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KERVEROS I: An Unmanned Ground Vehicle for Remote-Controlled Surveillance

Panayiotis Fofilos (2nd Lt, HAF)[1], Kyriakos-Isaak Xanthopoulos (2nd Lt, HAF)[2], Emmanuel-Athanasios Romanos (2nd Lt, HAF)[3], Konstantinos Zikidis (Maj, HAF)[4], Nikolaos Kanellopoulos (Maj, HAF)[5]

Abstract.

Recent technological advances have made possible the development of Unmanned Ground Vehicles (UGV), which are able to perform various tasks efficiently, such as patrolling and surveillance, sparing human resources. In fact, a UGV is a perfect candidate for patrolling missions, since it can provide enhanced mobility, endurance and surveillance capabilities, day and night and in adverse weather conditions. In this way, it can be used to ensure the security of various areas such as military facilities.

Following these principles, a UGV prototype has been constructed, operating on electrical power and receiving commands via remote control software from a computer, featuring a surveillance IP camera. It is based on a simple tricycle chassis and it is powered by a high capacity automotive battery, which provides adequate power for several hours of use. An electric motor moves the vehicle quietly and

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[1] Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Force Base, Attica, Greece
E-mail: fofilos@hotmail.com
[2] Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Force Base, Attica, Greece
E-mail: kyr89@hotmail.com
[3] Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Force Base, Attica, Greece
E-mail: ManosR34@gmail.com
[4] Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Force Base, Attica, Greece
E-mail: kzikidis@cs.ntua.gr
[5] Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Force Base, Attica, Greece
E-mail: nskanell@googlemail.com

efficiently, while the vehicle motion controller is connected to a small on-board laptop, receiving commands via Wi-Fi. The combination of a common 12 Volt battery and the electric motor provides a reliable and relatively low cost solution to the UGV mobility issue, minimizing maintenance requirements.

The vehicle is equipped with an IP camera, which transmits real time image and sound via Wi-Fi. Using some IR LEDs, it can also see at night, up to a certain distance. Both the UGV and the camera can be remote-controlled, using a web-based interface.

This prototype is proposed as a basis for further development. The construction was deliberately kept as simple as possible, allowing for future upgrades and keeping the development cost low.

Keywords: Unmanned Ground Vehicle (UGV), IR camera, remote control, surveillance.

1. Introduction

The current state of research and the continuous improvement of technologies related to the operation of unmanned vehicles, have made possible the development and operational use of such vehicles for military use, operating either on the ground, in the air or at sea and even underwater. An Unmanned Ground Vehicle (UGV) is a vehicle operating in contact with the ground, carrying equipment or materials and supplies, without human presence on board.

The word "robot" was coined almost one century ago. The concept of robotics has also a long history of several decades. However, the concept and development of UGVs and their relationship with robotics is a relatively recent development, although recorded examples of such vehicles can be traced back to the '30s, when a Japanese officer, Capt. Nagayama, managed to operate a remote-controlled small armored tracked vehicle. UGV development continued through WWII and accelerated during the Cold War.

