HeritageBot Service Robot assisting in Cultural Heritage

Marco Ceccarelli, Daniele Cafolla, Giuseppe Carbone, Matteo Russo
Dept. of Civil & Mechanical Engineering - LARM
University of Cassino and South Latium
Cassino, Italy
ceccarelli@unicas.it

Michela Cigola, Luca J. Senatore, Arturo Gallozzi, Roberto Di Maccio
Dept. of Civil & Mechanical Engineering - DART
University of Cassino and South Latium
Cassino, Italy
ceccarelli@unicas.it

Francesco Ferrante, Francesco Bolici, Stefano Supino, Nello Colella, Marina Bianchi
Dept. of Economy and Law - IMPRENDILAB
University of Cassino and South Latium
Cassino, Italy
f.ferrante@unicas.it

Carmelo Intrisano, Giuseppe Recinto, Annapaola Micheli, Domenico Vistocco, Maria Rita Nuccio, Maria Porcelli
Dept. of Economy and Law - FINLAB
University of Cassino and South Latium
Cassino, Italy
c.intrisano@unicas.it

***Abstract*—This paper presents results of HeritageBot, a regional research project for developing a robotic platform to be used in Cultural Heritage frameworks. The design and a prototype of HBOT Platform for demo purposes is introduced with features of low-cost construction and user-oriented performance. The design requirements are presented for application in monitoring and working within frames for conservation of goods of Cultural Heritage with characteristics that are aimed for technological transfer and entrepreneurship plans.**

Keywords- robot design, application for cultural heritage, techncological transfer, prototype

I. Introduction

The use of remote-controlled robotic platforms constitute a huge potential, both in terms of possible outcomes, and as a branch of experimentation and research in architecture and archaeology, [1]. The combination of robotics and Cultural Heritage has the potential to increase the awareness and the knowledge when environments are substantially inaccessible because of logistical or security reasons. In order to preserve the objects of study, the technical specifications (weigh and dimensions) of a robotic platform may be a good solution to ensure the preservation of the historical objects by suitable actions ensuring also knowledge acquisition on the Cultural Heritage aspects.

Up till today Robotics have had important developments to work out solutions mainly for use in external environments and for recreational issues. The technology we have now is ripe for creation of mobile and remote-controlled platforms that can have more different uses. In particular the possibility of a miniaturization of the components and a simplification of interfaces allow low-cost prototypes that are able to increase the use's range.

The examples of today available robotic systems are characterized by considerable size (for example the robot Bigfoot) or by rover-based structures for mobility by wheels or tracks (for example the Mars Rover or Project TRADR) with the peculiarities to meet the energy demands for machine operations and technical management. These solutions in general do not fit to the needs of application in the wide world of Cultural Heritage, where the actions are often characterized by low-impact approaches in order to preserve the findings integrity. Moreover, because of a the environments that characterize the spaces inside of Cultural Heritage sites, it is necessary that the assisting platforms will be capable of skills that can be today possible thanks to recent developments in order to emulate the human operator capabilities and beyond, [2,3].

In addition, the sensors currently in use for the investigations and surveys of historical sites and products, offer huge possibilities since their capabilities and reduced sizes can permit efficient new operation and even simplification of the historians' investigations. In addition sensors of digital type, that are suitable for acquisition of digital data, allows to integrate digital information within a single working platform.

Currently a challenge for an increase of capability and efficiency in activities in the Cultural Heritage frames can be considered in making accessible what so far is not accessible to human operators. For example, the stratigraphic nature of growth of the buildings over time as well as their physical response to time, constitute the characteristics on the basis of which it is necessary to operate with new procedures and means. Sometimes the plans for interventions on Cultural Heritage sites are limited by an incomplete knowledge of site status that can be a dangerous or inaccessible area for human operators.

978-1-5090-6724-4/17 $31.00 © 2017 IEEE
DOI 10.1109/IRC.2017.84

What is accessible and visible today is analyzed with digital instruments with a high level of detail that offer new investigation awareness to the operators, but very often the objects of study before the restoration are i areas not accessible to the operators or not accessible to the instrumentation. The miniaturization and robotization of the sensors and instrumentation will overcome these limits and they will even be usable in wider contexts by remote controlled platforms within suitable process of investigations as for the Cultural Heritage needs. At the same time the possibility of a mobile platform equipped with different tools and instruments can be also considered a possibility to open new and important research areas in Cultural Heritage frames with better investigations for documentation acquisition without expensive destructive and complex interventions.

