Design and Development of an Automated Guided Vehicle

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Abstract– **This paper reports on the development of the Automated Guided Vehicle (AGV) *Hellenak* that it is manufactured at the Machine Tools Laboratory of the Technical University of Crete. It has been designed with the use of parametric technology. The size of the model was 1.2 meters long and 0.7 meter wide. Vehicle's load capacity is 200 Kg and volume capacity exceeds the 1 m^3. *Hellenak* has a four wheel kinematics architecture (two powered wheels and two castors). A PC on board using Microsoft Windows operating system is controlling the vehicle. It can be controlled via Ethernet link from a remote terminal. Currently, it is equipped with two odometers and seven optic-electrical distance sensors, two digital cameras, four analog outputs, fourteen analog inputs and many digital inputs-outputs. *Hellenak* is able to move straight, make turns and spin around it's center of movement, even when loaded. A real time path-planning algorithm has been created to test the motion accuracy of the vehicle under development.**

1 Introduction

Automated Guided Vehicles (AGVs) are one of the most exciting and dynamic areas in material handling today. AGVs are driverless computer-remote-controlled mobile robots that operate automatically along pathways with in-floor wiring, fluorescent stripes, optical scanning of various markings or other navigation solutions. Through the years the technological developments (mainly in electronics and robotics) have offered AGVs several advantages over other material handling systems, such as, routing flexibility, reliability, low operating costs, unobstructed movement and easy integration with other systems. The variety in configurations of AGVs is endless and virtually any type of mobile material handling equipment can be converted to an AGV.

In the past decades, much research and many papers have been devoted to the technology of AGV systems [1], [2]. Hundreds of AGVs have been manufactured around the world, currently used in various material handling tasks.

In this paper, we describe the development of very low cost driverless vehicle, named *Hellenak* that can be used for material transportation within production systems. Section 2 presents the design and the maximum load estimation of the vehicle's chassis. The material used to manufacture the frame of the prototype, is also presented in this Section. Section 3 comments on the electrical installation of the vehicle. The kinematics together with the developed software for interfacing and control are briefly presented in

Section 4. Conclusions and future studies can be found in Section 5.

2 Frame Design

Hellenak's frame was designed with the use of parametric technology. Parametric modeling resulted in alternate draws and rendered views and gave flexibility in designing various aspects of the vehicle. Extensive stress analysis gave the final form of the chassis, which is shown in Figure 1.

The frame is built from 3mm thick, squared cross-section, aluminum profile. It has a 4-wheel kinematics architecture, with two powered wheels and two castors. The frame is 120 cm long, 70 cm wide and 58 cm high (Fig. 1). The powered wheels protrude from the main frame resulting more accurate turning.

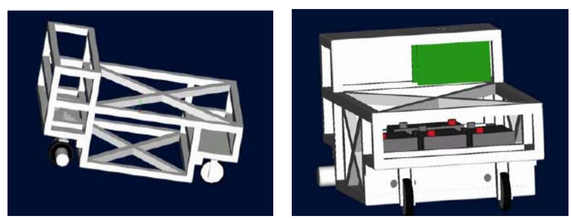

Fig. 1: *Hellenak*'s frame design.

There is a main loading surface that can handle heavy loads. All the electrical and electronic hardware can be installed in the interior of the vehicle. This way, sensitive equipment is protected from external affects and hazardous environmental conditions. This is a necessity in order the machine to able to work in most industrial environments. We note also that the space available for batteries is isolated from the space dedicated for electronic circuits, to avoid interpolation to these circuits from the magnetic field created around batteries in power.

A static analysis is conducted, in order to validate the strength of the aluminum structure. Specifically, the model of the structure is tested, in different loads, in order to estimate the limits of the design. Our main concern is to find out if the yield limit of the material used is exceeded and plastic deformations are developed.

