Application of robots for inspection and restoration of historical sites

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***Abstract*— 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 restoration of historical sites of architectonic interest. The work has been developed within a collaboration between DART and LARM Laboratories, of University of Cassino. Design requirements and peculiarities of operation of robotic systems are analyzed for the application in restoration of historical sites. The proposed application is completely novel and of great interest.**

***Index Terms*— Automation, architecture Analysis and survey, Non-industrial applications of Robots.**

I. Introduction

Analysis, inspection, survey and restoration of historical sites are strongly related, since they should be considered together to correctly analyze and recover historical sites.

In the field of analysis and restoration of historical sites it is becoming of great interest to have accurate and efficient operating methodologies. Indeed, robots and robotic systems can be designed and used for this kind of applications.

In this work a study of feasibility is proposed to design and build a mobile robot for the inspection and analysis of historical sites of architectonic interest.

In particular, the join work between DART (Laboratory of Documentation, Analysis, Survey of Architecture and Territory) and LARM (Laboratory of Robotics and Mechatronics) of Cassino can give the possibility to share knowledge and develop a new robotic system, which is able to inspect and analyze historical sites.

This novel application can be considered of great interest because nowadays the Cultural Patrimony is usually considered as common property of human beings for the cultural-social evolution. Therefore, the society should be responsible for a suitable preservation and transmission to future generations of historical sites of architectonic interest. Consequently, a continuous monitoring of the Cultural Patrimony is required to check and analyze the status of preservation of such sites [1].

II. Main requirements in robotized analisys and restauration

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. The survey activity is of fundamental importance for the historical analysis and restoration of architectonic sites 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 [2]. Therefore, the survey activity is characterized by an acquisition of a huge quantity of data from integrated view points.

In addition, the measurements and data acquisitions must be obtained with a high level of accuracy, mainly from graphical view point 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 scheme of the pavement [3].

Fig. 1. Cosmatesque pavement of Anagni, cripta of S. Magno (1224/1231)

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An example of these constraints is shown in Fig. 1, [4], 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 analysis of the mosaic drawing and scheme is characterized by the examination of the size and material of the used pieces as well as by the study of the assembling 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 by referring to the cases of Cosmatesque pavements [5] in Figs. 2 a to c [6]: survey and representation of a pavement as the whole within the architectural site (in scale from 1:100 to 1:50), as shown in Fig. 2a [6]; survey and representation (in scale from 1:50 to 1:10) of main compositions in the mosaic, as shown in Fig. 2b [7]; survey and representation (in scale from 1:10 to 1:1) of the geometrical units that give the majority of the schemes in the mosaic, as shown in Fig. 2c [6].

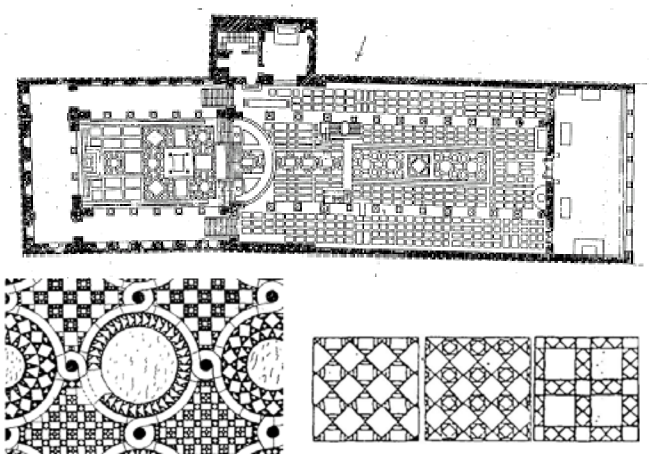


Fig. 2a Rome, pavement of S. Lorenzo (1243/1254), Survey 1:100.
Fig. 2b. S. Vincenzo al Volturno (Bn) pavement of S. Vincenzo. Survey 1:50
Fig. 2c. Rome, pavement of S. Prassede (1110/1125). Survey 1:5

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 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. Then, this drawing with 1:1 scale is elaborated 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 system 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 a data storage in an informatics frames based on the robot overall design.

