

A Novel Design of an Augmented Reality Based Navigation System & its Industrial Applications

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Abstract – The paper proposes a design of an augmented reality based navigation system, as well as investigate its potential areas of application within the industry. With the ascent of industry 4.0 (IoT), systems such as Augmented Reality (AR) and Virtual Reality (VR) benefit from the availability of bulk sensory data.

I. INTRODUCTION

Maintenance activities are integral within an industrial setting. The efficiency of these activities is associated with the total productivity of an industrial process/machine. A highly efficient maintenance policy/strategy usually results in relatively high levels of plant productivity. AR and VR may be incorporated into a maintenance strategy. AR and VR technology would enhance maintenance activities, and facilitate somewhat complex tasks.

A maintenance strategy includes a range of activities and may be categorized into administrative, technical and management processes. AR technology contains digital data, as well as other technical details, and is able to provide information about industrial machinery-equipment, without the need for equipment disassembling.

In this regard, we employed AR technology in developing a unique navigation system to replace/reduce the installation costs of traditional AGV navigation systems. The proposed AR system consists of a camera, which observes the QR-Code/Markers, and a processing unit.

Augmented Reality enables visualisation of any data and information, as well as control of a running process. It means it is possible to read various data within any equipment, during its operation and in real-time. This

facilitates analysis of “black box” systems.

II. AR IMAGE PROCESSING - OPENCV

Our main goal was developing a Cyber-Physical System (CPS) for an industrial robot laboratory and find ways of implementing IoT.

The department’s robotic laboratory includes a KUKA KR5 medium payload industrial welding robot[1], KUKA KR3, FANUC spider and Sony Scara SRX-611 [2].

The data and parameters have been encoded into QR-Codes and other unique markers. In the first test we use these codes as position markers and an instruction set to control a prototype AGV robot. The AGV uses an IP camera as vision sensors.

The Building Mechatronic Research Centre features several functional IP cameras, which were interfaced to the CPS system.

A computer serves as the CPS system’s processing unit. The computer has an Intel Corei7 CPU, 16 GB DDR3 RAM, 2 TB HDD & 2 x Nvidia GeForce GTX 650 TI. On the other hand we chose OpenCV, which is a vision library software with numerous algorithms, for image processing [3].

In order to implement the AR algorithm, a special plugin/library known as ARma was required.

AR gives an informative view of the world, and the main parts include a camera, a QR-Code [4] with hidden information and an image processing software/hardware to decode a QR-Code and detect the position of the code in real-time.

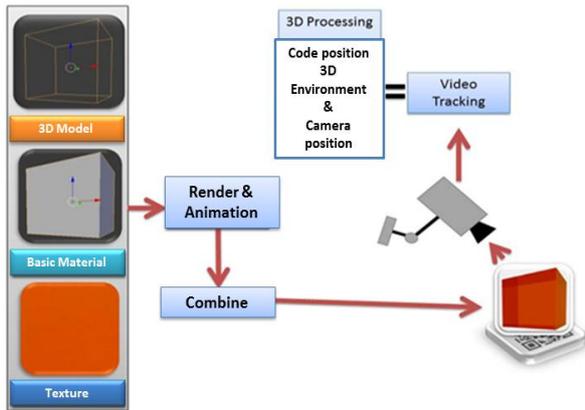


Fig. 1. ARma and OpenCV - working

The proposed AR system is require to track the motion of a point in a predetermined 3D coordinate system. Motion tracking involves the measurement of an object's velocity.

$$U = \frac{dX}{dt} = \left(\frac{dY}{dt}, \frac{dY}{dt}, \frac{dZ}{dt} \right)^T \quad (1)$$

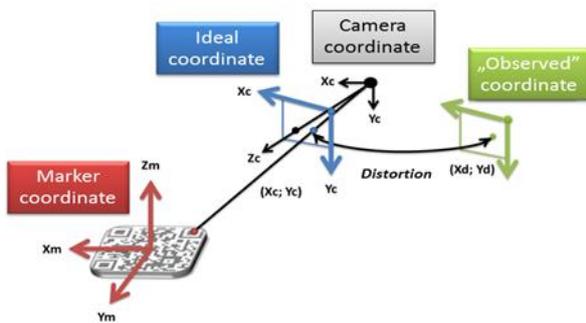


Fig. 2. Camera view & position detection of object

This is a rigorous method because first you need to design the 3D model in a 3D CAD software, and after it you need to decrease the polygon number of the 3D model. High polygon number values are computationally expensive. First we design all 3D models in a 3D CAD software, and after it with we decreased the numbers of the polygons to make our program run more efficiently [5].

