 Cassino (Italy), 1998 Smolenice (Slovakia), 1999 Munich (Germany), 2000 Maribor (Slovenia), and finally in 2001 in Vienna, Austria.

Though the „regional" nature of these workshops has been conserved in the past years, on one and the region concerned has been increased via the inclusion of the other countries along the river Danube, and on the other hand, participants yearly appear from different regions and even from different continents. RAAD goes more and more international.

During the past few years application of robots suffered significant changes. While robotics conserved its significance in the traditional fields of industrial application, novel potential areas of utilization as surgery, rehabilitation, rescuing, more or less autonomous navigation and other activities in a partially unknown environment, etc. seem to emerge with increasing significance. In contrast to the conventional industrial robotics these new fields require highly intelligent, cooperative and mobile robots. While traditional robot applications need no significant research activity in our days, the emerging ones require huge intellectual efforts.

Situating in the centre of Europe Hungary is a kind of cross-point between East and West as well as North and South Europe. Its special location in both the geographic and the legal sense of the word makes this country be an appropriate host to achieve a more balanced participation from the western and from the eastern parts of the Alpe-Adria-Danube Region. Balatonfüred near the Lake Balaton (one of Europe's greatest sweet water lakes) offers the participants ample possibilities for relaxation and regeneration in the breaks of the Workshop.

The program contains 4 plenary lectures delivered by very well known scientists in the field of robotics. This proceedings volume – available on CD-ROM and printed form too,– contains 80 contributions almost covering the whole field of robotics and related areas. Human-centered robotics, humanoid robots, playing with roots, nonholonomic nature of certain class of robots, and application of special purpose robots in nuclear power plants are considered, too.

On behalf of the Steering Committee and the National Organizing Committee we would like to thank you all for participating in this event and we hope that you will enjoy the technical as well as the social program.

János F. Bitó	Imre J. Rudas	József K. Tar
Honorary Chair	General Chair	Chairman of the NOC

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A STUDY OF FEASIBILITY OF USING ROBOTS IN ARCHITECTURE ANALYSIS AND SURVEY OF A HISTORICAL PAVEMENT

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Abstract – This paper is an overview of characteristics and problems of architectural sites for historical analysis and survey using robotic systems. Design requirements and operation peculiarities of suitable robotic systems are outlined and discussed in general, but for a specific example. A case of study is presented to show both the engineering feasibility and architects' interest in using robots through the proposed concepts for robot design and operation in architectural sites.

KEYWORDS: Architecture Analysis and Survey, Non-Industrial Applications of Robots

1 INTRODUCTION

In this paper a study of feasibility is presented for using robots or robotic systems in novel applications concerning with activities related to analysis and survey of ancient pavements, which are of archaeological, historical-artistic or architectonic interest. The aim of this paper consists of studying and discussing on robotic systems and automatic procedures that can enhance both the activity and results of analysis and restoration of architectural historical sites. But specifically at this preliminary stage of the research the paper is focused on robot applications for architectonic survey of historical pavements

This novel application of robots is characterized by the aim to achieve photographically survey, analysis measurements, and inspection of historical pavements with enhanced operation in terms of activity velocity and accuracy.

Mobile robots are increasingly being used in difficult situations, such as the inspection of the inner layer of atomic power stations, environment inspections, home servicing, forestry and agriculture, planetary explorations and exploration of non-accessible terrain like volcano craters. An additional novel application of robots can be advised in architecture analysis and restoration that will require mobile robots to perform difficult tasks in environments with limited human supervision.

In this paper we have proposed the use of robots with suitable mechanical design for architecture analysis and restoration. In order to perform this task a mobile robot is required for motion and vision capabilities and rather limited human supervision. The basic design and operation features of robots for applications in Architecture analysis and restoration activities are outlined with a general view, but a specific application for activity on historical pavements is discussed with details. A specific robot design is proposed for analysis and survey of a specific pavement in the Montecassino Abbey even with the aim to outline practical problems and requirements.

2 ARCHITECTURE ANALYSIS AND RESTAURATION B USING ROBOTS

Cultural Patrimony is usually considered as common property by this time and basic means for cultural-social evolution. Therefore, it is a good for the current society that is responsible for a suitable preservation and transmission to the future generations. Consequently, a continuous monitoring of the Cultural Patrimony is required to check and analyze its status of preservation.

Basic activity can be considered the operations of analysis and architectural survey. Architectural survey is a discipline whose aim consists of acquiring an in-depth knowledge of any architectonic site, including historical evolutions and transformations, specifically in terms both of dimensional and construction aspects. In fact, it is useful to know the preservation status of an architectonic sites by analyzing the degradation conditions and motivations as well as the static conditions of the construction [1]. Therefore, the survey activity is characterized by an acquisition of huge quantity of data from integrated viewpoints.

