# NEXT GENERATION MAIN BATTLE TANK. PART II: CONVERTING OLD MBTS INTO UNMANNED MBTS (UMBT)

Luca Piancastelli[1], Eugenio Pezzuti[2] and Stefano Cassani[3]
[1]Department of Industrial Engineering, Alma Mater Studiorum University of Bologna, Viale Risorgimento, Bologna, Italy
[2]Università di Roma "Tor Vergata", Dip. di Ingegneria dell'Impresa "Mario Lucertini", Via del Politecnico, Roma, Italy
[3]MultiProjecta, Via Casola Canina, Imola (BO), Italy
E-Mail: luca.piancastelli@unibo.it

## ABSTRACT

Modern MBTs (Main Battle Tank) are extremely expensive. Many outdated MBTs and other armored vehicles, often lacking the required armor protection, are still kept in depots. It is now convenient to upgrade them to optionally unmanned weapons by adding a humanoid driver, and a robotic arm as a loader. Sensors, an optional automatic driving system, a control and communication suite would complete the transformation. The main armament and secondary armament may be also changed or upgraded. The off-the-shelf huge electronic equipment can be installed wireless inside the hull. The old crew compartment may be spoiled of all the human related parts. Only the driver seat may be kept in order to leave the capability to remove the humanoid, robotized driver and reinstate the human one. This upgrade should also include a diagnostic system for the vehicle, the sensors and the additional systems to reduce the maintenance burden. An additional, specialized, lightweight armor suite should be focused to protect the mobilization system, the robots, the control and the communication system. This second part of the paper introduces a few options to convert the Leopard 1 MBT to an optionally piloted UMBT (Unmanned Main Battle Tank). A first, minimal step, is just the automation of the original tank. In a second step, the weight is reduced by installing a smaller 60mm cannon with a lighter, but more numerous ammunition storage. A third step increases the firepower by installing on the main turret an automated turret with a 12.7 or 30mm cannon with an optional additional 7.62 machinegun. It is also highly advisable to add an APU (Auxiliary Power Unit) and a battery to reduce IR (infrared) signature, improve main engine life and reduce maintenance.

**Keywords:**UCV, UMBT, MBT, update, automated turret, leopard 1.

## INTRODUCTION

The October 1921 issue of the "RCA's World Wide Wireless magazine" included a description of a working remote controlled car. A radio controlled this unmanned toy car. In those remote days that followed shortly WWI, someone thought that the wireless technology could be used to control unmanned battle tanks. The idea was not new, autonomous military systems, sometimes also called remote-controlled robots, have had a surprisingly long and interesting history. The French Crocodile Schneider Torpille Terrestre with its 40kg explosive head saw limited service in June, 1916. USSR used machine gun-armed Teletanks remotely radio controlled by another tank in the Winter War (1939-1940) and at the beginning of Operation Barbarossa in 1941. The Black-Prince, a remotely controlled Mathilda Tank, was developed in 1941, but was cancelled due to excessive costs. In 1942, the Germans used the remotely cable controlled Goliath tracked mine for demolition work. The Goliath was a development of a 1940 miniature French tracked vehicle. Unfortunately, the poorly armored, low speed, expensive Goliath proved to be a failure. Its main problem was that it was unable to negotiate even small obstacles like small trenches or ditches, being too small. Technology had to wait until the 1960 to see the first UCV (Unmanned Combat Vehicle). The Defense Advanced Research Projects Agency (DARPA) developed the Shakey. Initially, it was a wheeled vehicle equipped with TV camera, sensors, and a very nimble computer capable of picking up wooden blocks and placing them in certain areas. From this prototype, DARPA developed several autonomous vehicles with the U.S. Army. In this program, DARPA demonstrated that is was possible to implement an Unmanned Ground Vehicle (UGV) that could run autonomously at useful speeds off roads. In recent years, an enormous work has been done to develop autopilots for commercial cars. Even if this name was given to a few system installed to assist the car driver, a fully autonomous, reliable driving system is still not available for cars. However, for UCVs, the requirements are less stringent and it is already possible to install a reliable system with some limitations on Combat Vehicles. It is also highly probable that, in a near future, fully automatic systems will be available for cars and most ground vehicles. Today there are various operational autonomous military systems. Several other are currently under development. They are used, just to name a few, for guard duties, explosive ordinance disposal, logistics, reconnaissance, ballistic weapon platforms and even for repairing ground. Military robot increased from 150 into 5,000 by the year 2005 alone. Many UGVs were used by the U.S. Army to disarm over 1,000 roadside bombs in Iraq. Military autonomous systems are likely to grow in numbers and roles exponentially in the future. Among them, Unmanned Main Battle Tanks are one of the most interesting applications. Small Autonomous Battle Tanks (ABT) are ineffective. In fact, a substitute of a modern manned MBT should be able to negotiate the same obstacles and it should have at least the same firepower and mobility. For this reason, this paper will deal on a cost-effective method to convert an old generation MBT

(Main Battle Tank), like the Leopard I, into a UCV (Unmanned Combat Vehicle).

