Comparative evaluation of mobile platforms for non-structured environments and performance requirements identification for forest clearing applications

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Abstract— **The effort to automate is present across all industries. It has an economic purpose but an effect that goes far beyond economics. Research was carried out and a lot of investment was made in the automation of processes in industries such as agriculture and forestry, which resulted in incredible advances and the emergence of very interesting solutions for the most diverse applications. In fact, more solutions have emerged in the field of agriculture than in any other, what can be explained economically but also because of technical difficulties such as the navigation in special unstructured environments like forests. This paper, carries out a comprehensive review of existing platforms and presents a comparative study for an application in forest clearing. This evaluation is made in terms of its size, automation levels, traction energy source, locomotion systems, sensors/actuators availability and tools, resulting in an assessment of what characteristics it must have to succeed in its function. Hence, it will be possible to evaluate whether or not it is reasonable to perform refitting of an existing platform into an electric Unmanned Ground Vehicle for Forest Clearing or is more adequate to start from scratch its development. The evaluation results revealed that an electric Unmanned Ground Vehicle for Forest Clearing is currently unavailable in the market and that a new platform project development is needed. The performance requirements for such a platform are identified and proposed in the paper.**

I. INTRODUCTION

The panorama of destruction left by the forest fires each year globally is well known, due to their strong impact on society and on the environment. Apart from the natural environment destruction, the worst consequences of the wildfires are the loss of human lives and the destruction of property, including vehicles, houses and other infrastructures. High voltage lines were identified and being the cause of ignition in many forest fires [1], therefore it is essential to perform vegetation clearing in electric line corridors.

One preventive measure which can be adopted to minimise the impact of the wildfires is to reduce the amount of forest fuels available to burn, by adopting efficient biomass management strategies, followed by a reinforcement of the laws that regulate the land clearing and management, establishing strict deadlines for law compliance and fines for failing to do so. However, land and forest clearing is expensive and a slow task, performed with inefficient means and often with no valorization of the resulting residues or the clean spaces. In most of the cases, the vegetation cutting is performed with manual tools, like chainsaws or bush cutters. This not only requires a vast human workforce but also exposes human workers to extenuating and dangerous work conditions. Some forest clearing works are done with large forest Mobile Industrial Machine (MIM), operated by a human worker usually siting and controlling them from the inside. Once again, this is not only costly but also exposes the workers to uncomfortable environments, with dangerous levels of noise, vibrations and dust. This is where the need to develop MIM that perform this task as autonomously as possible comes in. Electric mobility has gained popularity in an effort to tackle fossil fuels dependency and greenhouse gases emission. Although it has already proved its superiority for urban and suburban transportation in rural areas, in which the activities require traction force and long working hours, the main energy source is still sourced from fossil fuels by using combustion engines. In industries such as agriculture, forestry and construction electric *MIM* are being introduced with relative success.

The aim of this work is to study the feasibility of refitting a MIM or developing an *Unmanned Ground Vehicle for Forest Clearing (UGV4FC)* for forests clearing. The study begins with the definition of the usage scenario followed by the definition of the Key Performance Indicator (KPI) characteristics that will make the developed UGV4FC efficient and competitive. The scenario corresponds to the forest environment that the MIM will find in operation. The set of specifications was achieved by comparing several existing MIM and analysing the suitability of its different systems to the specific characteristics of the forest clearing application. This methodology allowed to establish the best specifications for the development of the forest UGV4FC. The comparative study of existing Mobile Industrial Machines for an application in forest clearing in terms of its size, automation levels, traction energy source, locomotion systems, sensors/actuators availability and tools, resulted in an assessment of what characteristics it must have to succeed in its function, this assessment is vailable at `https://ipleiria-robotics.github.io/MIM_AC_UGV4FC`, .

A. *Usage scenario*

The base scenario for the UGV4FC operation is a fuel containment strip that may or may not be directly under a

*This work was not supported by CENTRO-01-0247-FEDER-045931
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high voltage line. These areas can present a high slope, rocky soils and bush that can reach 1 meter in height and on average 15 mm in diameter. These strips can be up to 50 meters wide and are flanked by trees or vegetation with heights that vary between 1 and 20 meters. The strips are intercepted several times by roads and forest paths. Fig 1 shows a typical fire containment strip in central Portugal.

