Mobile robots for investigation in specific application areas

Dimitar Karastoyanov, Milena Groueva, and Veneta Yosifova

***Abstract*—**The objects of cultural and historical heritage are often located in remote and difficult to access places. Occasionally, reaching them can be related to harmfulness and dangers. Also, buildings and facilities often have places that are narrow, difficult to access, or associated with dangers. Under current control or after an accident, inspections are required at such locations for energy losses due to insulation damage, thermal bridges, moisture, etc. The article describes the possibility of using intelligent mobile robots to transfer capturing, scanning, and thermography technique to narrow, difficult to access or dangerous locations. Approaches for use of mobile robots on outdoor terrain or in enclosed spaces are presented. 3D digitization of the received data were discussed, incl. for people with disabilities. Methods for increasing the energy efficiency of buildings and facilities by analyzing thermograms and using new methods and tools have been also discussed

***Keywords*—**Mobile robots, cultural and historical heritage, 3D digitization, Braille presentation, energy efficiency.

I. Introduction

THE development of 3D modeling technologies opens up great opportunities for solving scientific and applied tasks in the fields of medicine, history and archeology, construction, industrial production, and safety. In recent years, digital technology has been widely applied in museum expositions to present objects of cultural and historical heritage. The new generation of multimedia devices (3D scanners, 3D printers) are a powerful active technology that can play an important role in the interaction of visitors with exhibits of cultural and historical heritage. 3D digitization and creating of models of unique cultural and historical heritage objects solve problems in their presentation in the context of limited access to the originals and allow scientists from all over the world to conduct research. In addition, the task of applying 3D technologies to improve the quality of life of people with disadvantages, including ensuring the perception of objects of cultural and historical heritage by the visually impaired and / or blind people, is also relevant, [1], [2], [3].

Buildings are one of world's most energy consuming objects and are responsible for more than 40 percent of global energy used and up to one third of the world's greenhouse gas emissions, according to the United Nations Environment Program. Today, "green" architects and designers try to develop building's energy efficiency, from retrofitting older buildings to reduce their energy usage to building new ones that create more energy than they require.

Sustainable architecture has come a long way in the last few decades. The challenge is turning old buildings to energy efficient ones by reducing utility and operational costs.

The location and identification the places and the types the energy loses is one of the most popular methods for reducing energy consumption and increasing the sustainability of older buildings, [4], [5].

II. Mobile robots

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Mobile robots are now widely used in many industries due to the high level of performance and reliability. Mobile robots for inspection are mainly used to replace human in dangerous environment. Because of that these robots must have autonomous navigation to reach desired objects that will be inspected. For the safety of the humans, the robot and the subjects in the environment of movement, the robot must have obstacle avoidance function.

Often the objects are located in difficult accessible, narrow or dangerous places. In these cases, mobile robots can be used, equipped with special sensors to detect, handling and scanning the object.

A. *Mobile four-wheeled robot for obstacles overcoming*

We present here a four-wheeled vehicle (mobile platform) with electric drive of the wheels. The direction of travel is controlled by the electric drive of the steering bar. In addition, an auxiliary engine is mounted on the longitudinal axis of the platform which drives the front axle about the longitudinal axis up and down in a vertical plane. This makes it possible to raise the left or right front wheel while the vehicle remains stable on the other three wheels – Fig. 1, [6].

When lifting one front wheel and turning the steering bar to the other front wheel (the wheels do not move), the mobile platform may "cross" small obstacles (up to the radius of the wheel) or "climb" a stairway when driving in buildings. After returning to the horizontal position of the front axle and reversing the steering bar and the other wheel climbs to the

This work was supported by the BG NSF Grant No 17/21 - 2017.

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stairway. When the wheels are moved forward, the entire platform is "pulled" along the stairs. The maximum height of the overtaking step shall be such that the center of gravity of the mobile robotic system remains in the triangle of the three wheels (except the raised). This ensures dynamic motion resistance. This is an example of so named "wheel-walking" type motion of a mobile robotic system. The scheme of the mobile platform is shown in Fig. 2.