## BRIEF TACTICAL NOTES ON THE “MBT”

Firepower, Mobility and Protection are the three historical bricks around which the MBT is designed. Even if the order of importance has changed during the years to 1. Protection 2. Firepower 3 Mobility. For mobility, the basic concepts have not changed. Reading the very well written WWII German Manuals about MBT and, in general, armored vehicle usage, a few concepts may be derived. German manuals summarize and improve the Guderian’s tactics that combine air support, infantry, mobile and motorized armored divisions to work together and support each other in order to defeat the enemy. Guderian believed that information, communication and coordination are the key to success. After the introduction of the highly expensive Battle Tanks of the eighties, many experts theorized the end of the Guderian’s concept. They thought that lonely MBTs would engage alone with highly advanced weaponry in a rarefied front-line. In this scenario very few highly armored devices would hold the line and performs the attacks. This theory proved to be completely wrong, in fact the new tanks, called “pan tanks” from their flat shape, lacked of firepower. For this reason, WWII German manuals prescribed the use of Tanks in platoons of five tanks (for light tanks at the beginning of the war) or 4 tanks for heavy tanks at the end of the war. The “greatest” Nazi tank-hero, Michael Wittmann, the fruit of Goebbler’s propaganda, was, indeed, an expert veteran of war. In his last day, he was commanding a platoon of four Tigers I on loose line running in an open field. He probably had the wrong information that no enemy armored forces were in the area. Therefore, he took the risk to go into the open protected only by the firepower and the armor of four Tiger I tanks. History says that he was ambushed by a single Sherman equipped with a Firefly cannon hidden behind a stonewall. The battle was not so short, since the Sherman tank Commander, who was operating “open hatch”, was wounded by debris, (presumably coming from the surrounding stonewall) and he was replaced by another Commander before completing the fire-exchange. Three German tanks were destroyed at the price of no Canadian Tank. Probably the Germans were unlucky since they missed the single deadly enemy tank that was together with the other tanks of its platoons equipped with the ineffective (against heavily armored target) standard cannon of the Sherman. Wittmann had to operate against the German manuals that prescribe a previous knowledge of the battleground before engaging the enemy. Truly, in the last part of WWII German Tanks tended to adopt the tactic to move from one hidden position to the other, waiting for the enemy to come. For this reason Tigers, Panthers and PKW4s were less effective than Stug III and Hetzer. In fact, from a hidden position, the turret movement is severely limited and a low profile is of outmost importance. In any case, the Wittman’s four tanks platoon lacked of the firepower to defeat the single attacker in the relatively short time left after the identification of the attacker position. Even with modern sensors and warheads, this situation would have been even worse for modern tanks. In fact, the number of available battle tanks is smaller and the firepower have not substantially changed except for the lethality against armor of the main cannon rounds. The modern “pan tank” would face the same problems for the identification of the “true” enemy among the “fake” ones. In addition, the “pan tank” open ground capability have been severely hampered by the continuous increase in weight. The installation of more powerful engines has not solved the problem, due to increased track wear and the necessity to increase the power with a cubic law of weight when operating in wet mud. The capability of many “pan tanks” to operate in open field is limited. They will need hard ground, making their “possible” paths easy to detect. In addition, a few modern “pan tanks” still operate open hatch. Firepower and number of tanks is still critical for practical field operations. For this reason, this paper will deal on the cost-effective transformation of “old” battle tanks like the Leopard I in a UCVs or better UMBTs (Unmanned MBT). This paper demonstrates that, in this way, it is possible to have more tanks, more firepower and more mobility.

## UMBT TACTICAL NOTES.

During WWII offensive in France, Germans had observers on the front line and beyond it. In fact, many French speaking Germans were infiltrated in France to operate undercover inside French territory for information gathering and to convince people to flee. In this way, the migrants obstructed the roads hampering the Anglo-French mobility. These observers gave detailed data on the enemy to the German Command Center. The German Command Center had the front divided in sectors. Each sector gathered information for every available source, infantry, observers, airplanes. Starting from the so acquired situation awareness, the sector commander coordinated the attack, guiding the tanks into the battle, signaling targets, threats, obstacles and objectives. The German tank crew operated with closed hatches relying more on the radio-instructions than on the poor outside view. Frontal attacks were avoided at any cost. Usually, artillery or other tanks provided cover by shelling the enemy position, while the attack tanks operated on the weakest flank to override the enemy. As enemy tanks were approached, the tank-to-tank battle was considered as a last resource. Artillery and Stukas were used to deal with the enemy armored vehicles or ambushes were organized with PaK (Panzer abwehr Kanone) anti-tank guns. For several reasons linked to the extension of the Russian front, these tactics changed during the war arriving to the disaster of Kursk. Afterwards, original tactics were recovered and improved adding the line or diagonal platoon formation that gave improved firepower. Communications (radio equipment) and mobility were the key factors for the Blitzkrieg success even during the early stages of operation Barbarossa. In fact, during the 1940 Battle of France, the Allied lacked of coordination and information (due to lack of radio-communications). The poor situation awareness made havoc of the available military resources. French and British had antitank tanks and infantry supporting tanks with different armament and speed. The lack of flexibility proved also fatal to the Allied. Also for this reason, UGV cannot be too small, needing to negotiate obstacles and to carry heavy weapons and equipment. For this reason UMBT are the ideal choice. UMBTs cannot be expensive, being expendable. They may operate in platoons as Wittman did, in line on open field. The difference is that, if the UMBT can operate in "sentry mode", covering a defined angle of the 360-degree horizon, after the first shot, the platoon would immediately identify the enemy, reducing the reaction time to microseconds. Even the initial surprise would have been difficult with the modern off-the-shelf IR (Infrared) sensors. In this case, the attacking tank would have to operate in "stealth" mode relying only on battery at least for the first shot. In fact, commercial, modern IR sensors are capable to detect human body heat at 10km. Even the smoke out of a small APU would reveal the position of the attacker in advance. From the very beginning of the attack, the UMBTs report the information captured by sensors to the CCC (Control and Command Center) and rely on the information/command received from it. This is a crucial part of UMBTs missions. Therefore, fast reaction, high firepower and mobility are the key of success for UMBTs. The order of importance shifts from "1.Protection, 2.Firepower, 3.Mobility" of "Pan Tanks" to "1.Firepower, 2.Mobility, 3.Protection" for UMBTs. Protection for UMBTs means survivability. Communications being the basic background in any case. UMBTs can also operate as a service to an infantry platoon or company, being able to detect and suppress sniper and heavy fire easily. They can also provide protection and reaction against IEDs (Improvised Explosive Device), enemy artillery and other offensive weaponry. Finally, they can carry heavy equipment for the infantry. They should be easy to maintain and operate. For this reasons the technique of conversion of old MBTs into UMBTs is of primary importance. This conversion passes through the "pappy concept" as it will described in the following paragraph.