For the estimation of the stresses developed, the ANSYS specialized Finite Element Analysis (FEA) program is used. Finite Element Analysis is used more and more in the development of new products, providing the

manufacturers low cost redesign and optimization times [3].
For this type of analysis, once the geometry model has been created, the lines, surfaces and solids can be meshed (discretized) to create the beam, shell or solid elements. The type of elements used, depend on the type of the problem to be solved and on the design of the structure. Thus, in this case, the mesh of the model (Fig. 2), consists of shell elements with a thickness of 3 mm which can simulate satisfactory the structure. The type of material is a linear isotropic model, simulating the 6060 T5 Aluminum used. The parameters of the material, are: Poisson's ratio: 0.33, Elastic Modulus: 68900 N/mm^2, Minimum Yield Strength: 145 N/mm^2.
Two constraints of 6 degrees of freedom are placed at the bottom of the structure, where the wheels mount. This represents the static situation where the structure is still and rests on the wheels.

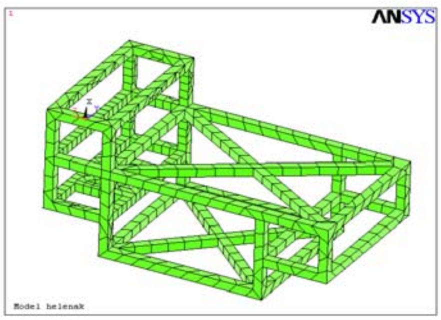

Fig. 2: Meshed model of *Hellenak*.

The loading conditions are three. Firstly, a uniform pressure of 1000 Kg is distributed along the upper surface of the structure (main loading surface). For this loading case the results obtained by the FEA program, showed satisfactory reaction of the structure, with stresses reaching a maximum value of 67.43 N/mm^2. In figure 3 a plot of the stresses developed is shown. At the bottom of the picture a color contour is used to represent their values. Since stresses do not exceed the yield limit of the material, the structure can withstand this load.
In the second loading condition, a concentrated load of 500Kg is applied in the middle of the structure main loading surface, exactly where the two bars creating an X, intersect. In this case the analysis has revealed that the stresses found are again lower than the yield strength reaching the value of 69.15 N/mm^2 (Fig. 4).
In the third and last loading condition, two loads of 250 Kg are placed in the side of the structure. Also, in this case no problems arise since the maximum value of stress reached is just 8.18 N/mm^2 (Fig. 5).
For the analysis presented, the stresses are computed using the Von Mises criterion [4], which takes in account the stresses in all directions (*x*, *y*, *z* axes).
Concluding, the analysis has verified that this construction can withstand much bigger loads than firstly considered (more than 1000 Kg) and the only limitation on this comes from the power of the rotors moving the wheels.

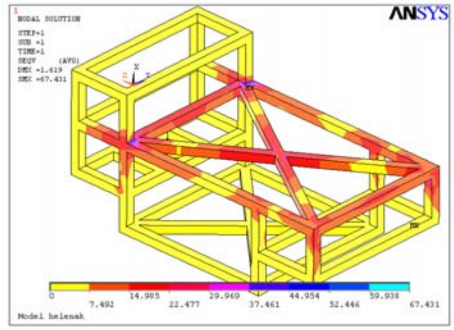

Fig. 3: Stresses found for the first loading case of the structure.

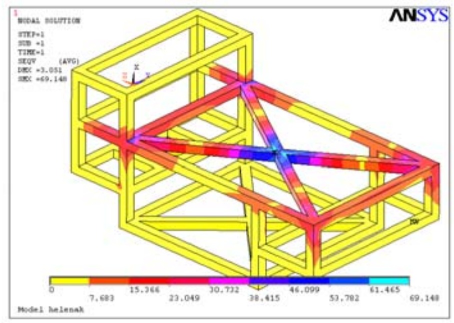

Fig. 4: Stresses found for the second loading case of the structure.

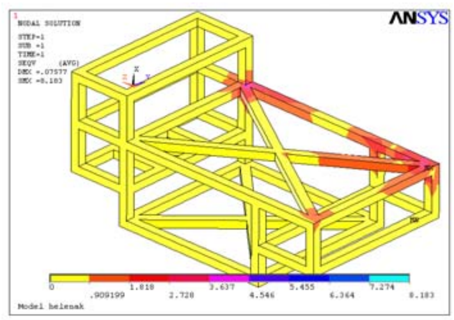

Fig. 5. Stresses found for the third loading case of the structure.