III. CHARACTERISTICS OF THE ENVIRONMENT

The above- mentioned considerations and concepts can be applied to a specific case of study in order to verify the feasibility of using the proposed robot in a survey activity of a historical pavement, and testing its operation for this novel application .

The case of study refers to the pavement of the Basilica of Montecassino Abbey that was built between 1066 and 1071 and 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 [8].

In Fig. 3 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 [9]. Some parts of the pavement were moved to other location in Montecassino

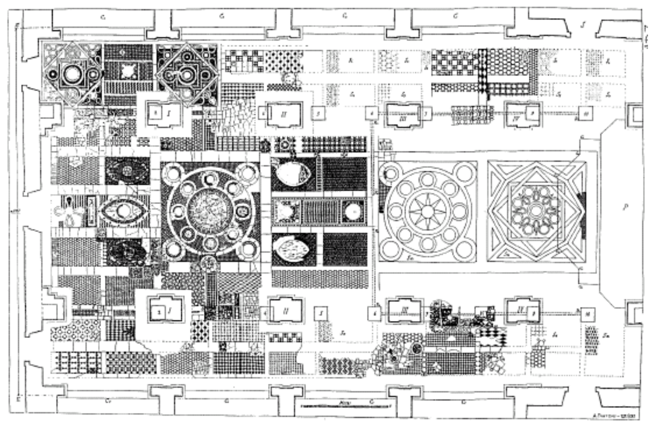


Fig. 3a Montecassino, ancient pavement of basilica (1066/1071) beneath currunt.in a survey of 1951-52.

Abbey, but most of the pavement is still located beneath the current pavement as shown in Fig. 4a. In particular Fig. 4b [10] shows the archaeological site and different level of about 1 meter between the ancient and current pavements.

IV. A STUDY OF FEASIBILITY FOR OPERATING A LEGGED ROBOT

The study of feasibility concerns with the analysis and simulation of the robotic system to be used for operating in historical sites. Basic features of mobile robots, either legged or wheeled, are well known, but specific requirements should be considered for the proposed application, which can be considered as novel in the field of Robotics.

Furthermore, robotic systems that show good characteristics such as flexibility and reliability, can be used in the case of study. The proposed task is to be able to move the robot into an unstructured environment, such as a pavement with slopes and obstacles. A future work can be the design a robotic system that is capable to perform an automatic analysis of historical pavement with suitable algorithms and inspection procedures.

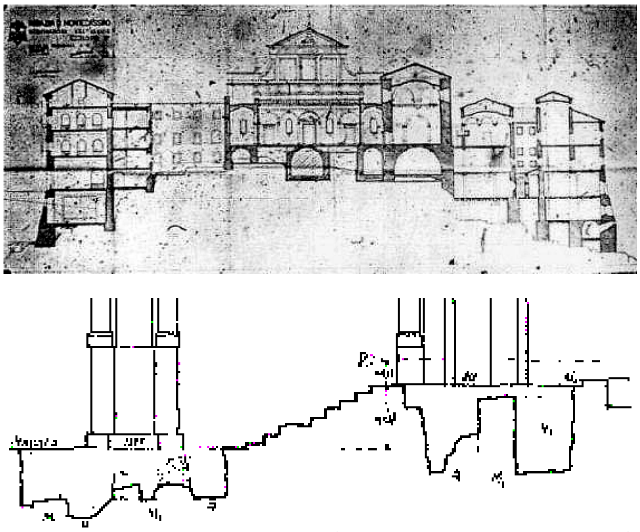


Fig. 4a-b Montecassino, cross section of the monastery and cross section of basilica made during reconstruction (1935/50)

Figure 4b) shows a middle-age pavement, which is located in an unreachable location for human operators. Only a limited part room is available for inspection and additionally the environment is not suitable for human operators since lack of light and air. Therefore, after the reconstruction, the pavement has been never inspected to check its status or enhance the knowledge of its Cosmatesque decoration. Therefore, the case of study is characterized to be not available for human operators for traditional procedures of Architecture survey.