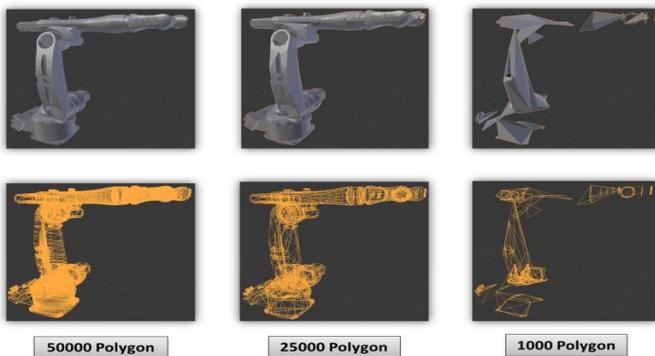


Fig. 3. Polygon reduction

The next step of our research was designing the AGV prototype. The AR AGV navigation system would include trajectory planning and tracking, as well as collision avoidance. The most important point of the robot is there are no sensors on the robot itself, it uses only the IP cameras of the robotics laboratory for trajectory tracking.

First, we designed the AGV concept in a 3D CAD modelling software and made a part lists with the necessary equipment [6].

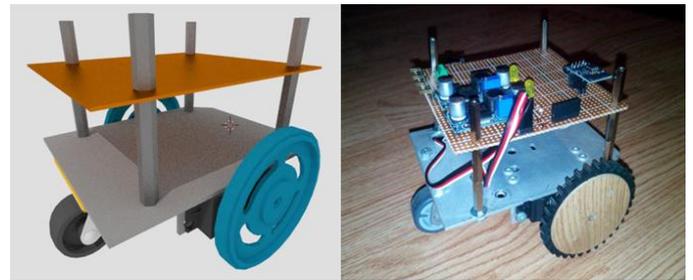


Fig. 4. AGV prototype robot

The core of the AGV prototype robot is an Arduino Nano, two LM2596 DC step down converter and an Wi-Fi-Serial module.

The weight of the robot with batteries is 483 grams. Two Li-Ion batteries were used for power supply, each providing 3.6 V voltage and 3600 mAh capacity.

Two rotating servomotors [7] were used for drive, which can deliver 0.27 Nm torque at 6 V power. The maximum current consumption of 200 mA each.

High battery capacity and the power consumption of the AGV prototype robot make long battery life. During the tests, depending on the operating speed and load, the continuous operation was 8 to 10 hours.

III. ROBOT LABORATORY AS AR ISOLATED ENVIRONMENT

The Robot Laboratory of the Building Mechatronic Research Center serves as an AR isolated environment, and is a member of the building's surveillance and security system network. Furthermore we can use the installed IP cameras as vision sensor owing to desktop pc which can store the recordings and strong enough to make CUDA based image processing/decoding [8].

Thus, it is possible to use QR-Code/Markers to place in the field of vision of the cameras, to identify their position. If the identification is done we can add other commands to the QR-Code/Markers to perform tasks.

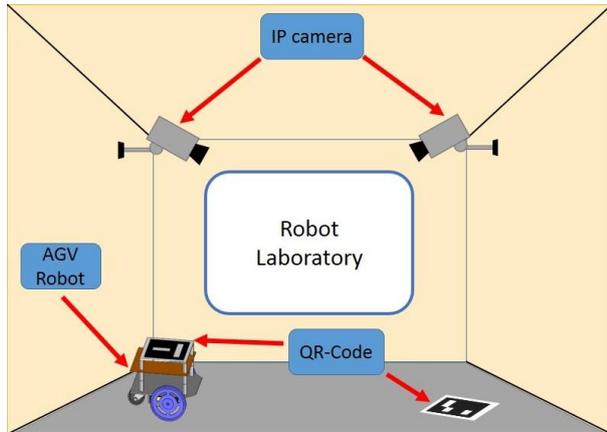


Fig. 5. AR isolated environment

The diagram shows the structure of the Robot Laboratory in a control task. The system consists of IP cameras and their QR-Code and the managed device. Images of IP cameras are processed by the central high performance computer.

On the controlled device, in our case the AGV robot, no detector is found, its position is determined by the cameras in the Robot Laboratory.