The prototype was manufactured by square aluminum profile as suggested by the design. The luck of reinforced aluminum profile in the local market imposed the use of aluminum profile with thickness of 3 mm. For the investment of frame is used 2 mm stainless sheet metal. In a certain area, close to the batteries is used perforated iron, in order to create better ventilation for this area. The loading surface, as well as the space where the batteries are located, is covered with reinforced sheet metal that strengthens the static sufficiency. The freely turning wheels installed are constructed to curry bear load of 250 kg each. The manufacture took place in the Machine Tools Laboratory of the Department of Production Engineering and Management at the Technical University of Crete, Greece. The time needed for the manufacture didn't exceed 20 labor hours and the overall cost was less than 3,000 euros.

3 Electrical Installation and Motors

The electric energy needed for the electrical and electronic devices comes from two batteries in series. Each battery outputs 12V voltage and has about Ahr capacity. The most common voltage inputs used from the devices of *Hellenak* are 5VDC, 12VD and 24VDC. There also devices that use cable power supply of 220VAC. For this certain devices is used a UPS that converts the DC output of the batteries to AC input. A second important function of the UPS is to provide stable power supply for the electronic circuits. The batteries chosen provide no topping-up throughout battery life, high energy density, compact arrangement and long life of use.

The motors used in *Hellenak* have been taken out from a *TRC Labmate* mobile robot. They have a rubber wheel attached on them and operate with 22-24V voltage input supply. In maximum torque they consume 9 Amps (Fig. 6). For each motor is used an H-Bridge driver for *Devantech Ltd*. There were no data from the manufacturer of the motors, and since the wheels where attached on them, as mentioned above, we had to experiment to find out if the motors can handle the desired loading capacity of 250Kg. A series of experiments were conducted with success.

Fig. 6: *Hellenak*'s motor installation

4 Kinematics and Control

In order to achieve open architecture and be able to experiment with different programming languages and user interface environments we used, instead of a typical controller, a computer unit. The computer unit is placed inside the robot frame. The computer unit communicates with the output devices through RS-232 and USB ports. The same ports are used for feedback signals from the input devices (Fig. 7).

The need for connecting multiple devices in few ports imposed the use of controlling cards. We use two U12 controlling cards manufactured from *Labjack Co.*. They are USB-based measurement and automation devices which provide analog inputs/outputs, digital inputs/outputs, and more. They serve as an inexpensive and easy to use interface between the computer unit and the physical world. Totally there are installed in *Hellenak* more than 30 terminal Inputs/Outputs, both digital and analog. There is a first order low-pass filter on each analog output with a 3dB frequency around 22 Hz, that help us to control our devices in real time.

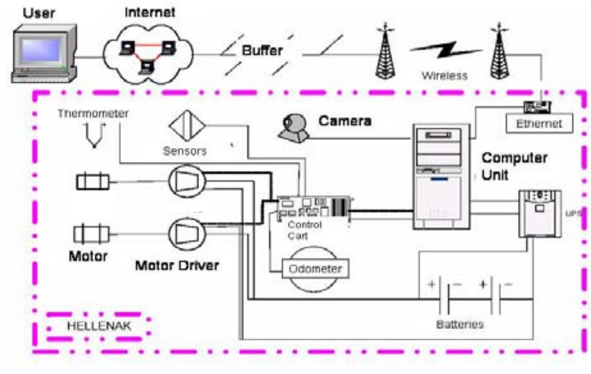

Fig. 7: *Hellenak*'s functional diagram

The computer unit communicates with the out world through a wireless Ethernet link. The link base is connected to the internet and has its own IP address. In this way we can establish a connection from remote terminal to *Hellenak*. We can inspect the function of the robot, give orders to it, fix errors and get feedback from the working space. In an industrial environment the link can be used for interaction with other devices.

The sensors installed on *Hellenak* are used for motion feedback. There are 2 HP Heds 9000 odometers, 7 photoelectric sensors and a digital camera. There is the option to install more sensors, digital and analog, on the current system without changing the architecture. There also exists the infrastructure for adding more actuators in the system. These actuators can form for instance a manipulator moving items on and off the platform.

The vehicle *Hellenak* has kinematics architecture of four wheels (Fig. 8). The two rear wheels have common axis of movement and are attached in the motors. The two front wheels are turning freely and have in their initial position common axis too. The movement comes from the rare wheels and the turning from the difference between the velocity vectors of these wheels.