## THE PAPPY CONCEPT

A few years ago, the Authors designed a radio-controlled pilot for airplanes and helicopters. The idea started from the consideration that test-pilot-safety greatly slowed down the test flights pace. Small increments in well-designed flight tests have to be implemented to exploit the flight envelope and acquire all the data necessary to pass from prototype N."0" to a serial production airplane. After the process, the prototype N."0" finishes in a Museum, in a deposit or in a wreck yard. On the contrary, when testing engines in a test bench, accelerated tests are performed and the engine is always broken before displacing it.

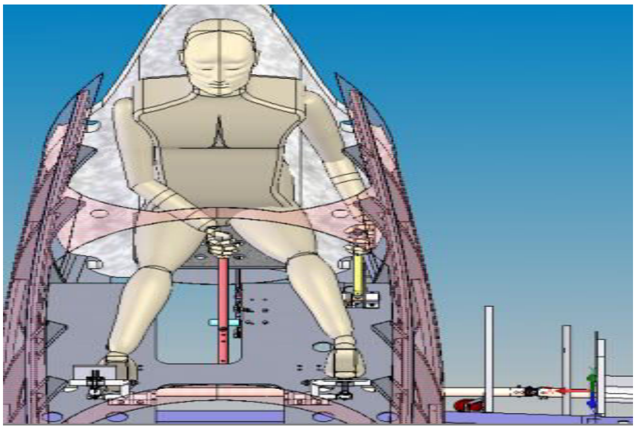

**Figure-1.** CAD ergonomic study of a traditional, small airplane pilot station.

**Figure-2.** The exact replica of the airplane cockpit usually available well before the flying tests.

The idea is to eliminate the test pilot risks and to reduce testing time. This is done at the affordable price to sacrifice prototype N."0". Figure-1 shows a CAD study of a small aerobatic airplane pilot station. Commands, levers, buttons, screens can be studied in detail, along with outside view. At the very beginning of the design phase, a 3D virtual image of the cockpit can be shown to the pilot. In addition, a physical mock-up of the pilot station is always manufactured well before the first part of the prototype. This mock up is completed with a visual system and it is also used by test pilots, customers and designers to study the airplane handling and ergonomics. In this phase, it is easy to design also a robotic pilot that can seat in the pilot station in place of the human test pilot. The human test pilot can drive the airplane from the ground control station with all the proper feedback of controls and the visual following the true airplane. The robotic pilot, who is actually flying, will copy the commands of the human one and feedback the control information along with the others that are gathered from the flying prototype. In this way, it is possible to reduce the risks and to accelerate the tests, reducing the development costs. The robot pilot should be bolted in place of the original seat and its robotic arms and legs should replace the human pilot (Figures 3 and 4). The robot design should minimize additional manufacturing and installation work. The name given to this robot-pilot was "Pappy" from the nickname of a famous WWII US ace. A very simple, multi-arms-legs robot was designed for the purpose. The limbs are directly clamped to levers and controls to avoid difficult positioning controls. Oil pressures feedback information of loads on control levers. Dually redundant oleo dynamic actuators were used for legs and arms, while a five times redundancy was introduced for ECUs (Electronic Control Units) and Communication systems. A twice-redundant small battery system would provide the possibility to control the aircraft in most cases. This is possible even in case of complete power failure, if the airplane is stable and flyable powerless.