Therefore, in this case of study is not possible for human inspection but it is accessible to suitable robotic systems.

The join work between DART and LARM laboratories make possible to put together expertize and knowledge on the case of study. In particular, DART has the knowledge to give the basic and fundamental features that are necessary to perform the proposed task. Informations such as shape of the room in Montecassino, slope of the pavement, presence of obstacles, are necessary to have design constraints that can be used by LARM, which has the experience on the design of robotic systems and developed preliminary studies on the proposed application [11] [12].

Basic features of the robotic system can be summarized as follows: the robot should be able to move inside the archaeological site carrying sensors such as a camera and a CCD camera. In the second stage, one can use also laser systems and thermographic sensors to obtain more precise information about the pavement.

The ancient pavement is characterized by the presence of obstacles, which can be parts of the pavement itself. Indeed, the mobile robot should be able to move correctly keeping its body in a plane parallel to the pavement plane.

Another important feature of the robot should be the capacity of measure the body orientation by suitable sensors, in order to reconstruct a map of the slope of the pavement, which is not constant in general.

At this first stage a suitable simulation has been carried out, as shown in (Fig. 5)., in order to test the designed robotic system acting on a simulated pavement, for several operating conditions.

The simulation is of basic importance, since it is not possible to test in advance the robot on site and there are not precise informations about the preservation of pavement under-study.

This simulation has been carried out on 3D reconstruction of the ancient pavement with different conditions and it has been also useful to test the operation of the robotic system.

V. 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. Basic task requirements can be summarized in the robot capability concerning with:

- travel distance that can be with maximum estimated range of 100 meters;
- average local pavement slope that can be estimated less than 5 degrees;
- DOFs of the robot in term of 2 DOFs for motion on the

pavement and 3 DOFs for manipulation of sensor equipment;

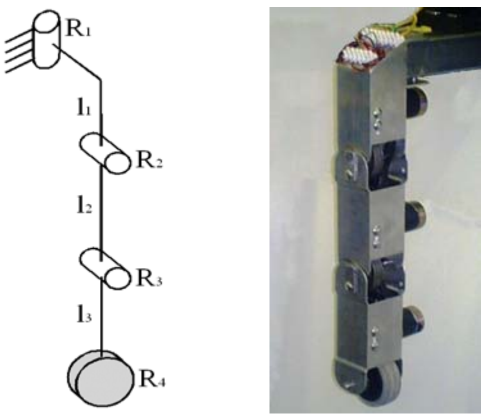
- sensors: vision system, orientation and proximity sensors.

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. In Fig.6 an hexapod robot is shown as 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.6. 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, [14].

A hexapod robot on a historical pavement can find obstacles or holes of big or small size as compared with the size of the robot. It is worth noting that the robotic system can overcome a hole or an obstacle just by using the wheels, if the size L of the step is lower than the radius of the wheel. Otherwise, it is necessary to operate the other DOFs of the anthropomorphic leg as shown for example in the schemes of Fig.7 and 8. In particular, Fig. 7 shows possible phases for ascending an obstacle whose size L is bigger than the radius of the wheel. Figure 8 shows possible phases for descending an obstacle whose size L is bigger than the radius of the wheel.