This paper is part of the products of the research project HeritageBot, [4], of the FILAS program of Latium Region in Italy that is carried out by the Department of Economics and Law of the University of Cassino and South Latium with researchers from DART (lab for Architecture and Drawing), LARM (lab of Robotics and Mechatronics), IMPRENDILAB (lab for Entrepreneurship), and FINLAB (lab for Finance) laboratories. One of the expected project results is a prototype of remotely controlled mobile platform called HeritageBot Platform that can be considered as an element of innovation in Cultural Heritage frames for its ability to act in sites for acquisition of digital data autonomously and in places otherwise not accessible.

The paper presents the project peculiarities and the activities that brought to the definition and design of a HeritageBot Platform with a prototype under development whose characteristics are outlined within the illustrated design process.

II. The HeritageBot Project Plans and Partnership

HeritageBot is a research project with multi-disciplinary contents that finalized to develop a wireless robotic platform equipped with suitable sensors with mobility by locomotion and small flight for monitoring operations and intervention in Cultural Heritage frames. The project activity is based on technological developments of patents in robotic field for market implementation and professional application in Cultural Heritage frames through service operations (industrial-like, cultural aims, educational etc.) of the further developed technological solutions. Expected applications as service operations can be considered for:

- The survey / knowledge of unsafe products
- The survey/investigation of not accessible areas by preventing deterioration of the environments (floors, mosaics, attics, etc.)
- The visual inspection with remote interface
- The survey and investigation of Cultural Heritage goods with action of analysis and restoration avoiding hazardous conditions and accidents
- The monitoring of Cultural Heritage goods and sites with remote interface

The characteristics of the project activity and platform design are summarized in the block diagrams in Figs.1 and 2. Fig.1 shows the multidisciplinary structure of the project with four different laboratory unit partners from Architecture, Robotics, Entrepreneurship and Finance, respectively, and plans for design and research activities with technical and non-technical aspects. The design of the HeritageBot Platform is expected to produce innovation that can lead to practical implementations with market challenges thanks to merging engineering issues with entrepreneurship interests.

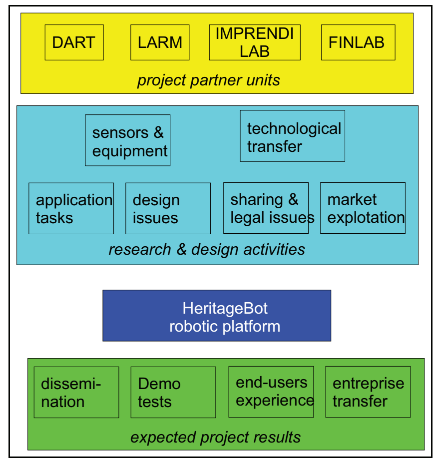


Fig. 1 Structure and activity of the HeritageBot project

In Fig.1 the partnership of the project is indicated by teams from the four laboratories DART, LARM, IMPRENDILAB, and FINLAB with expertise in very different fields as indicated by the lab names. The common interest of the teams has been designed in developing and exploiting robotic platforms servicing in Cultural Heritage frames from the very different perspectives as from technological aspects up to entrepreneurship success of implementable solutions of the designed platform and project itself. In the block diagram of Fig.1 is described how the different expertise views are expected to be integrated both in the research activities and expected results. One other important aspects of the project is the dissemination towards a wide public including fruiters of Cultural Heritage sites and technological transfer also by attracting, defining and forming new figures of professionals so that a prototype, although with the limited resource of the project, is planned for demo purposes with the specific features of low-cost solution and user-oriented operation capabilities.

The project is planned in two years with phases starting with the definition of the needs and requirements for the project problem, looking at existing solutions from similar or far applications as source of inspiration, designing and prototyping the robotic HeritageBot Platform for demo purposes by implementing all the outcomes from the lab activities, promoting dissemination and technological transfer of the activity results and prototype designs.