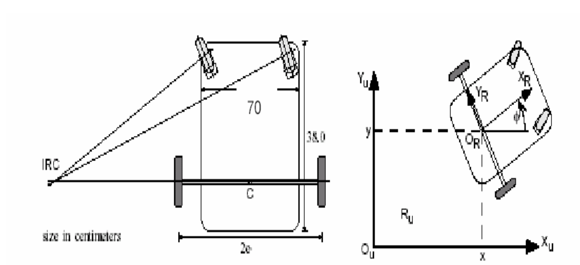

Fig. 8: The kinematics architecture

The position vector is

$$X = \begin{bmatrix} x \\ y \\ \phi \end{bmatrix} \quad (1)$$

where

$$x = \frac{(v_l + v_r)}{2} \cos \phi$$

$$y = \frac{(v_l + v_r)}{2} \sin \phi$$

$$\phi = \frac{(v_l - v_r)}{2e} \qquad (2)$$

There have been developed two software systems, the user interface and the algorithmic.

The user interface software, presented in Fig. 9, is a platform that enables manual guidance of *Hellenak*. It is a user friendly environment that works under Microsoft's Windows and sends data to the vehicle through a wireless Ethernet link (Fig. 9). It has a digital joystick input that translates the position of the joystick to speed in the motors. The software controls both the magnitude and the direction of the velocity vectors. The robot can turn, move forward and backward. The user has image feedback from the workspace and the speed of each motor. In this way *Hellenak* can be guided through non-friendly for humans' environments successfully, by non specialized users.

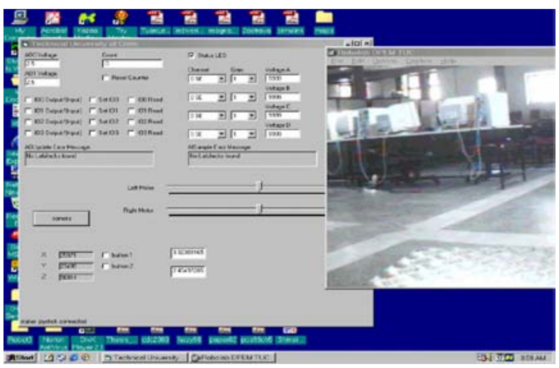

Fig. 9: User interface software

The second software system is a set of functions created in Mathwork's Matlab that move *Hellenak* in real time. The input to this functions is the distance, the direction and the velocity we want the vehicle to move. Their control is being done arithmetically by solving the kinematics equations. Most of these functions can be used to test algorithms or can be used to create a motion controller for *Hellenak*. There have been created similar algorithmic functions in other programming platforms, such as C, C++, VB, and LabView, so that users familiar with these platforms can experiment with their algorithms.

5 Conclusions

A series of experiments conducted show that *Hellenak* satisfies the initial specifications. It can move and turn a mixed load of over 200 Kg when operated from distance. To verify the above we created a real time mapping algorithm. In figure (Fig. 10) are showed curve motions of the vehicle.

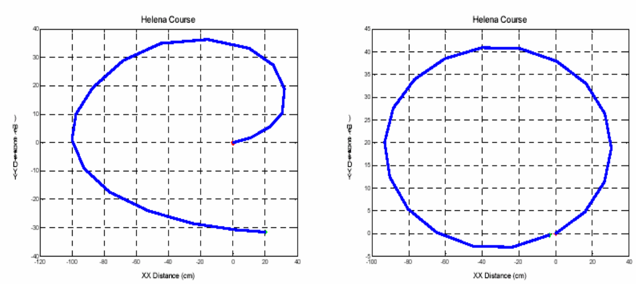

Fig. 10: *Hellenak*'s course figures

The frame of the vehicle is easy to make and can successfully handle heavy loads.

The batteries can provide the system with energy for about 2 hours, time that is enough to conduct experiments. If the vehicle is going to be used within industrial environments the need for more efficient energy supply system is obvious.

Important feature is the open architecture that allows more sensors to be installed, depending on the application, and the many options in programming the function of the system from several programming languages and environments. In this way *Hellenak* can be adapted and used in different tasks, without the need of special train for the user.

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