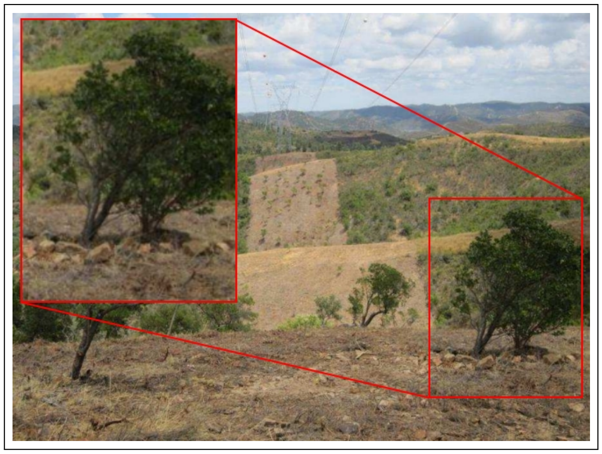


Fig. 1. Typical containment strip with slopes, rocky soil, and protected trees such as *Arbutus Unedo* (highlighted on the top left corner). Image courtesy of REN (Portuguese National Electricity Network)

B. Selected Mobile Industrial Machines

Table I contains the identified relevant MIM chosen to serve as technological baseline for this study. These MIM are very diverse, meaning that they have different propulsion systems, locomotion, steering, and control modes in addition to different levels of automation. Most of the selected MIM are used for agricultural applications, currently this area is richer in provided solutions but there are also construction and forestry MIM.

II. STATE OF THE ART

A. Forestry

In forestry the evolution towards the use of machines started around the 80's, by late 90's 95% of the wood harvested in the nordic european countries was already cut with machinery [2].

Over the years, a huge effort and investment has been made to increase efficiency, productivity and create better working conditions for operators through the development of increasingly automated equipment.

*1) **Timber industry**:* Timber industry operates in man-made organised forests. Here cut-to-length systems dominates, with a single-grip harvester fells, debranches, and cross-cuts trees into logs. A special purposed vehicle, designated has *forwarder*, is then used to pick up the processed logs from the ground and transport them to a landing area close to a road accessible by timber-trucks. These is a very efficient and productive industry thanks to this technically advanced machines. In terms of autonomy the most advanced equipment's are not fully autonomous needing assistance from a human operator. Fully autonomous systems are currently seen as highly unlikely in the short term due to the many complex decisions that have to be made, such as which tree to cut, in which direction, where to position each machine, and where to place the logs. Unmanned harvester remotely controlled by the *forwarder* human operator, loading directly onto the bunk is where the evolution to a fully autonomous system stands today.

*2) **Fuel management in forest areas**:* Global warming has led to an increase in extreme weather phenomena like forest fires. Today we see big fires taking place in geographies that were not previously affected, more often, with larger dimension and consequently more difficult to extinguish. In addition to the hotter and drier climate, the existence of bush on the forest floor makes it even more difficult to stop their progression once they gain some dimension. The bush is the fuse and fuel of major fires, hence the importance of its management.

Fuel management is particularly difficult in wild or poorly organised forests. This is the typical scenario of forests that have no industrial purpose. It ends up being in these forests that the biggest fires occur with the greatest material and sometimes human losses.

The clearing of the forest is essentially done manually. The MIM used are mostly tractors adapt from agriculture to transport the bush out of the forest. Recently, small remotely controlled machines equipped with mulchers began to be used. They are the more advanced equipment in terms of automation used up to now in this function.

B. Forest management of the future

*1) **Robot swarms**:* One day forests will be inhabited by swarms of organised robots responsible for their management keeping the forest clean and wealthy. Robot swarms are groups of robots that each act autonomously based on only local perception and coordination with neighbouring robots. The collective behaviour emerging from the self-organised interactions between the many robots of a swarm allow it to solve complex tasks [3]. The main benefits of this approach are scalability and reliability (robot failure is compensated by other units). Real world applications range from environmental monitoring to continuous maintenance of forests.