III. Target Requirements for Cultural Heritage

An investigation on Cultural Heritage goods of architectonic or archeological nature is aimed to achieve deep knowledge of the products with possibility both of analysis and intervention to fully understand the historical value and preserve it properly. This requires a synergic integration of technical actions with cultural studies that have been considered as requirements and goals of the development of the HeritageBot robotic Platform.

Thus, the requirements for HeritageBot robotic Platform for servicing in Cultural Heritage frames has been identified in operation peculiarities and structure characteristics, such as:

- capability of data acquisition with autonomous or supervision action, even with on- board storage capacity, in environments also of difficult access
- capability of small interventions for checking or collecting small pieces from the environment by suing the small arm or other devices to be installed on the platform on demand
- capability of investigations with different instruments (for example color-photogram analysis, radiography, etc) that can be equipped for specific purposes on demand for identification of the status of the environments/objects
- modularity of the robotic platform for mobility capacity in walking and small flight with suitable space available for equipment and instruments to be installed on-board on demand
- operation of the platform at skill reach of the users by using joy-stick or easy programming teach pendent
- cost of the platform at budget level of potential users both for high performance needs or limited capabilities by using the modular design
- design novelty for technological transfer that can be attractive for existing users and companies but also for stimulating new entrepreneurships.

The demonstrative prototype under construction will be equipped with basic instrumentation for monitoring purposes such as an high resolution digital camera, a Lidar vision scanner sensor, an infrared camera, and an integrated lighting system

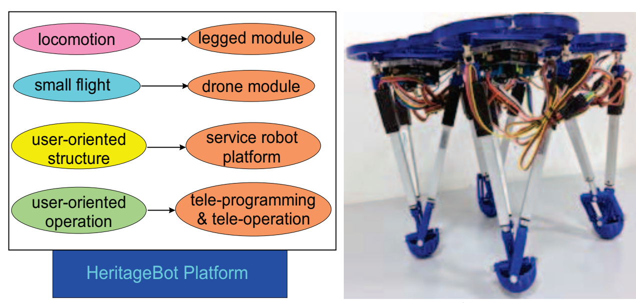
IV. Design and Prototype of HeritageBot Platform

HeritageBot robot platform has been designed by a multidisciplinary team with expertise in Robotics, Architecture, Entrepreneurship and Finance aiming to achieve a system that can be attractive, useful and affordable for stakeholders in Cultural Heritage frameworks. The design process has started by defining the market requirements and needs. This first market analysis has identified some potential in a device for exploration, restorations, surveillance tasks at Cultural Heritage sites especially for non-easily accessible environments. In fact, existing solutions are mostly limited to crawlers/wheeled mobile robots or drones. But, existing solution show clear drawbacks. For example crawlers can easily damage the operation surface. Wheeled mobile robots cannot overcome obstacles higher than the radius of their wheels. Drones are not suitable for exploring narrow spaces as well as they cannot perform restoration tasks.

Detailed specifications have been defined for HeritageBot robot platform to overcome the above-mentioned limitations also by considering specific features and constraints given by experts of architectural survey of Cultural Heritage Goods. Accordingly, HeritageBot design has been conceived with a modular structure that can provide specific features and equipments as depending on the specific application and functionalities that are requested by the users, [5].

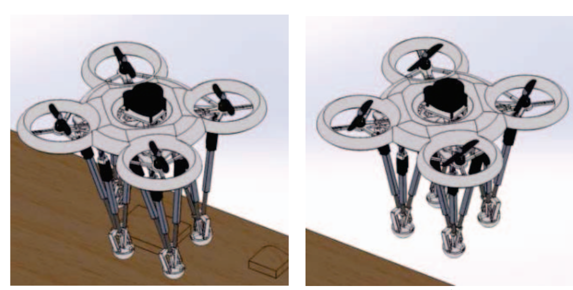
Three main modules have been designed, Fig. 2 a). The first module hosts the control and operation architecture (including batteries and communication hardware) as well as the specific sensors and instrumentation that are needed by the users. The second module is a quadcopter-like system that allows a small flight to help avoiding obstacles and for increasing payload/stability capacity of HeritageBot. It is to note that more propellers could be added to achieve larger flight heights. Nevertheless, this feature has been considered unnecessary in Cultural Heritage frameworks for several reasons such as the recent regulation constraints for flying devices as well as the limits given by the battery size and autonomy. The third module is based on a tripod parallel architecture, which is patent pending by the team at LARM, [6, 7]. The main features of this architecture are the very high payload to own weight capacity as well as a wide step range. Accordingly, it is possible to operate it in narrow spaces, in presence of obstacles comparable with the HeritageBot platform size while avoiding high pressures or damages on the operation surface.