The IP cameras used in the Lab are type TCIP-LPro213WDRMDN and have the following parameters:

- Sony 1/3 „1.3 Mpx. Progressive Exmormtm CMOS sensor
- 1280x1024 (SXGA); H.264, MPEG4, M-JPEG
- Lux (Automatic Infrared LED Lighting below 2 Lux)
- 2D noise reduction and sensitivity enhancement
- Motion Detection and Alarm
- Two-way audio and multicast
- Built-in Aspherical Day / Night Lens (f3.8 9.5 mm)
- 12V supply voltage [9].

In addition, IP cameras are available on both levels of the entire Building Research Centre, whose images are available from the central computer and processed. This allows the AGV robot to operate in any part of the building if necessary [10].

After the designing and building of the AGV prototype robot we needed to test system's detection stability.

In that aspect we analysed the detection ability of all installed IP cameras in the Robot Laboratory. In this context we made measurements of the illumination which is the most important thing in detection.

The graph below illustrates the measurable illumination in the centre of the Lab depending on the number of lights on.

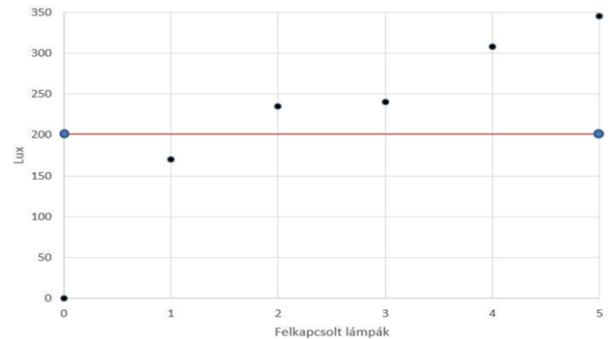


Fig. 6. Intelligent Space

Dimensions of the Robot Laboratory: width: 4.3 m; Length: 6.5 m; Height: 2.8 m.

The measurements have shown that there must be at least 200 lux above the exposure of the area, so that the TCIP-LPro213WDRMDN camera can detect the codes. The camera can see lower brightness but the image is not clear enough to recognize the code. In addition, in the absence of illumination, the camera will automatically turn on the infrared LED, which simply gives a black and white image and the infrared light shines differently from the different surfaces to the visible light, making it unsuitable for code recognition.

IV. AR BASED NAVIGATION SYSTEM

In the first part of our project we found a suitable place to test the system which was the robotics laboratory in the Building Mechatronic Research Centre. We designed the QR-Codes/Markers and printed it out in different sizes, and placed them in the right order to make the path for the robot.

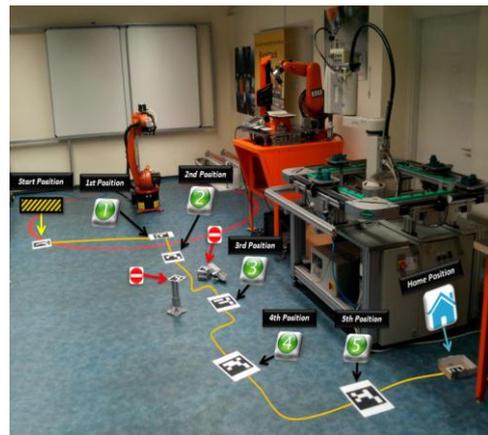


Fig. 7. Robot Laboratory as AR environment

The task of the AGV prototype robot is to leave the “Start” position go to the 1st position and wait until the KUKA KR5 goes to the position of the AGV and put on it the aluminium cube. After it reach the 2nd, 3rd 4rd, 5rd position and the Home position with the cargo. We printed a code for identifying the AGV’s orientation.

The distance between the positions, the time required to make the distance and the average speed calculated in the table below.

Table 1. Distance, time, speed values

Path	Distance [cm]	Time [s]	Speed [cm/s]
Start – 1	94	41.5	2.27
1 – 2	46	28.6	1.6
2 – 3	87	67	1.3
3 – 4	75	30.2	2.48
4 – 5	98	40.8	2.4
5 – Home	53	24.7	2.15

Distances have been determined by the software during route planning. The recording of time was determined by the time elapsed between touching the two targets.

There are differences between average speed values. The reason is the straight path, the applied algorithm simply determines the path and the robot moves without rotation.

For obstructions such as 2-3 routes, the algorithm bypass the path, and it must be included in the robot's path where the robot needs to rotate, which takes time and decrease the average speed.