In addition, the measurements and data acquisitions must be obtained with high level of accuracy, mainly from graphical viewpoint for a suitable representation of the architecture, since large scaled representation can be needed for a clear historic and technical survey. By referring to a historic pavement, the requirements of data accuracy and representation quality can be critical issues, since the survey must be variable as a function of the size of components and schemes of the pavement.

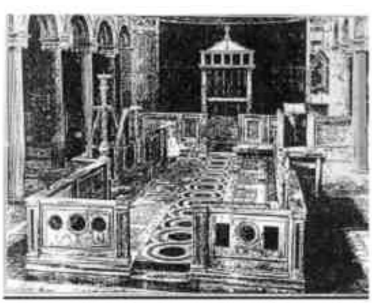


Fig.1: Pavement (dated in 1100-1120) in the St. Clemente Basilica in Rome.

An example of these constraints is shown in Fig. 1, [2], in which one can recognize different sizes of drawings and construction components, but within an available environment for human operators yet. As in the case of the pavement in Fig. 1, the study of the size and material of the used pieces characterizes the analysis of the mosaic drawing and scheme. Also the study of the assembling is important in term of the type and quality of surface roughness, the thickness and treatment of connections and the pose at large. In a correct survey, each element of a pavement must be identified both as a single unit and a surface component, with a specific attention to serial or repeated parts since their anomalies can characterize the pavement yet. In addition, particular care is required in the measurement of surface irregularities in term of global characteristics (like level variations, depressions, holes, etc.) and local void and adjustments that were made over the time. The survey process consisting of the measurement and graphical representation with different scales in the following activities can be outlined by referring to the cases of Cosmatesque pavements [1] in Figs. 2 a to c:

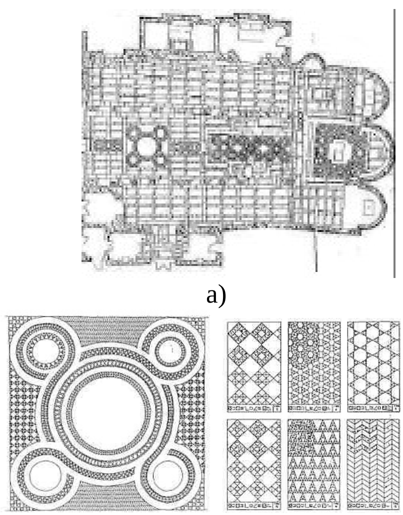
1- survey and representation of a pavement as the whole within architectural site (in scale from 1:100 to 1:50), as shown in Fig. 2a;

2- survey and representation (in scale from 1:50 to 1:10) of main compositions in the mosaic, as shown in Fig. 2b;

3- survey and representation (in scale from

[1] The 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 Monteccassino Abbey that was inspired by oriental sources and ancient Roman pavements.

1:10 to 1:1) of the geometrical units that give the majority of the schemes in the mosaic, as shown in Fig. 2c.
Generally, the activity at items 1 and 2 is carried out by installing a wire-netting over the pavement with suitable resolution in agreement with the sizes of the architectural units. By using the wire-netting, the location of the pavement is determined as a whole by using the position of main elements. Successively, once the overall representation is obtained, a further survey permits to determine position and shape of single components of the mosaic. The last item 3 of the survey process is usually carried out by using the so-called “contact survey” method, which consists of operating a manual copy of single part of the composition on a sheet of suitable material that is deposited on the pavement yet [4]. Then, this drawing with 1:1 scale is elabora-



a)

b) c)

Fig. 2: Examples of Survey’s drawings: a) drawing 1:50 of the whole pavement in Saint Lorenzo Basilica in Rome (dated in 1243-1254), [3]; b) drawing 1:20 of the pavement in Saint Quattro Coronati Basilica in Rome, (dated in 1105-1116), [2]; c) drawing 1:5 of geometrical units in the pavement of Saint Maria in Cosmedin Basilica in Rome, (dated in 1119-1130), [3].

ted in a suitable size to include it in drawing of interest.
The above-mentioned survey process gives usually two sets of results with graphical and photographical representation. The first set of results is aimed to advise the degradation status of the whole and single units. The second set concerns with a chromatic survey for identification of tonality, grain and types of used materials.
The need of 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 a suitable solution for pavement survey with the purposes of:

- operating in environments that cannot be reached by human operators by using proper instrumentation for even teletransmission of data and supervision;
- detecting the degradation status by avoiding the complicate netting and inspecting any deficiency of planarity;
- achieving data storage within Informatics frames based on the robot overall design.