A first prototype of HeritageBot Platform has been built at LARM as a proof-of-concept device, Fig.2 b), whose overall cost has been limited to less than 10,000 Euros. In particular, commercial components have been selected for the control and operation hardware, batteries, propellers, actuators, and cables and connectors. Main frame of module one has been made by using a laser cutting technique, while all the remaining components have been obtained via 3D printing, [8]. The overall size is contained in a box of 50x50x50 cm with a weight of 5.0 Kg when equipped, including batteries of 2.0 Kg for an operation duration of 2 hours while walking at about 250 m/h and flying at less than 1 m height with a tilting capability of 55 deg. The prototype is equipped with a sonar for obstacle detection, thermal and barometer sensors for environment monitoring, and a tele-communication of 80 m.



a) b)

Fig. 2 The design of the HBOT Platform : a) scheme for the conceptual design; b) a prototype built at LARM in Cassino with the leg module



a) b)

Fig. 3 The CAD design of HeritageBot Platform: a) in walking mode; b) in small flight mode

Figure 2 a) shows the general conceptual design of HeritageBot system as composed by modules for the mobility with locomotion and flight modules, for the instrumentation capacity in Cultural Heritage servicing, and for the user-oriented functioning with proper solution in motion planning and action commanding/supervision. The Figure 2 b) shows the prototype under construction with the locomotion module that is characterized by four tripod parallel-manipulator legs with a LARM patented design. The leg structure is capable of a large walking step as depending of the stroke of the linear actuators that ensure also a high payload with stiff behavior. As indicated in the modular design, the legged locomotor is fully equipped on board with the necessary control units and sensors by leaving specie for additional equipment as necessary for the application. The flight module is installed on top of the central plate with independent control units and sensors. It is designed for small flight that can increase the locomotion capability in over passing obstacles and can increase the payload capacity of the platform when used as floating unit.

Figure 3 shows a design simulation of the HeritageBot Platform in a typical motion operation combining walking with a small flight. The combination of walking and small flight makes the system useful in many applications where a single capability cannot be sufficient, beside giving more possibility of motion. The simulation has been also used to size the basic components of the locomotion and flight modules.

V. TECHNOLOGY TRANSFER ISSUES OF HERITAGEBOT

The traditional approach to the enhancement of the Cultural Heritage (CH) is based on the substantial separation between the stage of the recovery / restoration / conservation (RRC) and the stage of enjoyment by end-users of the output of the latter activities, [9]. This separation has so far also characterized the development and application of technologies in respectively, RRC and fruition. Among the main causes, the substantial public monopoly, at least in Italy, in the activities of RCC and their funding, poor communication between the different professionals involved at different stages due also to the absence of common codes, the reduced attention to the issue of the end-use. The professionals in charge of RRC are typically motivated by the objective of developing solutions useful for this purpose, with a reduced focus on the question of the fruition downstream of the CH, whereas the professionals in charge to make the CH available to the end-users have no control over the design of the technologies destined to the RRC activities. This separation may result in significant losses of efficiency and the lack of enhancement of enjoyment opportunities that require upstream interventions. This scenario calls for a different methodological and operational approach based on the adoption of the concept of filiere (or supply chain) for the analysis of the technological and entrepreneurial opportunity in the development of the CH.

The first advantage of this approach is technological in nature and is derived from an optimization process in the development of solutions for the RRC based on an integrated vision of the supply chain. For example, the development of diagnostic technologies according to a chain approach would take into account that the inputs acquired in the diagnostic phase (in quality and quantity, e.g. images of an archeological sites) can be used to expand the opportunities for downstream use (for example, multimedia apparatuses for the use of the images in museums, educational, trade in the strict sense).