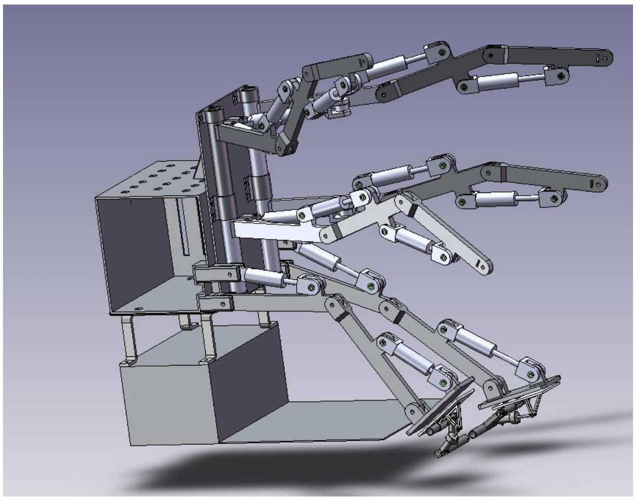

**Figure-3.** 4-arms-2-legs version of "Pappy".

Pappy was designed with an oversimplified fuzzy pilot to automatically take the airplane to a safe ditching area in case of complete failure of the system. The test pilot was to sit in the virtual cockpit (Figure-2) from which he could fly the test aircraft, with the feedbacks given by Pappy, who replicates the position of levers and controls given by the human pilot into the aircraft. A switchbox completed Pappy robotic interface. Therefore, Pappy was to be a multi-limp humanoid robot with each limp commanding a main lever or stick. Buttons and switches are replicated by a switchbox. Vision is given a multiple camera system that replicates the outside view in the human pilot remote station. The aircraft version of "Pappy" is a lightweight aluminum alloy humanoid robot weighing about 70kg, everything included except the antennas. The UMBT version of Pappy is slightly different. In fact, a few very old tanks require large command loads to operate. It is not a myth that T34 drivers used a hammer for operating the very heavy gearbox lever in emergency. In this case, it is sufficient to change the materials from aluminum alloys to steel, in order to reach 1,500N and 5,000N as maximum loads for robotic arms and legs. Even in this case, the overall weight of the system remains well under 100kg.

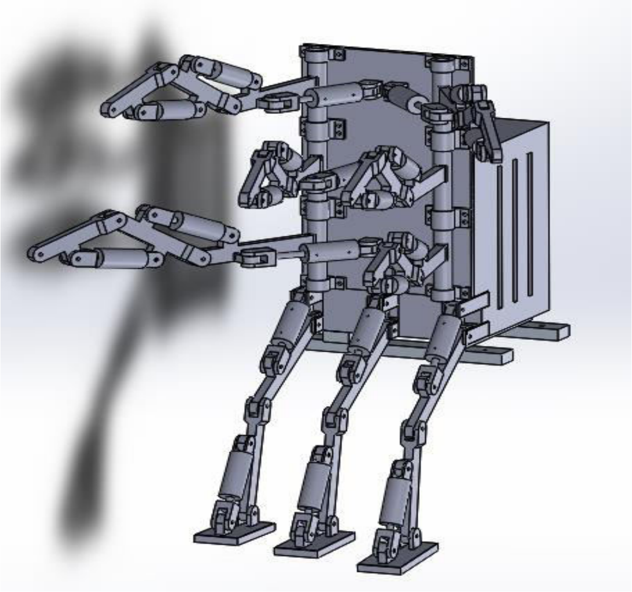

**Figure-4.** 6-arms-3-legs version of "Pappy".

Another problem is that the low efficiency oleo dynamic controls require cooling. In aircraft, it is quite easy to obtain fresh air from the air conditioning system. In UMBTs the adoption of a body armor for "Pappy" will make cooling more difficult. It may be necessary to redesign the system with electric actuators and motors instead of oleo dynamic ones.

## PAPPY AS AN UMBT OR MBT DRIVER

It is possible to install pappy in many MBTs to replace the driver. Driver position is very exposed and it is often difficult to escape in case of danger. Crew reduction limits the risks and the causalities. A robot is not subject to fatigue. In this way, it is possible to reduce the risk of accidents. Finally, a robot always obeys and understands orders. In addition, it is possible to drive "pappy" manually through a remote or a wired control. In any case, it is always possible to unbolt pappy and to convert the MBT/UMBT to the original human drive. Due to the huge investments, self-driving cars and trucks are a maturing technology with the capability to reshape mobility in the short term. On roads, many safety-critical tasks are present. They include the robust executions of vehicle movements through a continuously varying environment shared with other vehicles and pedestrians, following the circulation rules and within the allowed spaces. Driverless vehicles are computer driven systems that process a stream of data from sensors. Commonly used are radar, LIDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging), cameras, GPS/INS units, and inertial platforms. These data are merged with road maps, road rules, vehicle and sensor mathematical models to compute the values of the controlled variables that control the vehicle motion. Decision-making tasks are arranged into a hierarchical structure. At the highest level, a route is described as a family of waypoints. The trajectory through two successive waypoints is planned in the road network that abides by rules of the road. This phase is called route planning. Route planning is usually done in background. A set of curves and velocity arrays are defined to accomplish the local navigational task. Then a real-time control system tries to execute the planned motion. The errors generated during the execution of a planned motion are due in part to the inaccuracies of the vehicle and road models and others are due to variations in road availability and obstacles. In a few cases, a new route planning is required. Therefore, the largest problem is due to the robustness and stability of the closed-loop control system. In the simplest route planning model, the car is modeled as two slip-less wheels restricted to move in a plane connected by a rigid link. The front wheel has a second degree of freedom of rotation about an axis normal to the plane of motion. The nonholonomic constraint that limits the maneuverability is expressed as a differential constraint on the motion of the car (Figure-5).