The IP cameras of Robot Laboratory see the codes and streams data to the notebook via Wi-Fi. On the desktop computer, OpenCV and ARma recognizes the position of the code and decodes it, sends the information to the AGV prototype robot which plans and tracks the trajectory.

The RRT algorithm was used to design the route, which is the Rapidly-Exploring Random Tree, originally designed for humanoid robots to design motion. The RRT algorithm has advantage in many cases, provided a solution for 2D, 3D route planning.

The operation of RRT can easily be characterized, the algorithm grows from the initial configuration to "root" as a tree in the search space to detect the target configuration. If it cannot find a viable route, it will continue to search in the open space, while taking into account the criteria (barriers, limits, etc.). The size of the "roots" can be determined by the growth factor. The RRT algorithm will continue to search until it find the optimal path between the start and destination configurations.

In the first test we launched/programmed the KUKA KR5 industrial robot manipulator with our electronic PCB, the TiMo board, to control the robot's gripper. Furthermore we established a new Wi-Fi network with a TP-Link router to make the Wi-Fi signal stronger in the Robot Laboratory it was very important because we sent all signals trough Wi-Fi and we wanted to avoid the lag of the stream of the mobile phone.

For the first time we noticed lag in the Desktop computer, fortunately we could set the dedicated Nvidia graphic card to calculate instead of the core i7 CPU which was slower in this instance.

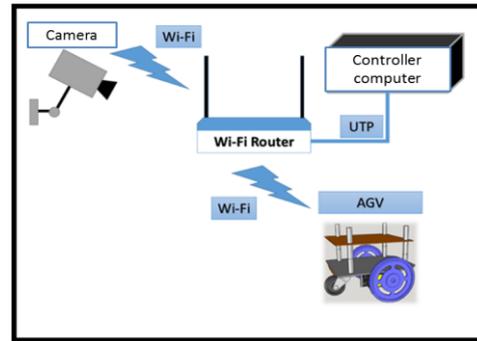


Fig. 8. Network communication system

When we began the first test, the AGV prototype robot was in the "Start" position and after it the AGV started to go to the 1st position and waited there until KUKA KR5 moved to the AGV position and opened the gripper to put the steel cube on the AGV. The next step was to reach the 3rd position marker and avoid the collision with the other objects. To realize this we made codes with other 3D models and we set the ARma a distance away from the other objects, and the AGV could avoid them during the motion. When the AGV reached the HOME position it stopped.

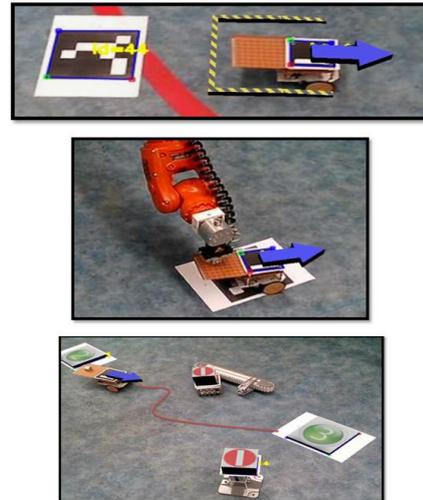


Fig. 9. AGV Prototype first test

The project task required the re-creation of the KUKA KR5 gripping system to be suitable for material handling. To the end a Japanese, Humphrey H040-4E2 type pre-driven electro-pneumatic bistable valve has been selected, which runs from 2 to 7 bar and 24 volts [11]. The control valve was installed into a gripper GRIP GmbH. To control the gripper, a self-developed control system has been used, the TiMo Board, which is suitable for controlling industrial pneumatic/hydraulic valves, has already been proven to control smaller production line cells [12]. The structure of the TiMo Board is shown below.

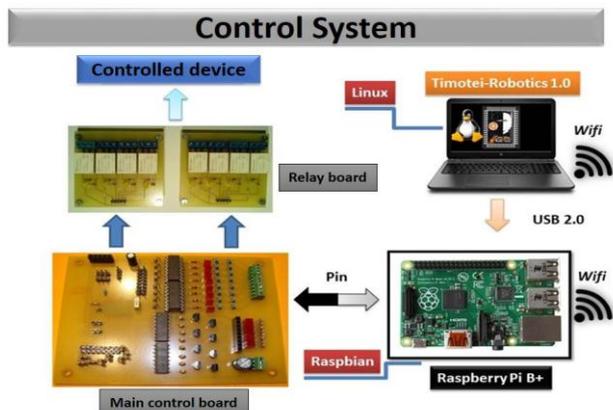


Fig. 10. Programmable Control System – TiMo Board

The TiMo Board is designed to be networked and managed, it is possible to program and supervise the Industry 4.0 / IoT considerations. The other part of the TiMo board is Raspberry Pi B+ minimized desktop computer [13] and the Timotei-Robotics Linux distribution Os which was installed on it.