The technological advantage, in terms of both quality and efficiency, generates results in an economic advantage. First, the optimization of the technological solutions according to a supply chain logic permits to compress the overall cost of the enhancement process. Second, the strengthening of enjoyment opportunities expands the potential market and the possibility of financing, upstream, the enhancement technologies.

A fundamental step in the direction envisaged is to build up interdisciplinary teams able to share a common view about the economic and technological bottlenecks to be overcome in order to maximize the value to society of the technology solutions developed in the RRC step and opening up new fruition opportunities along the filiere.

The adoption of this integrated approach also calls for a new approach to the entrepreneurial discovery process in this area. To this end, within the HB project, we implemented three activities: 1) we organized meetings with operators located at different points within the CH filieres (CHFs); 2) we presented the technological solutions we were developing very early in the development process, to groups of university graduates and students with different disciplinary backgrounds - who were attending a course of entrepreneurial education - in order to receive feedbacks on how to develop the technological solutions to exploit the envisaged market opportunities; 3) we implemented activities in the spirit of the open science citizenship in order to receive similar feedbacks.

From a methodological perspective, we adopted several instruments and tools that were developed in the last decade in Silicon Valley to pursuit the product market fit. In particular, we abandoned the product development centered strategies usually adopted by technologists in charge of RRC – "if we build it, they will come" – in favor of a customer development process based on hypothesis testing. Following this new methodology and using the evidence based entrepreneurship tools we tested from one side, the space of the problems along the supply chain and, from the other side, the space of our proposal technological solution. In other terms, we emulated the scientific method based on testing assumptions to catch data and insights from potential customers and end users. By several experimental loops, we gained knowledge about: 1) the minimum set of characteristics that satisfy the potential customers and end user needs; 2) the most suitable business model to deliver and capture value generated by our solution. Regarding the first point, after several minimum value products, we choose to implement a prototype strictly based on the end users feedbacks. We innovated from the architectural side designing a device technologically scalable in modular components. In other terms, we projected a platform that can be equipped with low-costs as well as high-costs sensors to respect the different budgets of users. Regarding the second point, we started to conduct several customer interviews on revenue model. In this stage, we discovered that leasing plus training can be a preferred solution for many target buyers. We based our discovery process, on a primary market research. On this side, we developed a matrix with several parameters (from the focus on end user benefits, to lead customers, to key influencers, to potential partners, to complementary goods and services, to market characteristics and so on) to explore along the filiere potential market segments. Then we decided our beachhead markets on the RRC side and on the fruition side. We completed this important step: 1) by several brainstorming sessions with the group of university graduates and students attending our courses on entrepreneurial education; 2) by activities based on open science citizenship. Following this discovery stage, we started the execution phase. To this aim, we develop a lean business plan based on respectively theoretical targets and milestones expressed by bullet points on operations, marketing and financial sides and two weeks of applied sprints of execution. We adopted this methodology to evaluate the fit between our assumptions and market responses in the execution stage and to decided very quickly to iterate or pivoting. At the end of the day, we employed all these methods to implement a new technology transfer approach less focused on stand-alone value of technology and business administration strategic approach (essentially based on pure execution and zero search) and more suited to catch an economic opportunity characterized by uncertainty on technological and market side by a startup really based on the search and the discovery of a repeatable and scalable business model.

The start-up companies enclose the concept of innovation, uncertainty and lack of financial resources. Finding the necessary resources to fill the financing gap is a decisive step for the survival of start-up and development of its potential. The main objective of this study is to evaluate the key factors to attract external financing in the field robotics for cultural heritage. To achieve this objective it is necessary to increase the interest of non-traditional investors as venture capitalists, business angels and equity crowd-funding investors.

The financing of innovative start-up is characterized by high levels of risk. These are associated with the need to identify, develop and support a potential and unspoken market question or fulfilled by other existing services/products. In starting a new business project, an obstacle is finding financial resources. The possibility to finance depends on the degree of risk and development phase.