*2) **Forest automation challenges**:* Aiming at fully-autonomous systems, over the past two decades, researchers have been developing collaborative systems in which the human operator and the machine work together. Such research has addressed the levels of automation available for handling the various aspects of data acquisition, data and information analysis, decision-making, action selection and implementation appropriate for various task or sub-task goals and parameters.

The capacity of perception, reasoning and action of a human being is hard to matched by robotic systems however the capabilities of the human and the robot can complement each other [4]. Human-robot systems have been subject of constant research and the results have taken many shapes and forms, evolving from continuous human-controlled master-slave mechanisms to robots incorporating artificial intelligence under supervisory of an human operator [5].

Intervention of a human in the operation loop generally improves the performance of the global system by increasing guidance accuracy, enhancing target identification, shortening processing time, reducing system complexity, and handling unknown and unpredictable events that fully autonomous systems cannot deal with [6].

III. Key metrics for the development of a forest clearing machine

In this section we will analyse the key features for the development of the UGV4FC. In order to assess which characteristics best meet the requirements imposed by the forest clearing function in the previously established scenario, the selected equipment will be compared in terms of its mobility, energy source, type of control, perception, communications, tools and availability. For this purpose, each compared parameter received its own adequacy scale that varies between 1 and 5, with 1 not being adequate and 5 being very adequate.

A. *Mobility*

The Society of Automotive Engineers defined vehicle mobility as ”the ability of vehicle to transverse a terrains”. In ground robotics vehicles mobility is better defined by the ability of the robot to interact with the ground maintaining a defined orientation at a certain speed. The various subsystems that contribute to mobility will be analysed below and their suitability for the scenario created above will assessed.

*1) **Locomotion**:* The locomotion subsystem of a mobile platform (MP) plays a key role in achieving mobility. Robotic vehicles have been developed in different shapes, sizes, and configurations [7]. The main types of locomotion systems are - wheeled as the tractor in (Fig 2(a)), tracked like (Fig 2(a)) MIM, legged , and hybrid. The locomotion system is defined taking into account the application or function within the application that the system will execute. The characteristics of the terrain, its orography, the type of soil, the number, shape and type of obstacles, are just some of the aspects to be taken into account when defining the locomotion system.

- Wheels 2
- Tracks 3
- Hybrid 4
- Legs 5

*2) **Steering type**:* There are also several steering systems for MP. The most common are: conventional, articulated, coordinated steer, skid steer, and independent. The steering system type largely depends on the application and may be determined or conditioned by the locomotion system. This happens in vehicles with two fixed tracks that have a skid steer type steering like the MIM in (Fig 2(a)).

- Conventional 1
- Coordinated steer 2
- Skid steer 3
- Articulated 4
- Independent 5

*3) **Gross Weight**:* Weight is critical to the mobility of any MP. Too much weight impairs mobility just as too little weight can limit functionality. Agricultural tractors are perfect examples of the balance between weight and functionality as they need to be heavy to exert force on the attachments and they need to be light to be able to transit over soft terrain. According to the established scenario and the challenges it presents in terms of weight the ideal weight is around 2500 kg. Lighter machines do not have the capacity to clear the bush that are expected in these areas and heavier machines will encounter difficulties in terms of stability.

*4) **Payload**:* The payload corresponds to the weight that the MP can carry in addition to its own weight. This load adds to the overall weight with the implications for mobility that have already been noted. A large payload capacity allows the use of more systems, and larger tools. In bush clearing, the tool used is a mulcher, its size and weight determines the removal capacity and the time it takes to clean a certain area. The greater the payload capacity of the MP, the better.

*5) **Turning radius**:* The turning radius corresponds to the radius of the arc described by the center of the path made by the outside front wheel (or outside track) of a MP when making its shortest complete turn [8]. In other words, it corresponds to the capacity of a MP to reverse its direction of travel in the smallest possible space. This ability is very important in tight spaces such as the forest, and construction sites. According to the established scenario and the challenges it presents the turning radius is important as it allows to get around obstacles and navigate through intricate spaces such as the bases of the electrical towers.