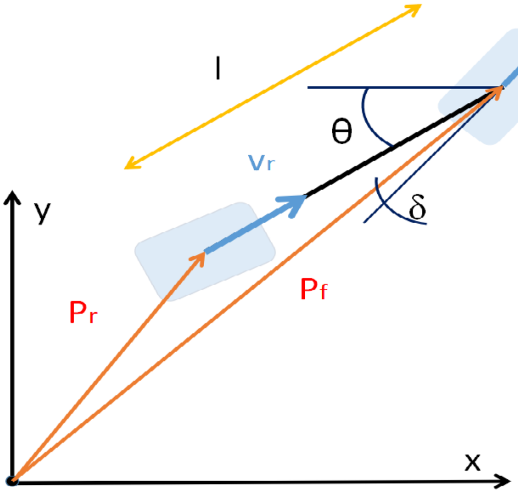

**Figure-5.** Simplified vehicle model.

In reference to Figure-5, the $P_f$ and $P_r$ are the coordinates of the front and rear wheel contact points in an earth coordinate system (x, y, z). The vehicle heading θ is an angle between the vehicle and the x-axis or the angle between vectors x and $P_r \rightarrow P_f$. The steering angle δ of the front wheel is expressed as the angle between vector $P_r \rightarrow P_f$ and the velocity vector of the front wheel. The motion of the contact points must satisfy the no-slip assumption and is path is tangent to the contact-point velocity-vectors. Equations (1) describes the velocity vector of the vehicle body starting from the contact point of the rear wheel. Continuity of the steering angle is also imposed (2). This kinematic model is suitable for planning paths when inertial effects are small. To avoid the major drawback of this model of permitting instantaneous steering with large angle changes, limitations in steering acceleration (3) and angle should be introduced (4).

$$\begin{aligned} \dot{x}_r &= v_r \cos(\theta) \\ \dot{y}_r &= v_r \sin(\theta) \\ \dot{\theta} &= \frac{v_r}{l} \tan(\delta) \end{aligned} \tag{1}$$

$$\begin{aligned} \dot{x}_f &= v_f \cos(\theta+\delta) \\ \dot{y}_f &= v_f \sin(\theta+\delta) \\ \dot{\theta} &= \frac{v_f}{l} \sin(\delta) \\ |\dot{\delta}| &\le |v_\delta| \end{aligned} \tag{2}$$

$$|\ddot{\delta}| \le |\ddot{\delta}_{\max}| \tag{3}$$

$$|\delta| \le |\delta_{\max}| \tag{4}$$

Additional limits are added by reducing the radius of curvature of bends in relation with speed (this is done by the trajectory planner) and atmospheric conditions (rain, snow). For road operations, the problematic of UMBTs are similar to one of a car with the advantage that in an operational context the circulation rules may be ignored. On normal roads is also possible to remote control “pappy” with a wireless or a wired system with the pilot on board. It is also possible to remove pappy and drive the UMBT or MBT fully manually. On soft grounds, a few problems are added by the soil nature that may be extremely variable due to water content. An initial global earth mapping is available on Internet for slope and feasible paths. The real-time part of the autonomous drive system would also deal with obstacles and unforeseen terrain slopes. In this way, it is possible to define an ideal, planned trajectory between two waypoints. A real-time guidance system can then be implemented to automatically drive the UMBT. This system is aimed to avoid capsizing and impossible slopes or obstacles. The brake and throttle pedal position history are given in input from the velocity vector associated to the trajectory. The required trajectory is defined as a sequence of parametric bends. Two parallel controllers make the driving system: a cinematic and a fuzzy one. The cinematic controller works in open chain and defines an initial theoretical steering anglestarting from the required trajectory. This angle is different from the trajectory planner due to real-time adherence data. In fact, it uses a model of the UMBT and the available data on the soil and vehicle performance. This model is continuously updated by result of the previous maneuvers. The fuzzy controller of Figure 6 uses a feedback based logic that takes into account of GC position $\{x_{1G},x_{2G},x_{3G}\}$, yaw angleψ, yaw rateψ’ and GC velocity (Velocity).

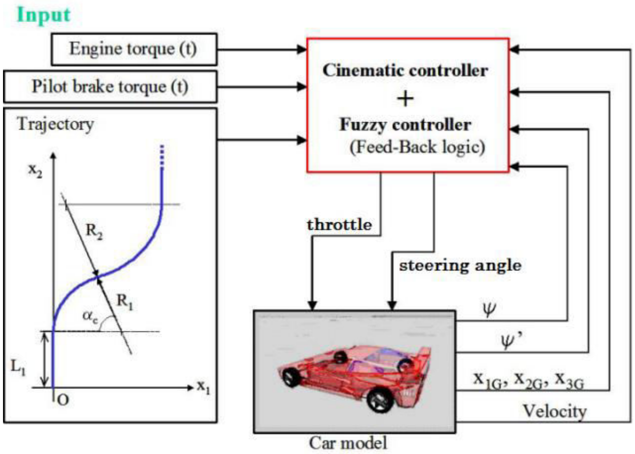

**Figure-6.** Fuzzy control schematic.

The fuzzy controller is not very accurate for trajectory errors, but it is very simple and robust. It is also possible to drive the vehicle directly from a "remote station" with puppy that replicates the driver commands. However, transient communication problems and delays may arise during operations. For this reason, it is better to provide "Pappy" with an autonomous driving system. To improve mobility and reduce driving problems it is imperative to have a good mobility. This is achieved primarily by low ground pressure and in second place by high engine torque. Table-1 shows the Author defined "Mobility Index" in percentage relative to the best one (T34=100%). The mobility index $I_{mobility}$ is defined by equation (5).