In the seed phase the degree of risk associated with the possibility of failure of the innovative project is high, while the financing needs are limited. The start-up phase has a very high degree of risk but also strong need for financial resources to create prototypes and supporting marketing activities and product promotion. The phases early growth and sustained growth have a more reduced degree of risk than the previous phases and during the initial stage of expansion the financial need is still rather substantial. The company to grow up must develop widespread product distribution and marketing.

The financial balance must be sought since the start-up phase to ensure business solvency. New businesses produce negative economic results due to the inability of company to cover fixed costs with sales: new products and innovative services haven't its target market yet. This determines the necessity to recur to external financing sources. Given that there isn't an optimal financial structure for the start-up, the financial decisions have to be oriented to the search of a continuous balance among funding sources. Thus, for example, during the start-up and early growth phases, the company will opt for a financial structure equity oriented that is a patient capital: it does not require fixed payments and allows to investors to participate actively to the creation of value through combined contribution in term of professional experience, technical and managerial skills and through a network of other investors and financial institutions. A financial structure debt oriented can be adopted in the other phases of the life cycle.

The presence of equity helps the company in the search for debt capital, increasing its borrowing possibilities. Equity is more flexible in deadlines and does not involve periodic payments as debt. Briefly, it can be argued that, in the early stage of the life cycle, this source of funding is critical, although isn't advised to start a business only with risk capital.

A particular form of equity investor is the business angels that are informal investors who provides capital for financing a business idea. They invest own funds and give their professional skills to support the innovative project. Venture capital funds are another way for financing innovative companies. They support the companies not only in financial terms but also in managerial terms: investors are specialized in investment value, sector, geographical area and so the entrepreneur must address the choice towards the potential partner that presents preferences and investment characteristics compatible with its own financial needs. Therefore the choice of the investor is a key element in the decision about new businesses. Finally crowd-funding represents a further funding source.

The equity based crowd-funding offers new and potentially unlimited opportunities for investment and allows smaller investors to buy small stakes in potentially profitable activities. These types of financing can more develop if there is an equity market, as the Alternative Investment Market (AIM) that has simplified procedures, so that it could enable smaller companies to finance their growth acquiring funds directly. The AIM is based on dynamic SMEs and offers them the access to investors that are oriented to small caps. It provide a faster and more flexible path to the listing, but at the same time it protects investors, thanks to an efficient regulatory system that meets the needs of small firms and investors.

Open-Citizen Science activities have been designed and worked out in the following aspects: access to a large human computational power (e.g. through the so called crowd-sourcing initiatives); raising a broader awareness and knowledge on specific scientific topics even from a general public; early understanding of the market needs and expectations; testing early versions of the research outcome by potential users. An ad hoc methodology has been developed in [10] as based on the combination of the general citizen science process and the action research practice.The activity is based on an integrated online-offline knowledge dissemination and public integration by using social we media with user-friendly scientific information regarding the research flow and its open issues. On the offline side, a series of seminars and workshops are organized to show the final version of the device and its capabilities and to allow the public to contribute through questionnaires, brainstorming and Q&A sessions.

VI. PLANNED ASSISTED ACTIVITIES AND LAB TESTS

The prototype will be used in demonstrations both for the technical validation of the system feasibility and operation soundness of the application in Cultural Heritage frames. The system is checked in lab tests and later in on-field experiences. The operation feasibility is worked out in tests within archaeological sites with specific goals according to the equipment that has been provided to the prototype. The platform is provided with cameras and a LIDAR laser scanner that were tested to acquire at 3 m of distance with an error 2 cm. Lab tests are finalized to confirm the design goals and to characterize the prototype performance, mainly in terms of mobility and user controllability. At LARM, the prototype has been tested successfully in walking mode and small flight mode separately, confirming the designed data and low-energy consumption. The user controllability has been planned and verified through a control panel in a laptop with a WiFi connection to the prototype’s on-board control units.