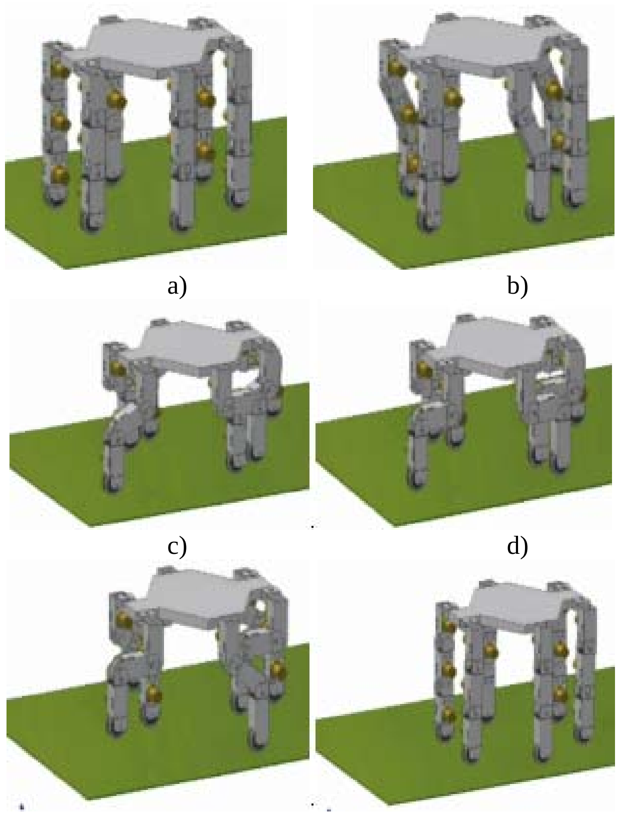
The operation of a hexapod robot for overcoming an obstacle of big size (as compared with the size of the robot) can be based on the phases that are reported in Figs.7 and 8. In particular, it can be divided in the following phases: lift up a fore leg; move forward by means of the wheels; lift up the second fore leg; move the two fore legs to the vertical configuration; lift up the two intermediate legs; move forward by means of the wheels; move the two intermediate legs to the vertical configuration, move forward by means of the wheels. The operation of a hexapod robot for overcoming a hole of big size can be similarly described.

A simulation example of operation of a hexapod robot on a historical pavement is reported in Fig.9.



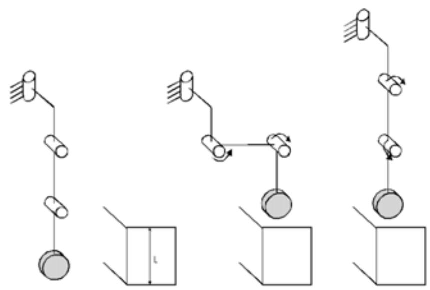
a) b)

Fig. 5 An anthropomorphic wheeled leg as developed at LARM: a) a kinematic scheme; b) a built prototype.



a) b) c) d) e) f)

Fig.6 A simulation of hexapod robot keeping the platform horizontal during walking.



a) b) c)

Fig.7 Possible phases for ascending an obstacle of big size: a) initial straight leg configuration; b) forward lifted-up configuration; c) final straight leg configuration.

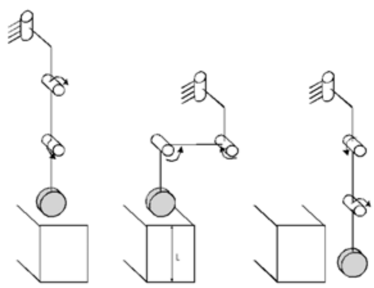


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Fig.8 Possible phases for descending an obstacle of big size: a) initial straight leg configuration; b) backward lifted-up configuration; d) final straight leg configuration.