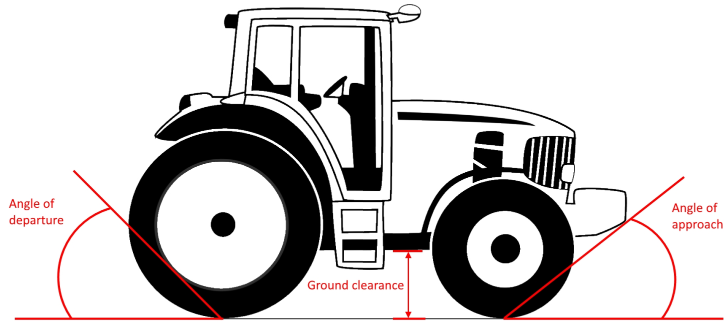
*6) **Ground clearance**:* In a simplified way corresponds to the distance between the underside of the MP and the ground. It is a crucial characteristic for mobility because it partly defines the MP ability to overcome obstacles. According to the established scenario and the challenges it presents the ground clearance must be greater than 250 mm height from which most obstacles such as stones are avoided.

*7) **Angles of approach and departure**:* As shown in Fig 2(b), the approach and departure angles are the maximum angles that a MP is able to overcome when approaching and exiting an inclined terrain. In the forest the change in slope can be very sudden and therefore high approach and departure angles are extremely important to travel in these places.

*8) **Max climbing angle**:* The maximum climbing angle is the angle from which the MP cannot progress on sloping terrain due to loss of traction. Factors such as weight and the locomotion system are decisive in the maximum climbing angle that a vehicle can overcome. In the forest the ability to climb high slopes is essential as we can see Fig 2(a).

*9) **Max lateral slope angle**:* The maximum lateral slope angle corresponds to the maximum inclination that a MP can traverse on a course perpendicular to the direction of the slope without overturning. Factors such as weight, width and position of the center of gravity are critical to travel along

(a)



(b)

Fig. 2. MIM examples and KPI: (a) PRINOTH tracked RAPTOR 100, remote-controlled carrier vehicle equipped with the M450h mulcher cutting bush on a slope, climbing angle KPI detailed in figure; (b) Ground clearance; Angle of approach; Angle departure.

a hill. This type of movement is very common in forestry applications.

B. Power

Diesel is the most common source of energy in agricultural, construction and forestry MIM, however, with the introduction of increasingly automated vehicles, the number of electric MIM has been growing.

*1) **Propulsion system**:* The type of propulsion is related with the time of use and the power required for the application. It is also necessary to take into account the use and consequent power consumption of auxiliary systems such as tools and attachments. MIM have been equipped with high power diesel engines known for their robustness and reliability when subjected to heavy duty tasks in harsh environments. More recently, work has been done towards hybrid electric systems as alternative propulsion units. These allows increasing the overall efficiency of the MIM reducing the amount of pollutants produced per unit of work. Full-electrification of MIM is increasingly seen as the way to further reduce emissions, reduce dependence on fossil fuels and boost automation. For the development of UGV4FC, it makes sense to focus on power solutions that are environmentally friendly and that at the same time facilitate the automation of processes.

- Petroleum-derived fuels 1
- Hybrids 3
- Full-electric 5

*2) **Operational range**:* The operational range is a very important parameter as it determines the time that a certain MP actually works with one tank of fuel or battery charge if it's electric. For certain applications, a large operating range is necessary due to the effort or distance to be covered; others are not so demanding and even allow breaks for re-charging or re-fueling. Operate in the forest presents several logistical challenges, a large operational range means more hours of uninterrupted work which allows a lower operational cost and greater efficiency. The UGV4FC ideal operational range would be around 8 hours without interruptions. To achieve this performance, it is important to select the proper battery technology and/or define the most suitable charging strategy for the application.

*3) **Battery technology**:* Advances in battery technology have been vital to the development of a wide range of industries, from autonomous vehicles, robotics, and drones [9].