When programming the control panel (TiMo Borad), the program is written on the Timotei-Robotics Os, in standard PLC ladder diagram. The TiMo board control panel has been installed in the pneumatic gripping electric circuit of the KUKA KR5 industrial robot.

V. AR APPLICATION AREAS & DEVELOPMENT

In the first part of our project we tested the AR based navigation system successfully, but there are many other ways to use QR-Codes and AR technology in development or in education.

In the industrial robotics laboratory we installed robots of various types. Maintenance can be of these robot are relatively difficult, because we need to register all robots. In this aspects we collected all datasheet, uploaded to our private network system and we embedded them into QR-Code. The core of the private network system is a Raspberry Pi mini desktop computer, which has Raspbian Linux distribution system and a 64GB SDHC card. When someone need information about the robot in the robot laboratory he have to decode the QR-Code and in that moment we receive a notification that someone decoded one of our dynamic QR-Code and we can see on diagram which code have been decoded.



Fig. 11. QR-Code decoding - monitoring

On the other hand we can use the QR-Code as AR marker in order to visualize the position of axis of KUKA KR5 or set position in the workspace of the robot dynamically.

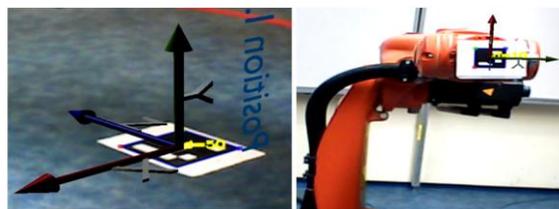


Fig. 12. AR code to set position & axis visualization

The AR technology is also able to test standalone systems and items. We developed a gripper to KUKA KR5, we reduced the polygon number of it and mounted “virtually” on to the robot arm.

Furthermore the codes can be established interactive connection between each other.

In one of our tests we used another marker which consist of a column 3D model.

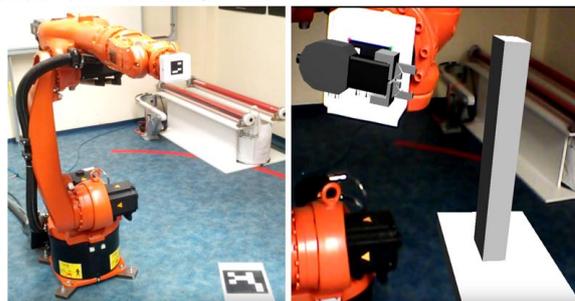


Fig. 13. Virtual AR items

When we moved the real KUKA KR3 with the virtual mounted gripper and it could push away the virtual column.

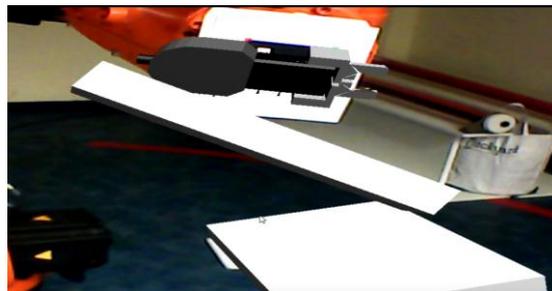


Fig. 14. Virtual collide

VI. CONCLUSION

The Augmented Reality technique is potentially effective because we can set up a firewall system protecting information embedded in the codes. Furthermore we can encrypt commands for robots as we did to command a prototype AGV. Moreover we can upgrade the robots virtually and perform tests for collision avoidance, gripper replacement testing, etc.

During the tests we used GPU image processing, because the integrated VGA is not able to calculate fast.

Unfortunately we can clearly say for these tests we had to use a relatively fast processing computer because it is computationally expensive.

The system we create does not only recognize QR Code in read-only information, but can also recognize these codes as so-called Markers that can represent the status/position of an AGV robot or the axis of robot arms. This has enabled AGV robot to control and the attachment of virtual AR devices to physical machines.

The AR based navigation system to AGV is fully autonomous and no human intervention is required.

The AR technology recommend huge knowledge in 3D modelling, polygon reduction and image processing.

Further improvements are underway to enhance these areas of application.

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