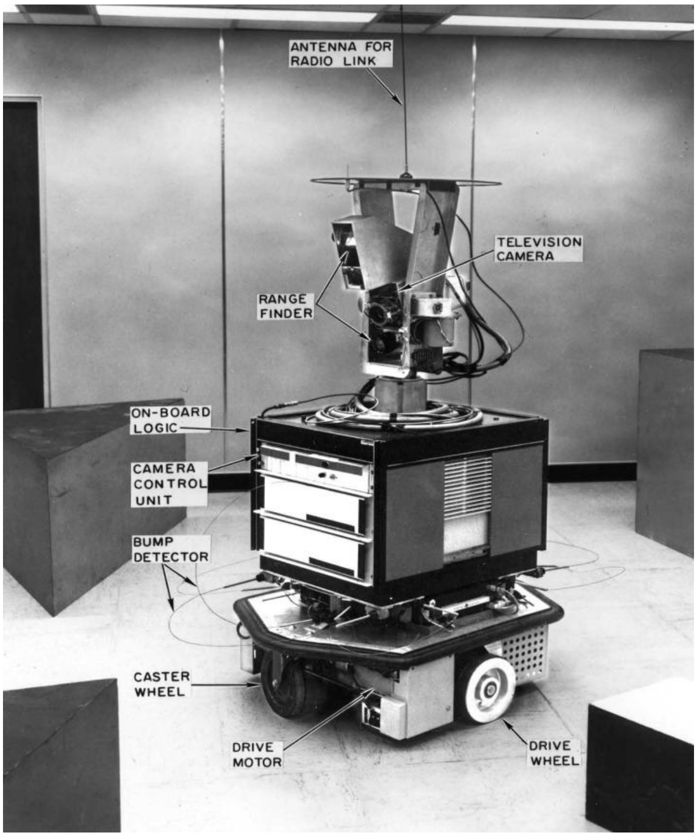

Figure 1. Shakey the robot. Probably the first mobile robot. It was developed at the Artificial Intelligence Center of Stanford Research Institute (now SRI International), from 1966 to 1972 ([1]).

Nevertheless, the first major effort to develop a UGV and the first appearance in its modern form, took place in late '60s, with the creation of Shakey the robot. Shakey was created in the research department of Stanford University by the division of artificial intelligence of DARPA (Defense Advanced Research Projects Agency). This was a wheeled vehicle equipped with a moving TV camera, an ultrasonic range finder and contact sensors, linked with RF link to the main computer, which performed navigation and exploration ([2]).

What advantages does a UGV offer in the modern battlefield and what functions can be performed? A UGV can be an excellent moving platform carrying sensors that perform surveillance, target detection and identification. A UGV can operate in an environment that is particularly risky or even lethal for personnel, performing tasks such as enemy identification within residential areas, minefields neutralization or explosives disposal. It can also perform combat support missions such as the transfer of soldiers' personal equipment, medical evacuation, supplies and ammunition transportation. The scope of the proposed vehicle development is the surveillance of military installations. UGVs provide enhanced surveillance capabilities, minimizing the numbers of security guards and the exposure of personnel to any hazard.

2. UGV Categories

Depending on the degree of control (capability class), the categories of UGVs can be defined as follows ([3]):

1. **Teleoperated ground vehicle** (TGV): The control of the vehicle is entirely dependent on a human operator. Sensors and the communication system provide the operator with the image of the surrounding environment in order to transfer to the vehicle the appropriate commands. The proposed UGV, Kerveros I, belongs to this category.
2. **Semi-autonomous proceeder-follower** (SAP/FUGV): These vehicles are designed to either follow or precede the combat units. Especially in the latter case, the vehicle must be equipped with an advanced guidance system to minimize the control requirements by the operator.
3. **Platform-centric autonomous ground vehicle** (PCAGV): Fully autonomous vehicle entrusted with a mission, collecting information from other platforms and perhaps by the operator.
4. **Network-centric autonomous ground vehicle** (NCAGV): The level of autonomy of the vehicle allows operation in conjunction with other vehicles embedded in a Network Centric System.

Figure 2. The well known QinetiQ North America's (ex Foster-Miller) TALON. Initially deployed in 2000, the TALON family of robots has been widely used for various tasks, such as improvised explosive device (IED) and explosive ordnance disposal (EOD), reconnaissance, communications, CBRNE (Chemical, Biological, Radiological, Nuclear, Explosive) missions etc ([4]).

The future technological challenge lies undoubtedly in the pursuit of increasing autonomy of UGVs. It should be emphasized that the successful design and operation of a UGV depends largely not only on the development of the corresponding technologies, that should cover several different disciplines, but primarily on the ability and successful introduction and integration of these technologies into the same platform. The variety of technologies includes, without limiting to, navigation systems, communications systems, power supply systems and power engineering, various types and classes of sensors, fault diagnosis, and also weapon systems, which should be operated and reloaded without human intervention.

3. KERVEROS I UGV Design / Construction

The present approach began as a project in the frame of an undergraduate thesis. The scope is the design and construction of a UGV, which is electrically powered, carries a surveillance IP camera and receives commands via remote control software run from a laptop, for purposes of surveillance of a military air base or other military installations. The UGV should be able to move outdoors, in normal roads with small bumps, offering sufficient range and autonomy. The aim was to come up with a functional vehicle, which would be used as a prototype for demonstration, evaluation and testing of various subsystems and further upgrades. Following these guidelines, a tricycle design was chosen, which is more simple and easy to construct than the standard four wheel approach, while it can be used without a differential and a suspension system.

Figure 3. The Guardium Mk I by G-NIUS, an example of a modern semi-autonomous surveillance vehicle. It is operationally deployed by the Israeli Army ([5]).