The operation feasibility in Cultural Heritage frames is programmed in tests within the sites in Fig. 4 and 5 with different needs and constraints.

a) b)

Fig. 4 The Roman amphitheatre in Cassino as area for demo applications: a) the archeological areas; b) a details of the archeological environment


a) b)

Fig. 5 The Roman Pyramid in Rome as area for demo applications: a) the pyramid; b) a details of the inside small corridor

The site in Fig. 4, [11] is an area of the Roman city in Cassino and it is characterized by a large space with a broken ground with a task of inspection of hidden/closed areas like the one shown in Fig. 4b. The site in Fig. 5 is the Pyramid of Cestius, (built about 18 BC–12 BC as a tomb for the magistrate Gaius Cestius) in Rome as a very important archaeological site still not completely explored and it is characterized by an inside area with a bulky structure that is unreachable for human operators because of dimensions and atmosphere like the inside tunnel in Fig.5b).

The activities that are planned for the HeritageBot Platform in both sites is an exploration of areas that are so far not completely known with a task of a visual survey and some other operation for investigating the conditions and dimensions of specific areas. But since the differences between the two sites both in term of cultural significance and site peculiarities, the HeritageBot Platform will be equipped and operated differently but a successful service is based on the walking-flight mobility and platform structure for any sensor and equipment useful for activities in Cultural Heritage sites.

VII. CONCLUSIONS

The project HeritageBot is presented with a multi-disciplinary team in order to develop a robotic platform for servicing in Cultural Heritage frameworks with features of entrepreneurship and technological transfer in new fields of applications and professions. A built prototype of HeritageBot Platform is presented with low-cost design and user-oriented operation to show both the results of the HeritageBot project and the feasibility of the robot design for servicing in Cultural Heritage frameworks. Novel aspect of the HeritageBot Platform can be recognized in the modular design combining a legged parallel-manipulator locomotor with a drone with small flight capability giving additional payload capacity.

ACKNOWLEDGMENT

The authors are grateful to the Latium Region government for supporting the HeritageBot research project through 2015-17 grant FILAS-RU-1044.

REFERENCES

[1] Ceccarelli M. and Cigola M., “Service Robots for Restoration of Goods of Cultural Heritage”, Chapter 12 in: Service Robots and Robotics-Design and Application, Engineering Science Reference (IGI Global), Hershey, 2012, pp.213-228.

[2] Ippolito A., Cigola M., (Eds.), “Handbook of research on emerging technologies for Architectural and Archeological Heritage”, Hershey, IGI Global. 2017

[3] Cigola M., Gallozzi A., "New technologies for the analysis and the conservatipon of architectural heritage", Italian Survey & International Experience. P. Giandebiaggi & C. Vernizzi Eds. Rome: Gangemi, 2014, pp. 795-802.

[4] Ceccarelli, M., et al., “HeritageBot – Robotic System for Culttural Heritage”, www.heritagebot.unicas.it, accessed 28 December 2016.

[5] Ceccarelli, M., Cafolla, D., Russo, M., Carbone, G., “Device with legs and helices”, Italian Patent Application n.102016000103321. (in Italian).

[6] Russo, M., Cafolla, D., Ceccarelli, M., “Device for tripod leg”, Italian Patent Application n° 102016000097258, 2016. (in Italian).

[7] Russo, M., Ceccarelli, M., “Kinematic design of a tripod parallel mechanism for robotic legs”, The 4th IFToMM Conference on Mechanisms, Transmissions and Applications. Trabzon, 2017.

[8] D. Cafolla, M. Ceccarelli, M. F. Wang, G. Carbone, “3D printing for feasibility check of mechanism design”, International Journal of Mechanics and Control, Vol. 17 (1), 2016, 3-12.

[9] Piccialli, F., Chianese, A., “Cultural Heritage and New Technologies: Trends and Challenges”, Personal and Ubiquit Computing, Nov. 2016, pp. 1-3 .

[10] Colella N., Bolici F., “Public Engagement in a Research Project: designingcitizen science activitiesas part of its business model”, IEEE, Global Wireless Summit (GWS). Aarhus 2016.

[11] Cigola M., D'Auria S., Gallozzi A., Paris L., Strollo R.M., "The archaeological site of Casinum in Roman era. The reasons for study and knowledge among an urban and archaeological context". The reasons of drawing. S. Bertocci & M. Bini Eds. Rome: Gangemi, 2016, pp. 201-208.