- **Lithium-ion (Li-ion)** batteries have gained tremendous attention in the last decade. The rapid decline in costs is mainly due to massive increase in scale and the increase in cell performance, making cells cheaper on a cost/kWh basis. Lithium-ion batteries have high discharge current, good thermal and chemical stability and low cost when compared to other batteries technologies, reason why they are widely applied in electric vehicles.
- **Nickel-Metal** Hydride batteries are composed of nickel hydroxide as a positive electrode, different materials as a negative electrode, and a potassium hydroxide solution as the electrolyte. In comparison with lead-acid batteries, a Ni-MH battery has up to double the specific energy and a greater energy density. However, Ni-MH batteries do have disadvantages, such as having lower charging efficiencies than other batteries, and a higher self-discharge that is exacerbated in a high-temperature environment.
- **Solid-state batteries (SSBs)** are considered the next-generation energy storage technology [10]. Unlike lithium-ion batteries, (SSBs) won't need extensive monitoring, cell balancing, or cooling systems. They have more capacity, they are smaller, simpler, and lighter energy storage systems. They promise higher energy density, wider operating temperature range, and improved safety for electric vehicles. Lithium metal anodes (Li), with sulfide-based solid-state electrolytes (SSE), and nickel-rich cathodes are the most promising compositions. However, the battery cycle life at high cathode mass loading and high current is still limited because the failure mechanism is not fully understood. This is preventing the technology to scaled up to the sizes

required for electric vehicles [11].
- **Lead-acid** battery were the first rechargeable batteries ever made. Although the technology is outdated, it has stood the test of time and is still among today's most widely used types. It is popular due to its low cost of capital and ability to operate efficiently even at low temperatures, which often prevails over their low energy densities and low life cycle times.

*4) **Charging strategy**:* There are two main strategies for charging an electric vehicle's batteries; "opportunity charging / online charging" or "battery swapping". In opportunity charging the batteries are charged several times during the working hours while in battery swapping the battery is used until it is necessary to substitute it with a fully charged one. In forestry applications both opportunity charging and battery swapping may be feasible. Opportunity charging became an option if the MIM operating range allows charging to take place outside working hours, or if the fast charging option exists and is so fast that it makes sense to interrupt the operation to recharge [12]. Battery swapping in the other hand, makes sense if the swap operation is simple and fast. Either way, this two forms of charging the batteries only make sense if the energy that charges the batteries comes from a clean or renewable source.

*5) **Charging time & swap time**:* The time it takes to charge a battery can be a determining factor in the ability to run a particular application. Different battery technologies have different charging times, which is a determining factor in choosing the ideal technology for a given application. The charging times of an electric vehicle do not compare with the time of filling the fuel tank in an internal combustion vehicle, at least with the battery technologies existing at present. Swapping batteries also presents some challenges. Batteries are usually heavy and therefore difficult to manoeuvre. The swap has to be done by some type of mechanism that is not exactly at the place of operation, which implies travel to change the battery. In the forest, the UGV4FC will sometimes be far from the charging point and/or the battery swap point, but once there, swapping batteries can have advantages as this operation takes much less time to perform.

*6) **Available power**:* The available power is the sum of all the power sources that make up an MIM. In conventional combustion MIM, the available power is produced by the combustion engine, which then feeds the remaining systems. In electric MIM the power distribution can be centralised or decentralised. In a centralised system, the available power is the power produced by a single electric motor, similar to what happens with combustion MIM. In a decentralised power distribution, each system has its own electrical motor and actuators.

*7) **Hydraulic power**:* The hydraulic system can be independent or connected to the MIM main power system. Either way, there must be enough power for it to work when requested.The size and capacity of the hydraulic pump are the characteristics that define the power of the hydraulic system. The request can be permanent if all actuators are hydraulic or intermittent. The size of the system and the demands on the actuators define the power required for the hydraulic system to work. The attachment used in UGV4FC for forest clearing is very demanding in terms of torque so it would make sense to be hydraulic and therefore having a hydraulic system in the UGV4FC.Its power must match the power that the biggest attachment possible to fit the UGV4FC requests.