3 ROBOTS FOR ARCHITECTURE SITES

A historical pavement can be seen as a difficult environment that requires features that could cause robot entrapment or loss of stability. Indeed, an analysis of the State-of-Art of available mobile robots can be useful to determine what type and number of degrees of freedom (DOFs) can be suitable to perform architecture analysis of ancient pavements.
Articulated or wheeled mobile robots can be used in architectural sites. 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 measuring local pavement slope through servo-inclinometers. This 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. Basic task requirements for the robot capability can be summarized as:

- travel distance that can be estimated with maximum range of 100 meters;
- average local pavement slope can be estimated less than 5 degrees;
- DOFs of the robot can be evaluated in term of 2 DOFs for motion on the pavement and 3 DOFs for manipulation of sensor equipment;
- sensors are needed like vision system, orientation and proximity sensors.

For inspection of architectural site it is desirable to estimate pavement lay out and detect obstacles in real time. Therefore, motion planning is another important issue. Path planning methods for robots have been proposed using techniques such as graph-search methods, potential fields, fuzzy logic. But traditional motion planning methods usually cannot be successfully applied since they assume perfect knowledge of the environment and ignore pavement features.

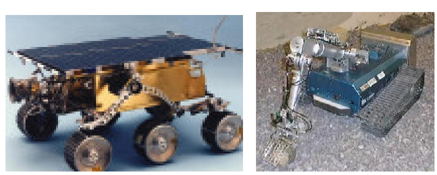
Many mobile robots for planetary explorations have been developed with characteristics that can be recognized as suitable for the non-conventional application under consideration. Sojourner is the name given to the first robotic roving vehicle shown in Fig.3a that will be sent to the planet Mars, [5]. Its weigh is 110 N on earth. It has six wheels and can move at speeds up to 0.6 meters per minute, with great stability and obstacle-crossing capability. The goal is to acquire measurements of some rock near the robot: the rock can be selected through an evaluation of the panoramic image of the landing site taken by a camera. A vision-based mobile robot that uses a single camera for obstacle avoidance has been developed at MIT as shown in Fig.3b, [6].

In the past years efforts have been made to develop walking and climbing machines to open new fields of application. Compared to wheeled vehicles walking machines show the advantage that they can act in highly unstructured terrain without streets or rails. Legged robots cross obstacles more easily, and they do not depend on the surface conditions and quality and, in general, they exhibit better adaptability. However, they have also specific features which make difficult both their design and control, like:

- a biped robot design integrates a large number of joints with their actuators and transmissions in a narrow space;
- the robot must be continuously in equilibrium, either static or dynamic, which may require high peak actuating torque;
- in case of falling, the robot should not break and furthermore should be able to recover its standing position;
- the available space and payload are small, which makes small also the energetic autonomy of the system, since batteries or other kinds of power generators can be stored in small quantity.

Several walking robots with two legs can be found in literature. Illustrative examples are shown in Fig.4. One of the first prototypes was developed at Waseda University in Tokyo, [7], Fig. 4a). Fig. 4b) shows a prototype of Wall Climbing Robot With Scanning-Type Suction Cups II, that has been developed at Tsukuba University, [8]. Fig. 4c) shows the prototype of EPWaR-II, [9], which has been developed with electro-pneumatic actuation and two suction cups beneath each foot at the Laboratory of Robotics and Mechatronics in Cassino.

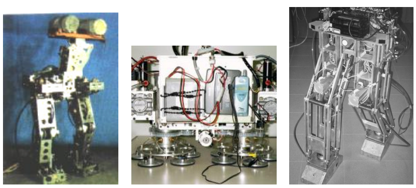
The walking locomotion requires more actuators than the wheeled method of locomotion, and the drive system is heavy; in addition it is not simple to control.



a) b)

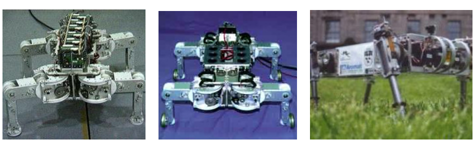
Fig. 3: Examples of existing mobile robots for planetary explorations: a) Sojourner; [5]; b) MIT vision based mobile robot [6].

However, walking machines can be used for several tasks, since they can move while selecting the point of leg contact with the ground in order to adapt the step to the shape of the terrain. They have suitable characteristics for application in architectural survey like the following: they can move over a rugged surface, and can pass over fragile objects on the ground surface without touching them; they can make holonomic omnidirectional motion without slipping or damaging the ground surface. In addition, by using four or six legs robots can perform a stable motion, because it is possible to maintain 3 or more legs in contact with the pavement.



a) b) c)

Fig.4 Examples of biped robots: a) Wabot developed at Waseda University in Tokyo; b) Wall Climbing Robot developed at Tsukuba University; c)EPWaR-II developed at LARM in Cassino.



a) b) c)

Fig.5: Examples of four legged robots: a) TITAN VIII, [10]; b) roller walker; c) ARLScout II, [11].

a) b)

Fig. 6: Examples of 6-legged walking robots: a) LAURON III, [12]; b) Eye Walker, [13].