The mechanical parts involve the chassis, the power transmission, the steering system and the wheels. For the chassis, two galvanized steel rods of approximately 2 m were used in the longitudinal direction, with a cross section of 3 cm by 5 cm and thickness of 1,5 mm, along with a number of transverse beams. The battery and electronics support were placed between the two longitudinal steel rods, in a way to keep low the center of gravity. The DC motor support was fixed to the aft beam connecting the two rods. Two bearings were adapted to the rear ends of the two rods, housing the rear axle (length: 106 cm, diameter: 2 cm). A sprocket gear with a diameter of 8 cm was welded in the middle of the rear axle. The power is transmitted from the DC motor by a roller chain to the sprocket gear and the axle.

The upper part of the steering column is connected to the steering servomotor and the lower part ends at the steering wheel. The steering column is connected to the chassis using two bearings, in a way to obtain a caster angle of 8°, offering the ability of getting the vehicle back on the straight course when no steering torque is applied.

The power source used is a high capacity 12 Volt lead-acid automotive battery of 100 Ah. The main motor operates on DC at a voltage from 12 to 24 Volts, offering a maximum power output of 250 Watts and 2750 rpm. The main DC motor can operate at both directions, so it may act as a brake. The electrical parts include also a high-torque, analog servomotor, for the steering system, connected to the upper end of the steering column, operating at 4,8 to 6 Volts and offering up to 24 kgr · cm of torque.

Concerning the electronic parts, the "heart" of the control system is the main control board *Arduino Uno*, a low-cost board commonly found in remote controlled applications. It is based on a microcontroller running at 16 MHz, which can be connected to a PC via USB and programmed in C language. It offers several I/O connections, both digital (using Pulse Width Modulation) and analog. Several add-on modules can be connected to this board, offering features like Wi-Fi communication, GPS, various sensors etc, as will be discussed later.

Figure 4. Kerveros I chassis with wheels and battery. The main DC motor can be seen just behind the battery.

The main control board provides sufficient output power to handle the analog servomotor of the steering system, which is directly connected to one of the analog outputs. However, the main DC motor used for the vehicle movement cannot be handled directly by the main control board, which operates at 5 Volt DC. Therefore, a polarity control board is used, which acts as a power switch, controlling the DC motor voltage at ±12 Volt (in both directions), according to the commands of the main control board. Needless to say that some voltage converters are required to provide 5 Volt DC from the 12 Volt supplied by the battery.

The primary equipment of the vehicle is a wireless IP camera, providing day and also night vision, transmitted through Wi-Fi (or ethernet). The camera employed in our case was one of the *Foscam* family, offering VGA or QVGA resolution, and also the possibility of horizontal and vertical rotation, providing sufficient coverage even when the vehicle is stopped. There is a ring of 10 IR LEDs surrounding the lens, offering night vision up to 8 meters in complete darkness. Also, there is a loudspeaker and a microphone, allowing two-way communication with someone who is near the vehicle. The camera is connected to an existing Wi-Fi network and can be accessed and controlled using an internet browser.

For the movement control of the vehicle, a special code in C was created and loaded on the main control board. In order to connect the main control board to the Wi-Fi network, a small netbook was employed. For the control of the vehicle, *Team Viewer*, a free software commonly used for remote access through internet, was loaded on both the on-board netbook and also on the laptop used as control station. In this way, by pressing certain keys on the control station laptop, the relevant commands are transmitted through internet, using the existing Wi-Fi network, to the on-board netbook, which by its turn transmits them to the main control board through USB connection.

Figure 5. The steering wheel column, fixed with the help of two bearings on the front end of the chassis. The analog servomotor used for steering is connected to the top of the steering column.

During field testing, the vehicle was able to move at the speed of 10 km/h, the turning radius was 2,2 m and it was able to overcome obstacles up to 15 cm. The current consumption was 2,5 A at idle, 8,5 A when cruising and 18 A during acceleration. A conservative approach would yield an autonomy of 3,5 hours. Please note that in the current configuration, the netbook uses its own battery, limiting respectively the system autonomy.

The total expenses, including vehicle parts supply and labor cost, reached approximately 900€. In other words, the objectives set were met: a remote-controlled vehicle was built at a relatively limited cost, exhibiting sufficient movement capabilities and carrying on-board electronic equipment (an IP camera). The purpose was not to come up with a UGV with full operational capability but a demonstration vehicle which could be used as a test bed, allowing experimentation with various technologies.