C. Control

*1) **Degree of autonomy**:*

- **Manual**: Range of machines and tools that depend on the human operator at all levels, from position and attitude control to decision making. Equipment without any ability to give feedback back to the operator or adapt to changing conditions. The human operator is at the heart of the operation and therefore at greatest risk while operating these equipment.
- **Remote-controlled**: Remote operation by means of a remote control as shown in the Fig2(a) allows the operator to be taken away from the action, which gives him greater protection against any type of dangerous event in the vicinity of the operation. These MP may have sensors and safety systems that alert the operator to events that may be unknown to him and that may lead to some danger.
- **Operator assisted autonomy**: Operator assisted autonomy allows operators to focus on the application as their MIM drives itself. While MIM are still manned by an operator, guidance technologies help maintain row-to-row MIM accuracy in the field in order to to reduce overlaps and skips. This category of automation uses both vehicle and environmental data to develop an information hub. MIM equiped with ISOBUS Class 3 functionality fall into this category as this technology allows, among others, the control of tractor ground speed and Power Take-Off (PTO) functions. Satellite imagery and soil sampling maps help in the coordination and optimisation of in-field path plans, which fall in the category of operator assisted autonomy. These technologies help save fuel, decrease labour costs, and reduce operator fatigue while also maximising crop yield.
- **Supervised autonomy**: The supervised autonomy category of automation allows to provide in-field supervision while unmanned MIM perform designated tasks. With unmanned MIM, supervised autonomy takes productivity and efficiency to a new level by enabling would-be-operators to monitor the performance of their MIM while simultaneously accomplishing other strategic, in-field tasks. MIM with this autonomous capability are equipped with high precision GNSS and intermediate level sensing and perception to avoid environmental obstacles.
- **Full autonomy**: Full autonomy is the most advanced category of automation. Full autonomy allows MIM to be operated with remote supervision - such as from the farm office - or via artificial intelligence. Additionally,

MIM with full autonomy have the ability to account for weather and moisture levels, which serve to further increase productivity and efficiency of the farming operation.

D. Perception

Perception is vital for an MIM to acquire knowledge about its work environment and itself. This is achieved by means of sensors and subsequently extracting relevant information from those sensor's measurements.

*1) **Position and Attitude sensors**:* Position sensors are devices that can detect the movement of an object or determine its relative position measured from an established reference point.

Attitude sensors are instruments for determining the angular deviations of the axes of a object from preset directions.

A combination of accelerometers, gyroscopes and magnetometers measure body's specific force, angular rate and the orientation. The magnetometer is commonly used as a heading reference sensor. These sensors are often combined in what is called a inertial measurement unit (IMU), typical configurations of IMU contain one accelerometer, gyro, and magnetometer per axis for each of the three principal axes

*2) **Application specific sensors**:* Force torque sensors used to know what force is being apply at a particular point. They are especially useful in situations where force limitation as to be performed. They can also be found in force feedback systems. Contact and proximity sensors detect the presence of objects and measure their proximity.

*3) **Awareness and Safety sensor systems**:* Awareness and Safety systems are not composed of a particular type of sensor, they usually involve complex algorithms as well as heterogeneous sensor fusion. These systems are used to prevent dangerous situations from occurring, namely The detection of people and/or animals around the MIM, the adaptation to the ground conditions and the blocking or activation of actuation systems.

E. Communications

*1) **Internal communications**:* Modern MIM, such as tractors or highly automated harvesters, employ numerous Controller Area Network (CAN) networks to enable communication within the control system, such as engine CAN and vehicle CAN. Due to the growing number of subsystems that these MIM have, a specific communication protocol called, ISOBUS based in CAN was developed. ISOBUS came to standardise communications so that any tool or attachment can be added and controlled by the MIM regardless of its manufacturer [13].

*2) **External communications**:* Connectivity technologies are an essential part of modern MIM, which utilises various digital technologies to improve the efficiency of operations. Emerging communication technologies—5G, sensor networks, satellite systems, and tactical networks as wireless backbones—provide greater control while the operator is freed from less productive functions such as driving.

F. Tools or attachments

Tools on agricultural and forestry MIM are called attachments. This is because these are attached to the machine giving it a function. In agriculture the MIM have high diversity of attachments, while in the forestry and in construction it is more common for each machine to have only one or two functions and therefore fewer attachments. The limit of the attachment is related to the weight of the MIM and the PTO characteristics. There are International Organization for Standardization (ISO) standards that regulate the various aspects of attachments, such as, their fitting and connection to the PTO and therefore there is interchangeability of attachments between different manufacturers. The mulcher attachment is used for forest clearing. Although there are other attachments that are complementary or that can replace the mulcher in certain situations of forest clearing, the main attachment is the mulcher. This can be actuated by the PTO or independently by its own motor. The mulcher can be attached directly to the front, rear or end of an articulated arm for clearing in hard-to-reach places. The mulcher itself is composed of a steel cylinder with teeth called hammers that rotate against the bush, breaking it into small pieces as the machine advances. The standardised fittings, the allocated power and its size are relevant factors with regard to tools and attachments when developing an UGV4FC.