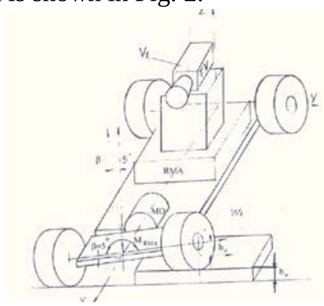


Fig. 1. Mobile platform with steering bar and additional engine

On the mobile platform, a conventional hand-manipulator with remote control can be mounted. In addition, various types of sensors and camcorders can be mounted. Thus equipped, the mobile robotic system can be sent for study in harmful conditions (radiation), or to manipulate with hazardous materials (chemicals). It can solve tasks of observation, sampling, measurement of harmful environmental parameters (radiation, chemical), movement among debris, manipulation with and transport of dangerous objects (bombs), etc. The mobile platform can also be used to explore and scan hard-to-reach objects of cultural and historical heritage. In Fig. 3. is shown the constructed working laboratory model of a mobile platform overcoming obstacles - stairs.

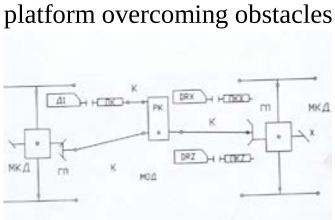


Fig. 2. Scheme of the platform

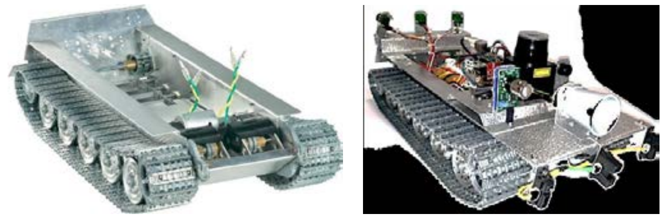
Fig. 3. Obstacles overcoming

B. Two-chained mobile robot for inspection

For the purposes of the development, a two-chained mobile platform (Fig. 4) will be used, produced by REELY. The construction is made of aluminum and has dimensions of 445 x 226 x 92mm, mass 4.7 kg and maximum load capacity 1 kg. The platform is powered by two electric motors - RP380-ST3, mounted to tooth gears with a gear ratio of 63. The chains are made of metal segments with torsion hang of the rollers, [7]. The gathering of the information needed to guide the robot is done through the sensor system. It includes three different types of sensors:

- Precision URG-04LX flat laser infrared laser scanner manufactured by Hokuyo Automatic Co., Ltd,
- Ultrasonic sensors model MB1020 LV-MaxSonar® - EZ2 ™ developed by Maxbotix4;
- Sharp5 Digital GP2Y0D805Z0F Digital Infrared Sensors

The power unit is implemented as a bridge voltage inverter with complementary P-MOSFET and N-MOSFET transistors directly controlled by the Microchip6 TC4469 drivers. A feature of the bridging scheme is that the direction of rotation of the motors is determined by which one of the P-MOSFET channel transistors is undrawn. The speed of rotation of the motors, respectively the speed of motion of the mobile platform, is determined by the impulse filling coefficient, which controls the N-MOSFET transistors.



a) the mobile platform b) the control and sensor systems

Fig.4. The mobile robot:

The control system of the motors is implemented with Microchip7 microcontroller PIC18F452 programmed to produce a 20 kHz PWM signal and a filling coefficient of the control pulses according to the required speed. In addition to controlling the motors, the implemented control unit also provides an opportunity for wireless communication of the operator with the platform necessary for carrying out initial tests related to its mobility.

To determine the position of the robot in the working scene, the RoBoard company's 9-axis inertial measuring device RM-G146 is used.

Two independent wireless devices operating in the 434MHz and 2.4GHz are provided for communication with the mobile platform.

To meet the energy needs of the robot board systems, ANR26650 lithium batteries of the A123 Systems9 Company were selected.