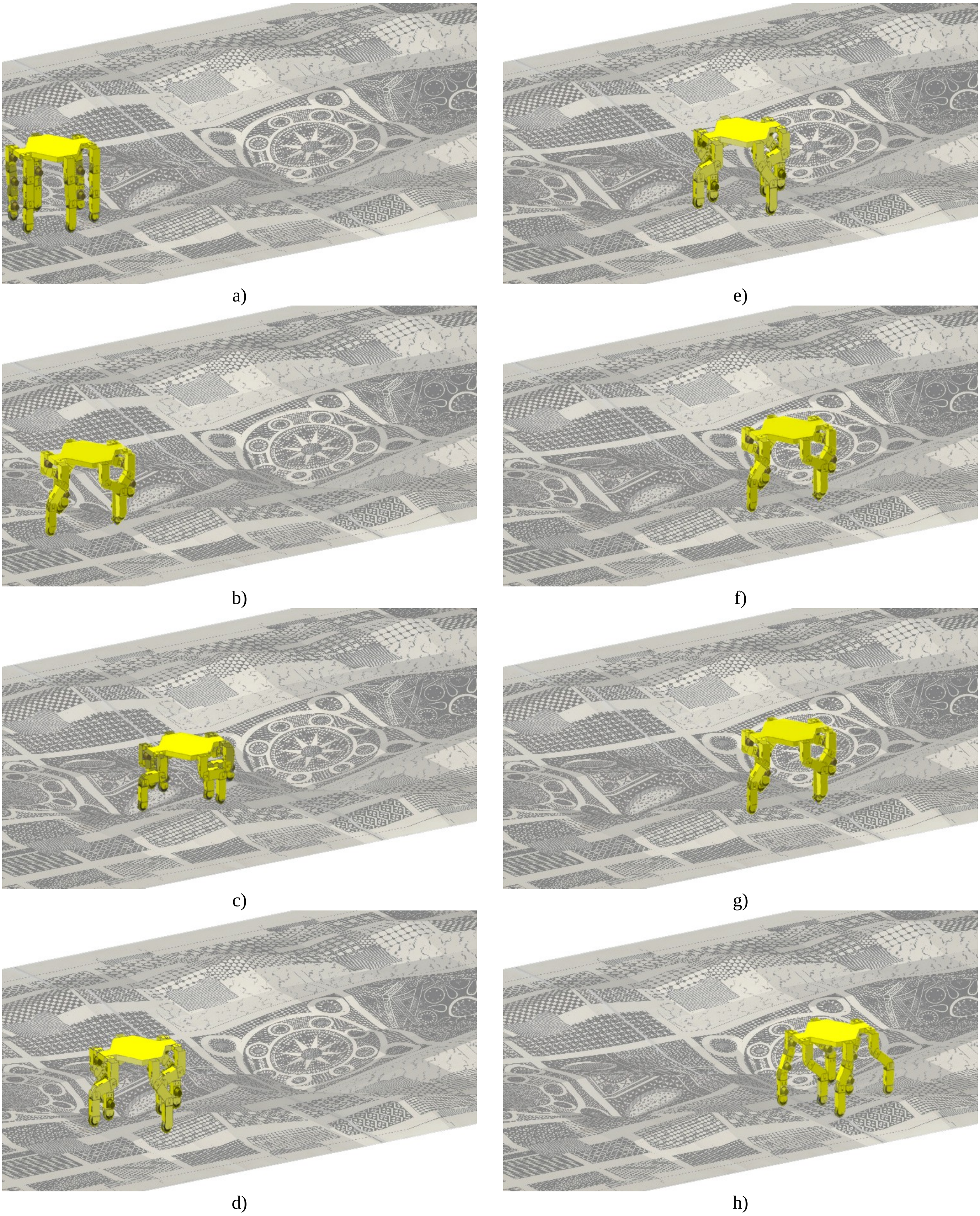

Fig.9 A simulation example of operation of a hexapod robot on historical pavement of Fig. 3.

I. Conclusion

At this moment, our research is in the final phase concerning the design and construction of the robot prototype. A continuous review of the work is done by LARM and DART laboratories. In fact, this activity is directed to formulate a general problem in which the design of a suitable low-cost easy-operation are well defined also for not expertise in the field of robotics; this activity is performed with the aim to design a specific test-bed.

The application is related to a specific Cosmatesque pavements in the Montecassino Abbey, environments. that cannot reached by human operators.

The goal is to verify the feasibility of a new robot design to be used for analysis and restoration of historical sites of architectonic interest. The application can be considered a novelty for robotic systems.

It is also of great interest to study the middle-age Montecassino pavement, which is of great interest from architectural point of view. The development of new procedures for analysis, architectural survey and restoration preservation status of an architectonic sites by analyzing the degradation conditions and motivations as well as the static conditions of the construction.

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