G. Availability and price

The availability of equipment for clearing the forest is relatively large if we consider that this operation can be carried out by MIM normally used in agriculture and construction. Specific solutions for clearing the forest are relatively recent and are already available for sale. As the level of autonomy goes up, there are fewer solutions on the market and their prices rise sharply. MIM for clearing the forest and for the timber industry with a high degree of autonomy are still in academia or concepts without validation.

IV. Comparative analysis of different platforms

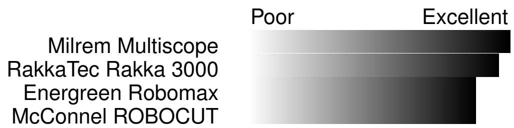
After characterising the most relevant parameters of a mobile robotic platform for use in demanding outdoor environments, such as forest clearing, a set of MIMs was selected to be compared. The aim is to identify the most suitable MIM platform to serve as basis for refitting it into an electric UGV4FC.

In this section, the MIMs were compared in terms of its mobility, power, control, perception, communication, tools and availability. The MIM's selection criterion at this stage was based on a macro assessment of its suitability for work in the forest environment.

A. Overall results

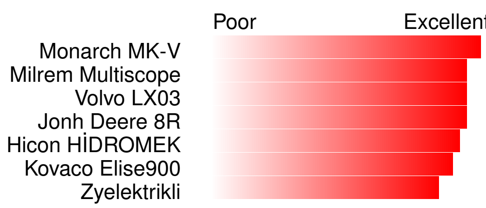
The graph in Fig **??** contains the analysis performed on 34 characteristics divided into 7 groups identified as key to the development of a UGV4FC.In this section, the results in each of the feature groups are discussed and the set of features of the machine to be developed is defined.

*1) **Mobility**:* Four MIM stand out themselves in terms of mobility KPI:



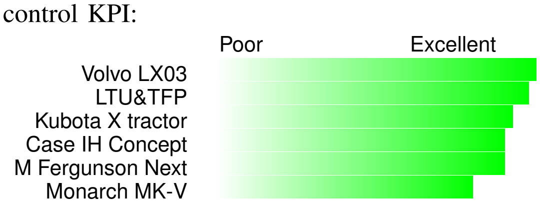
All of them were developed with forestry applications in mind, they therefore have the appropriate characteristics to move in this type of terrain. The first three use tracks and a skid steer steering system while the RakkaTec Rakka 3000 uses wheels but compensates with an articulated steering. Weight is a characteristic that greatly impairs mobility, MIMs such as the LTU&TFP and most agricultural tractors were penalised in relation to other lighter systems. The payload capacity on the other hand put at disadvantage MIMs like the Green Climber LV600, which despite having similar characteristics to Energreen Robomax does not support a tool attachment as big as the later one.

*2) **Power**:* In terms of power KPI seven machines distinguished themselves:



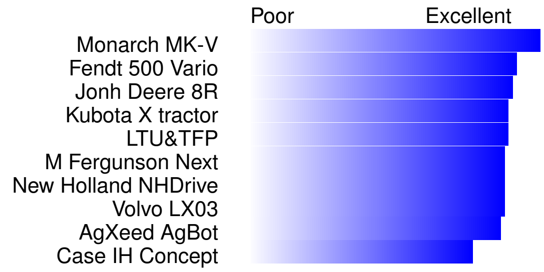
Most have electric motors. Those that are not electric have either a hybrid engine, namely the Milrem Multiscope or an extremely powerful and efficient diesel engine such as the John Deere 8R. Most used battery technology is Lithium-ion, with the exception of Kovaco Elise900 which uses lead-acid batteries. Of the electrical machines, those that have longer operating time, shorter charging times and that have hydraulic systems stood out, namely Monarch MK-V. The Monarch MK-V distinguishes itself by also presenting the option to swap batteries in addition to the opportunity charging.