Table 1. Main characteristics of examples of legged mobile robots of Figs. 4 to 6.

robot	Size (cm)	Weight (N)	Payload (N)	Speed (m/s)
Fig.4a)	43x27x21	85	20	0.3
Fig.4c)	40x120x60	300	100	1.0
Fig.5a)	60x25x40	190	70	0.9
Fig.5c)	46x40x45	270	--	1.4
Fig.6a)	50x30x80	180	100	40
Fig.6b)	35x20x30	20	--	--

Illustrative examples of four legged robots are shown in Fig.5; Fig. 5b) shows the hybrid mobile robot named roller walker, that has been developed as a new version of the TITAN-VIII. Illustrative examples of six legged robots are shown in Fig.6.

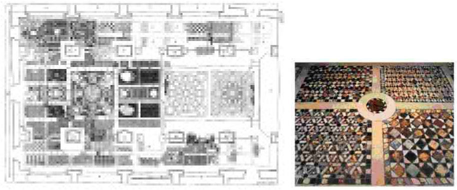
Characteristics are summarized in Table 1 to compare the legged robots of Figs. 4 to 6.

4 A CASE OF STUDY: THE PAVEMENT OF THE MONTECASSINO ABBEY

The above- mentioned considerations and concepts can be applied to a specific case of study in order to verify the feasibility of using a proposed robot in a survey activity of a historical pavement.

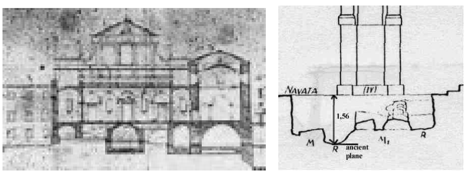
The case of study refers to the pavement of the Basilica of Montecassino Abbey that was built between 1066 and 1071. Today is located beneath the pavement of the current Basilica that has been rebuilt in agreement of XVIIIth century design between1948 and 1952 after the destruction during the II world war [14].

In Fig. 7a) a graphical representation of the survey carried out in 1951-52 is reported to show the medieval pavement status before the reconstruction of the Basilica. Some parts of the pavement were moved to other location in Montecassino Abbey as shown in Fig. 7b), but most of the pavement is still located at 1 meter beneath the current pavement as shown in Fig. 8. A limited room is available for inspection and the environment is not suitable for human operators since lack of light and air.



a) b)

Fig. 7: The ancient pavement in the Basilica at Montecassino Abbey: a) a survey drawing in 1951-52, [15]; b) a part in the Saint Anna Chapel, [16].



a) b)

Fig. 8: Reconstruction design for the Basilica in Montecassino Abbey: a) an overall cross-section, [17]; b) a cross section between the ancient and current pavements.

After the reconstruction, the pavement has been never inspected to check its status or enhance the knowledge of its decoration.

The proposed robot in Fig. 9 for inspection of architectural sites is composed by a 6-legged walking machine with 12 DOFs (2 for each leg whose 1 DOF is for the walking and 1 DOF is for the turning) and a 5 DOFs CaHyMan parallel-serial manipulator, which has been designed and built at LARM in Cassino [9]. The robot will be equipped with wheels on the tips of the legs in order to avoid slipping at foot contacts and the hybrid manipulator can be installed on the top or below the body plate of the walking machine. Other main design and operation characteristics can be identified in: the leg size of 0.6 m, the size of the body plate of 0.6 x 1.0 m, the size of the hybrid manipulator of 0.5 m; a video camera that is installed on a telescopic arm with two dofs; sensor equipment that consists of led sensors for obstacle avoidance, inclinometers and/or gyroscopes for navigation purposes but survey accurate location.

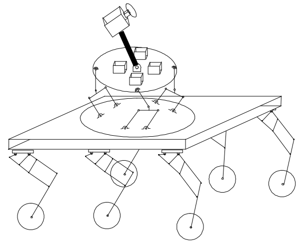


Fig. 9 A kinematic scheme for the proposed robot for the survey activity on the Cosmatesque pavement of Figs. 7 and 8.

5 CONCLUSIONS

This paper has presented a study of feasibility of using a robot in a architecture survey activity for the ancient pavement of the Basilica in Montecassino Abbey.

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