$$I_{mobility} = \frac{Power}{V_{\max} GP^3 d_{plane}} \frac{W}{L} \tag{5}$$

This mobility index takes into account of the maximum torque that is proportional to the ***Power*** divided by the maximum velocity $V_{max}$. The most critical factor is the ground pressure ***GP*** that defines the amount of sinkage in off-road. $d_{plane}$ is the diagonal of the rectangle formed by width ***W*** and length ***L*** or the MBT hull. Finally, the ratio ***W/L*** is the leverage of the tracks when turning. For good driving control is necessary that the mobility index is as high as possible. A good mobility index reduces also track loads, improving the availability of the UMBT by reducing track repair/replacement. Since the crew-less UMBT works continuously between maintenance time and refueling, it is essential that reliability is kept to the maximum reasonably possible. Fault tolerant design should be adopted. For example, it is better to install more sensors on the sides that a single sensor on a rotating turret. In fact, the failure of a sensor will only reduce operational capability in a multisensors system, while the single sensor option suffers of the sum of probability failures of the rotational system and of the sensor itself.

**Table-1.** Data of several armored vehicles.

| Armored Vehicle | Relative Mobility Index(%) | WW (t) | B (cm) |
|---|---|---|---|
| M113 | 23 | 10.4 | 38 |
| Centurion | 53 | 42.5 | 61 |
| Stalin | 45 | 46 | 65 |
| T34 | 100 | 26 | 55 |
| Sherman | 20 | 30.3 | 42.1 |
| Tiger I | 22 | 57 | 72.5 |
| Panther | 27 | 44.8 | 66 |
| Hetzer | 17 | 16 | 35 |
| Leopard 1 | 25 | 42.4 | 55 |
| Leopard 2 | 45 | 55.1 | 64 |
| Challenger2 | 37 | 62.5 | 65 |
| Merkava | 33 | 66 | 64 |
| Abrams | 22 | 67.7 | 64 |
| Ariete | 34 | 54 | 65 |

## THE ADDITIONAL DIAGNOSTIC SYSTEMS

For UMBT reliability, it is fundamental to add a diagnostic system to the original MBT. The essential data are track tensioning sensors and a computerized control system of the sensors already existing on the vehicle. In many cases, it is convenient to substitute these old-fashioned sensors with new automotive ones. In fact, automotive sensors have self-diagnosis and emulation systems. Pappy was conceived to embed already these systems. The reconfiguration/emulation capability is essential to keep the UMBT operational as long as possible and to simplify maintenance outputting a diagnosis of the parts that are failed, faulty or going to fail. To simplify maintenance it is essential to go wireless as much as possible. The tank hull is a Faraday cage and it is possible to install quite robust wireless/optical systems inside it. Wireless systems, not only reduce the installation costs, but also greatly simplify the maintenance. In fact, wiring failures are difficult to diagnose [1-23].

## THE LEOPARD 1A1 CONVERSION INTO AN UMBT

It is possible to convert many MBTs into UMBTs by using Pappy and other "industrial" robots. For example, a T34 can be converted in UMBT by installing "Pappy" in the driver and gunner station. An automatic turret would operate the external machinegun. Cameras, radars and sensors should also be added for autonomous drive and control. Additional sensors are also necessary to feedback the situation awareness to the control station(s). A central computer would replace the commander. A redundant communication suite would transfer data and an "industrial" anthropomorphic robot would replace the loader. Unfortunately, the T34 has not the main cannon stabilization system and the "sentry mode" would be limited to the (small) automatic turret. The problem can be reduced by installing a larger machinegun or automatic cannon in the external automatic turret. Still, the UMBT will be not ideal. On the contrary, the Leopard 1A1 has already a main weapon stabilization system. In this way, it is possible to replace the gunner with a switchbox and to operate the main cannon in "sentry mode". The Leopard 1A1 is still available in large numbers and it is possible to make an assembly line to overhaul the old tanks and to transform them into UMBTs with large cost savings. The limited number of rounds available for the main weapon (57) is the main limitation of the Leopard 1A1. During the initial overhaul and upgrade to MBT it is compulsory to replace the original old barrel. In this case it may be convenient to replace the whole cannon with the OTO 60mm ultraspeed cannon, that has a much smaller round. With this cannon it is possible to increment the internal storage to more than 150 rounds. All the human related equipment can be removed with a significant reduction in weight and a corresponding improvement in mobility especially for the main turret. Another problem of the Leopard 1A1 is the lack of secondary weapon firepower. It is possible to install a larger weapon on the automatic turret installed on the main one. The driver is to be replaced by a "Pappy" robot, while an industrial robotic arm substitutes the radio operator/loader. Two switchboxes allow remote operations in substitution of the Commander and the Gunner. Sensors should be added outside the hull and the turret for autonomous drive and situational awareness. Additional outside and inside cameras are also necessary to assess the operational state of the UMBTs. The additional sensors can be interfaced with the CCcC (Central Control coordinating Computer) to detect automatically enemy fire and position. The CCcC is interfaced with the Communication Suite to transmit the data from the UMBTs sensors and optronic systems and to take orders. The UMBT can be directly controlled and fired from a remote station or can drive autonomously with the weapons in sentry mode for the two turrets [24-29]. The Leopard 1A1 is a fairly simple vehicle and the interfaces with "Pappy" and the switchboxes are relatively few and simple to implement. The interface between "Pappy", the switchboxes, the CCcC and the Communication suite can be wireless or through optical fiber or data-bus. It should be kept in mind that a main problem of UMBT is maintenance. A good policy to reduce maintenance is to limit the wiring and number of boxes. The wireless solution is to be preferred. To reduce the IR signature of the UMBT is fairly simple to install an APU on the frontal armor. A 500kg battery can be added for low power "stealth" operations, to check the systems before starting the vehicle and to keep the systems operational after a complete engine power failure. Finally, a bulldozer blade can be added in the front for engineering works.