4. Possible Upgrades – Future Work

Possible modifications – upgrades which will be studied in the near future are the following, starting with the electronics, which would be more easily upgraded:

– Use of a GPS module, as a low-cost means to acquire the position of the vehicle, with acceptable accuracy, at least during open-door movement.
– A low-cost inertial navigation system (INS) can be combined with the GPS module, providing accurate position reference (in the short term), even in-doors. However, due to the unavoidable error accumulation on the position estimation, the INS requires correction at certain time intervals by some more accurate means, like GPS.

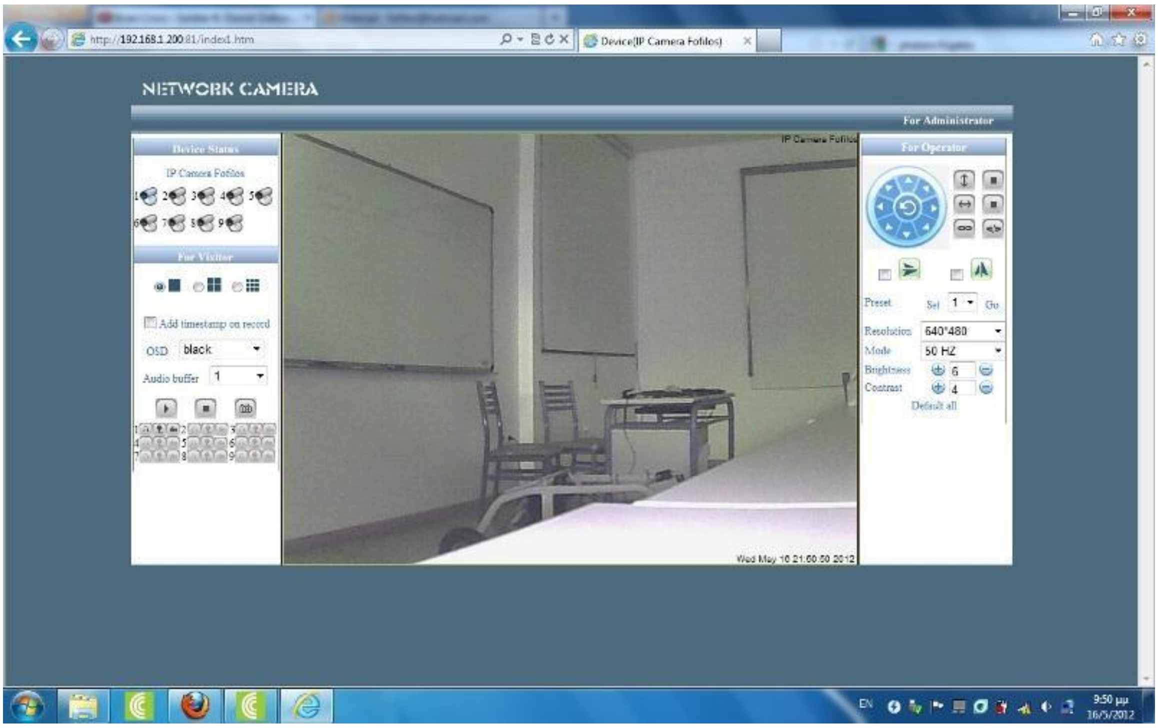

Figure 6. The camera web interface. The camera is looking at Kerveros I, before being installed on it. The snapshot is from a HAFA classroom, in complete darkness, with the help of the 10 IR LEDs surrounding the lens.

– An important upgrade, is the use of an ultrasonic sensor ring, which, with the help of appropriate software, would provide local navigation and obstacle avoidance capabilities [6][7]. In other words, the operational usage of the vehicle, in its present form, is limited, because a person is required to actually drive the vehicle by remote control, using visual information provided by the camera. The addition of navigation and obstacle avoidance capabilities would allow autonomous vehicle movement, without the need of human engagement, while the camera will be exclusively used for surveillance purposes. Such capabilities, combined with INS/GPS, would allow the vehicle, e.g., to follow a predetermined path for patrol. In this way, the proposed system will become a mobile robot, able to perform autonomously some simple tasks.