III. Special sensors

For cost oriented research and according to the low load capacity of the mobile robots, at the beginning for the generating of 3D models and different types of images we use sensors as follows, [8]:

A. Kinect sensor – Fig. 5

Inside the sensor case, a Kinect for Windows sensor contains:

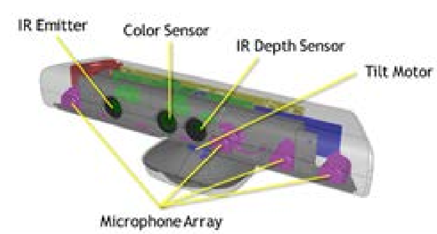


Fig. 5. Kinect sensor

• An RGB camera that stores three channel data in a 1280x960 resolution. This makes capturing a color image possible.

• An infrared (IR) emitter and an IR depth sensor. The emitter emits infrared light beams and the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are converted into depth information measuring the distance between an object and the sensor. This makes capturing a depth image possible.

• A multi-array microphone, which contains four microphones for capturing sound. Because there are four microphones, it is possible to record audio as well as find the location of the sound source and the direction of the audio wave.

• A 3-axis accelerometer configured for a 2G range, where G is the acceleration due to gravity. It is possible to use the accelerometer to determine the current orientation of the Kinect.

Each frame, the depth sensor captures a grayscale image of everything visible in the field of view of the depth sensor. A frame is made up of pixels, whose size is once again specified by NUI_IMAGE_RESOLUTION Enumeration. Each pixel contains the Cartesian distance, in millimeters, from the camera plane to the nearest object at that particular (x, y) coordinate. The (x, y) coordinates of a depth frame do not represent physical units in the room; instead, they represent the location of a pixel in the depth frame.

B. CATERPILLAR CAT S60 – Fig. 6

a) b) c)

Fig. 6. CATS60: a) Condensation; b) Moisture; c) Thermal bridges

The Mobile Phone contains:

• A FLIR thermal camera with MSX Thermal sensor 17mm pixel size, 8 – 14 mm spectral range. The Thermal resolution is 80x60 and the Visual resolution 640x480. The temperature range is -20°C – 120°C, accuracy ±5°C or ±5%..

• The device uses Android 6.0, has Wi-Fi and Bluetooth for sending files, pictures and videos.

IV. Specific Application Areas

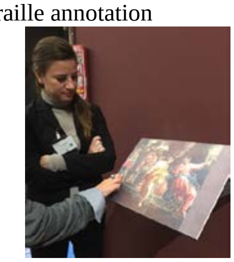
In the area of application of 3D technologies, the Institute of Information and Communication Technologies at the Bulgarian Academy of Sciences (IICT-BAS) provides data to blind people. In cooperation with Pavia University, Italy was created and presented at the International Exhibition EXPO 2015 in Milan, Italy a 3D exhibition based on “The Battle of Pavia – 1525”, available for receipt including for the blind people. 7 large tapestries (9 x 4 m) with scenes from the battle were used as the starting 2D data. From a 2D source - tapestry, picture, photo or other, using specialized software Cinema4, as well as a 3D CAD product, data is extracted to create 3D models of the relevant figures from the 2D source. The 3D created models are assigned texture (coloring) in accordance with the 2D source. Then the models are printed on a color 3D printer and the scene of the tapestry, picture, photos or more is recreated, [1].

In addition, for the visually impaired, contours of the designated figures are drawn - soldier, horse, weapon or others. Each closed area enclosed by a contour is positioned adjacent to such adjoining closed areas such that, in addition to the dividing contour, which has a higher level than the enclosed area, there is a difference in the levels between any two adjacent areas.

The development of the technology from the Exhibition "The Battle of Pavia - 1525" is the realization of the painting by BRERRA Gallery - Milan, Italy "Christ and the Samaritan at the Well", for which IICT-BAS and Pavia University were also made a tactile copy with contours of figures and Braille annotation.

The tactile tile is exposed alongside the original in the gallery so visually impaired visitors can "see" the picture by touching the contours of the figures on the tile and reading Braille annotations to them - Fig. 7.

a) Tactile version with Braille annotation



b) Original and tactile tile c) Visual impaired visitor

Fig. 7. Christ and the Samaritan at the Well, BRERRA Gall., Milan

For navigation, mapping and creating of 3D models the Kinect sensor is used, [9].