## THE UMBT PROTECTION AND ARMOR

It is possible to install an active protection system against shaped charges and other anti-tank weaponry. Unfortunately, these systems are expensive and dangerous for the infantry around the UMBT. In addition, most shaped charges and penetrators kill instantly the human crew and set the tank on fire. In the case of the UMBT it is possible to install an armor suit on Pappy, on the loader robot and to protect the most critical systems inside the tank. In order to limit the internal pressure build-up it is possible to design holes in the hull in the most convenient positions to keep the balance of the internal and external pressure. A fire suppression system may reduce the fire hazard. In this way, the probability that a direct hit destroys the UMBT fighting capability is reduced.

## DIRECT REMOTE OPERATIONS

It is possible to install a "direct" wireless remote control and a wired one to make it possible to operate the UMBTs by local ground forces. For example, infantry platoon support can be easily fulfilled by the UMBTS. In this case, the platoon commander or a specialized operator can operate the UMBT directly from the field. The wired remote unit is convenient for moving the UMBT on roads, maintenance facilities, etc. It is fairly easy to add a removable or retractable driving station for this purpose on the UMBT. Due to the ease to remove Pappy, it is also possible to reinstate the original, human driving station.

## CONCLUSIONS

Updating an outdated battle tank to an unmanned one (U-MBT), is a relatively simple process that can be resolved by installing robotized units, switchboxes, sensors, computers and communication suites. Care should be taken to adopt the most cost-effective solutions. This paper introduces a reasonable update of the Leopard 1 into an UMBT. A minimalistic approach was adopted by installing a humanoid robot in the driver station and a robotic arm in the loader position. Computers, sensors, switchboxes and communication suites complete the conversion. In the case of the Leopard 1, it may be convenient to replace the original 105mm cannon with a much smaller 60mm one with a substantial increase of the number of cannon rounds available. A mortar, Merkava style, can also be added externally to the turret. A secondary automated turret with a 12.7 or a 30 mm cannon is added on the main one to increase the firepower for ground troop support and urban warfare. The substantial increase of internal and external ammunition storage will improve the overall firepower. Specialized protection armors can be added to the robots, the control systems and to the mobilization systems to increase the survivability of the UMBT in case of hits. An efficient, automatic fire extinction system would complete the transformation from MBT to UMBT. It is possible to add an active armor protection system. Unfortunately, these systems are expensive and dangerous for the infantry around the UMBT. In addition, they require maintenance. To reduce maintenance and increase reliability, an electronic diagnosis system should be installed for the vehicle and its main systems.

## BIBLIOGRAPHY

[1] Piancastelli L., Frizziero. L. 2014. Turbocharging and turbocompounding optimization in automotive racing. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(11): 2192-2199, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[2] Valentini, P.P., Pezzuti E. 2016. Computer-aided tolerance allocation of compliant ortho-planar spring mechanism. Int. Jour. Of Computer Applications In Technology, 53: 369-374, ISSN: 0952-8091, doi: 10.1504/IJCAT.2016.076801.

[3] Pezzuti, E., Valentini P.P. 2016. Accuracy in fingertip tracking using Leap Motion Controller for interactive virtual applications. Int. Jour. On Interactive Design And Manufacturing, p. 1-10, ISSN: 1955-2513, doi: 10.1007/s12008-016-0339-y

[4] Pezzuti E., Valentini P.P. 2013. Design and interactive simulation of cross-axis compliant pivot using dynamic spline. Int. Jour. On Interactive Design and Manufacturing, 7: 261-269, ISSN: 1955-2513, doi: 10.1007/s12008-012-0180-x.

[5] Piancastelli, L., Cassani, S. 2017. Maximum peak pressure evaluation of an automotive common rail diesel piston engine head. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(1): 212-218, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[6] Piancastelli, L., Cassani, S. 2017. Power Speed Reduction Units for General Aviation Part 2: General Design, Optimum Bearing Selection for Propeller Driven Aircrafts with Piston Engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 544-550, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[7] Piancastelli, L., Cassani, S. 2017. High Altitude Operations with Piston Engines Power Plant Design Optimization Part V: Nozzle Design and Ramjet General Considerations. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2242-2247, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[8] Piancastelli, L., Gardella, M., Cassani, S. 2017. Cooling System Optimization for Light Diesel Helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(9): 2803-2808, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[9] Piancastelli, L., Cassani, S. 2017. On The Conversion Of Automotive Engines For General Aviation. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(13): 4196-4203, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[10] Piancastelli, L., Cassani, S. 2017. Convertiplane Cruise Performance with Contra-Rotating Propeller. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(19): 5554-5559, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[11] Ceruti A., Bombardi T., Piancastelli L. 2016. Visual Flight Rules Pilots Into Instrumental Meteorological Conditions: a Proposal for a Mobile Application to Increase In-flight Survivability. International Review of Aerospace Engineering (IREASE). 9(5).

[12] Piancastelli L., Cremonini M., Cassani S., Calzini F., Pezzuti E. 2018. Intake and exhaust position optimization in the cooling duct of diesel helicopters ARPN Journal of Engineering and Applied Sciences. 13(17): 4811-4819.