- A further upgrade would be the incorporation of a LIDAR system, for more accurate knowledge of the surrounding environment.
- There are some specialized modules available for the *Arduino* main control board, e.g., the wireless communication board *XBee*, utilizing the IEEE 802.15.4 communication standard, which would permit secure communication between the vehicle and the control station up to several kilometers, without the need for a netbook. However, a Wi-Fi infrastructure may still be required for the camera transmission, if the relevant audio/video stream cannot be handled through the specialized communication channel.
- Other available modules are special sensors, such as temperature, pressure (barometer), dangerous gas, smoke or fire sensors, which can be easily added to the main control board, transforming the UGV to a forward operating probe.

Figure 7. The Gladiator TUGV (Tactical UGV), developed by the National Robotics Engineering Consortium of the Robotics Institute of Carnegie Mellon University, in partnership with BAE Systems, for the US Marine Corps [8]. Equipped with cameras, GPS,

RF link, etc, and also with a machine gun, grenade launchers or even an obscuration smoke system, it is considered as the first armed UGV.

- Possible upgrades concerning the electrical parts would be the use of a more advanced battery and the power supply of the netbook (if needed) by the main battery through a specialized voltage converter.
- There are some mechanical upgrades under consideration, even though the related cost would be considerable. E.g., the use of a suspension system (with springs and shock absorbers) and of a differential system for the rear axle would offer considerable capabilities concerning the movement and maximum speed. On the other hand, such modifications would involve a radical redesign of the vehicle.
- Concerning the operational exploitation of the vehicle, the installation of some kind of weapon should be considered, like a small assault riffle or a submachine gun, possibly using a dedicated camera for targeting. In any case, the view of an armed UGV by a potential unprepared intruder, asking him to surrender, will at least put a stress on him, or even lead him to obey, presuming extreme firing power and targeting capabilities of the vehicle.
- The on board armament/equipment could also include a mortar or grenade launcher, a Light Vehicle Obscuration Smoke System (LVOSS) or also a robotic arm, for dealing with potential explosive devices.
- One of the most dangerous threats for aircraft are MANPADS (MAN Portable Air Defence Systems), which are shoulder-launched surface-to-air missiles, like systems of the Stinger family and their eastern-made equivalents. Such systems could engage and shoot down fighter aircraft during the take-off phase, when they are vulnerable (low altitude, low speed, full AB – high IR signature). A UGV could help counter MANPADS by carrying a MAWS (Missile Approach Warning System) and also a flare launcher. In this way, the vehicle could patrol in or around an air-force base, and start launching flares either if a SAM (Surface to Air Missile) were detected by the on board MAWS, or just before an imminent take-off, protecting in this way fighter aircraft taking-off from being targeted by MANPADS devices.

- Finally, the case of a suicide mission could also be considered, where the vehicle would be loaded with explosives and guided close to the enemy lines, in order to cause casualties and havoc.

5. Conclusion

Unmanned Ground Vehicles have drawn considerable attention during the last years. Several systems are being developed independently, in many countries, at various universities, private companies and military research institutes. UGVs started as simple remotely operated vehicles and now are moving gradually to the autonomous mobile robot domain. In any case, they can relieve humans from hard, difficult, dangerous, delicate or maybe boring tasks. Taking into account that research and development in the UGV area involves also (or mainly) military interest, it becomes evident that the progress made may have advanced much more than what it is publicly known.

In this context, a functional remote-controlled vehicle has been constructed, following a low-cost approach, able to move outdoors and carry electronic equipment such as an IP camera. It is a simple tricycle design, using a standard 12 Volt automotive battery as power source and a DC motor connected to the rear axle by a roller chain for movement. An analog servomotor is connected to the upper end of the steering column, in order to steer the vehicle. A programmable control board is responsible for the control of the vehicle. This board is connected via USB to an on board netbook, which communicates through Wi-Fi with the control station laptop, used to remotely control the vehicle. At the same time, the video camera sends live video through the Wi-Fi network.

The proposed system is far from being considered as a mobile robot or a fully operational weapon system. However, it is a first step towards experimentation in the UGV area, offering a test-bed for various technologies and potential upgrades. The first steps under consideration for upgrade is the use of INS/GPS for global positioning and the addition of ultrasonic sensors and relevant software, offering local navigation and obstacle avoidance capabilities. Further steps may involve communications upgrade, addition of various sensors and even the installation of some kind of weapon system, having in mind mainly the task of patrolling and protecting an air-force base.

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