The navigation was tested in indoor. The robot has made map on a floor of a building using the Kinect sensor, and then navigate in it - Fig. 8.

The Kinect sensor is also useful for creation 3D models of big and non-mobile objects of cultural and historical heritage.

Fig. 9 shows the creating of 3D printed prototypes based on given 3D models of static objects with possibility of coloring.

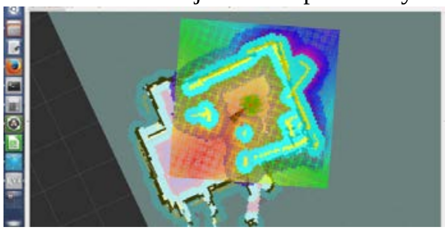


Fig. 8. Robot base position and path generation

Fig. 9. The original an the 3d scanned and 3D color printed copy of The Portal of the Chertosa Cathedral near to Pavia, Italy

Another specific area of application of a mobile robot with a thermal sensor is in buildings - architectural or historical monuments with difficult access, like pyramids – Fig. 10.

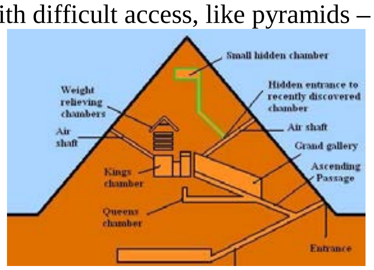


Fig. 10. Applications in cultural-historical heritage: Inside of a pyramid

In such situations, hidden voids, rooms or corridors can be found in the objects of cultural and historical heritage based on changes in the thermal image. Also, in difficult access areas, 3D models of the objects of cultural and historical heritage can be made using a 3D sensor carried by the mobile robot. For example, a Kinect Sensor with RGB camera, infrared (IR) emitter and an IR depth sensor can be used.

Other specific application area:

The most important factors for energy loses in the buildings are condensation, moisture intrusion and thermal bridges/leakages. Often the effects are hidden in the narrow places, tubes, air conditioning paths etc. For observation the target surfaces we can use autonomous mobile robots with mobile phone camera on board, or with thermal camera (see Fig. 6). For images transfer Wi-Fi or Bluetooth can be used.

After detecting the problems, decisions as ventilation and insulation can be applied. An additional method is to introduce solar panels, LED lighting, radiant heating, as well as BMS (Building Management Systems) with program control.

V. Conclusion

In recent years, museums have welcomed millions of visitors to their galleries and exhibitions. New generation multimedia is a powerful, emerging technology that can potentially play a major role as regards interactions between visitors and exhibits, [2]. Often in the past, digital technologies for cultural heritage created ties between visitors and artifacts that led to the latter being overshadowed by technology. Rather than attracting visitors, they often created a gap between visitors and artifacts, [3]. In case of difficult to access places or dangers, the use of intelligent mobile robots with possibilities for 3D scanning, remote control and obstacles overcoming is the decision.

Another important aspect is by using the possibilities of the information and communication technologies to provide access to the cultural and historical heritage objects for people with disadvantages (for example visually impaired or blind people) so that they can also "see" by touching with their fingers and hands. This will provide them better understanding the relevant presented object – painting, flag, etc.

On the other hand, energy efficiency is one of the most popular topics in modern world. It takes place in all economic directions including civil engineering, [4]. Although many innovative techniques for green building are developed, old buildings and architectural city-sights also need modernization and sustainable improvement, [5]. Most popular approach is upgrading the construction — insulation of roof and surrounding walls, changing windows. Other important factor for rising energy efficiency is reducing electricity consumption. Building and managing an entire system of photovoltaic batteries and modern, cost effective appliances is the most productive way of forecasting building's energy consumption and saving. For localization and identification of the place and types of energy loses in buildings it is possible to use mobile robots and thermal images.

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