[13] Piancastelli L., Cassani S., Pezzuti E., Pompei L. 2018. Multi-objective optimization of the cooling system of a diesel helicopter. ARPN Journal of Engineering and Applied Sciences. 13(16): 4610-4616.

[14] Piancastelli L., Bernabeo R. A., Cremonini M., Cassani S., Calzini, F., Pezzuti E. 2018. Optimized parachute recovery systems for remote piloted aerial systems. ARPN Journal of Engineering and Applied Sciences. 13(16): 4590-4597.

[15] Piancastell, L., Cassani S., Calzini F., Pezzuti E. 2018. The decisive advantage of CRDID on spark-ignition piston engines for general aviation: Propeller and engine matching for a specific aircraft. ARPN Journal of Engineering and Applied Sciences. 13(13): 4244-4252.

[16] Piancastelli Errani, V., Cassani S., Calzini F., Pezzuti E. 2018. An analytical solution for the determination of the loads acting on a semi-elliptical wing: The case of the Reggiane Re 2005 WWII fighter. ARPN

Journal of Engineering and Applied Sciences. 13(14): 4393-4400.

[17] Piancastelli L., Cassani S., Pezzuti E., Cassani S. 2019. Energy transfer from airborne high altitude wind turbines: Part I, a feasibility study of an autogiro generator from an existing helicopter. ARPN Journal of Engineering and Applied Sciences. 14 (7): 1407-1413. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[18] Piancastelli L., Cassani S., Pezzuti E., Cassani S. 2019. Energy transfer from airborne high altitude wind turbines: Part II, performance evaluation of a autogiro- generator. ARPN Journal of Engineering and Applied Sciences. 14(17): 2972-2979. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA,

[19] Piancastelli L., Cassani Sportiello L., Pezzuti E., Cassani S. 2019. Study and optimization of advanced heat sinks for processors. ARPN Journal of Engineering and Applied Sciences. 14(5): 1082-1088. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA,

[20] Piancastelli L., Pirazzini A., Cremonini M., Cassani S., Calzini F., Pezzuti E. 2018. The optimization of power generation in low-cost mass-produced wheeled wind turbines. ARPN Journal of Engineering and Applied Sciences, 13(15): 4466-4474. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[21] Piancastelli L., Bragaglia L., Cremonini M., Cassani S., Pezzuti E. 2018. Feasibility study of the installation of an additional "over lift" wing on the CH47 Chinook for cruise performance improvement through the lift-compound approach. ARPN Journal of Engineering and Applied Sciences. 13(19): 8142-8149. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[22] Piancastelli L., Colautti D., Cremonini M., Cassani S., Torre A. 2018. Feasibility study and preliminary design of a Ram-Pulsejet for hypersonic passenger Air Transport. ARPN Journal of Engineering and Applied Sciences, 13(20): 8356-8365. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[23] Piancastelli L., Frizziero L., Donnici G. 2015. The Meredith ramjet: An efficient way to recover the heat wasted in piston engine cooling. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(12): 5327-5333, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[24] Frizziero L., Rocchi I., Donnici G., Pezzuti E. 2015. Aircraft diesel engine turbocompound optimized, JP Journal of Heat and Mass Transfer. 11(2): 133-150.

[25] Frizziero L., Donnici G. 2015. Common rail diesel - Automotive to aerial vehicle conversions: An update (Part I), ARPN Journal of Engineering and Applied Sciences. 10(6): 2479-2487.

[26] Piancastelli L., Frizziero L., Donnici G. 2015. Common rail diesel. Automotive to aerial vehicle conversions: An update (Part II), ARPN Journal of Engineering and Applied Sciences, Volume 10, Issue 8, Pages 3286-3294.

[27] Piancastelli L., Frizziero L., Donnici G. 2015. A new concept for low inertia electric turbocompounding in racing spark ignition engines, JP Journal of Heat and Mass Transfer.

[28] Donnici G., Frizziero L., Francia D., Liverani A., Caligiana G. 2018. TRIZ method for innovation applied to an hoverboard, Cogent Engineering. 5(1): 1-24.

[29] Donnici G., Frizziero L., Francia D., Liverani A., Caligiana G. 2018. Project of inventive ideas through a TRIZ study applied to the analysis of an innovative urban transport means, International Journal of Manufacturing, Materials, and Mechanical Engineering. 8(4): 1-24.

## SYMBOLS

| Symbol | Description | Unit |
|---|---|---|
| $x_f, y_f, z_f$ | Front wheel contact point coordinates $P_f$ | m |
| $x_r, y_{r, fr}$ | Rear wheel contact point coordinates $P_r$ | m |
| ϴ | Vehicle angle relative to the x axis | rad |
| $v_f$ | Front wheel velocity | m/s |
| $v_r$ | Rear wheel velocity | m/s |
| l | Distance between theoretical contact points of front and rear wheels | m |
| δ | Front wheel steering angle relative to the vehicle body | rad |
| $I_{mobility}$ | Mobility Index | $m^3s^4kg^{-2}$ |
| GP | Ground pressure | $N/m^2$ |
| $V_{max}$ | Maximum design speed | m/s |
| Power | Engine power | W |
| W | Vehicle width | m |
| L | Vehicle length | m |
| $d_{diagonal}$ | Diagonal of the rectangle WxL | m |
| B | Track shoe width | cm |
| WW | Vehicle mass | t |