*3) **Control**:* Six MIMs have had notable marks in terms of control KPI:



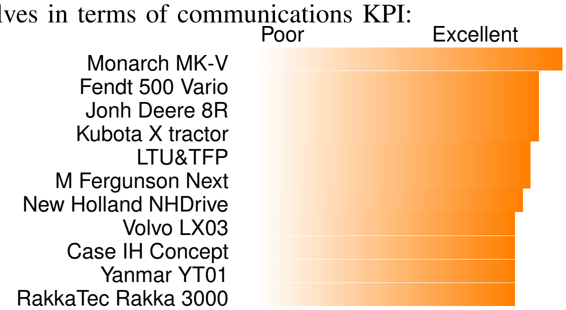
In terms of control, equipment with a high degree of autonomy and control systems more adaptable to the forest environment stood out despite the fact that only the LTU&TFP is a forestry equipment. They are all fully autonomous and partly because of that they are all still concepts, but what they promise is revolutionary and that's why they stood out.

*4) **Perception**:* In terms of the perception KPI there are prominentten MIMs:



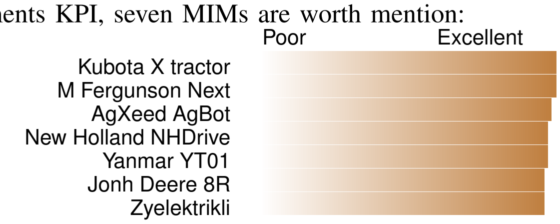
The machines that stood out are those with the largest number of sensors. Despite not being fully autonomous the Monarch MK-V, is equipped with a series of specific sensors which allow it to predict near future environment conditions. This sensing capability is also essential for forest clearing.

*5) **Communications**:* Eleven MIMs distinguished themselves in terms of communications KPI:



Agricultural machines stood out in terms of communication. Not only do they have a huge number of internal systems, but they increasingly communicate with each other in joint operations, as they communicate with the cloud to obtain and send data, whether positional or meteorological. All of these devices use the same communication protocols that were developed specifically for agriculture operational MIMs. LTU&TFP, RakkaTec Rakka 3000 and Volvo LX03 were not developed for agriculture but also have advanced communications systems. The forest environment creates some communication challenges as operations can take place in places without network coverage and densely forested. The LTU&TFP MIM is probably the only one that has developments made in this direction since it a research project specifically developed for the forest.

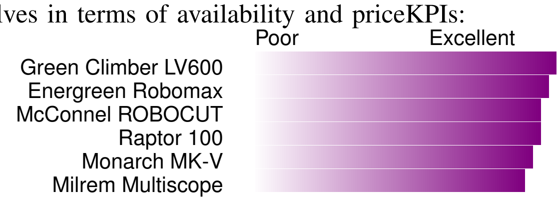
*6) **Tools and attachments**:* Regarding tools and attachments KPI, seven MIMs are worth mention:



As in the previous KPI (communications) the agricultural MIMs also stand out. The largest number of attachments are made to adapt to the standard connections of agricultural equipment: Cat 1 & Cat 2 & 3-Point Hitch. There are also ISO standards for the other MIMs such as ISO 24410:2020 for earth-moving machinery like skid steer loaders, but there are not nearly the same number of solutions. The AgXeed AgBot stands out because it has a three-point front linkage

Cat 2 and a three-point rear linkage Cat 3, like an agricultural tractor and a powerfull electrical PTO.

*7) **Availability and price**:* Five MIMs distinguished themselves in terms of availability and priceKPIs:



It was precisely the forest clearing machines that stood out in this category. In addition to availability in the market, these have a reduced cost when compared to larger agricultural machines. Once again the Monarch MK-V stood out, which in a way proves that it is feasible to develop equipment with a very high degree of autonomy at a competitive cost.

B. *Conclusion*

A comprehensive survey was carried out on the available platforms which can provide technical solutions to be used for forest clearing applications. Although the market is in rapid transformation towards sustainable energy solutions, and increased autonomous operation capabilities in non-structured forest environments, there is not yet an commercially available of the shelf solution for forest clearing. The study has identified critical requirements which the platforms must achieve for that purpose.

From the analysis carried out, taking into account the metrics defined as important for the application, its possible to remark that, both the development from the scratch of electric Unmanned Ground Vehicle for Forest Clearing and the adaptation of an MIM are reasonable. As shown in table I, the best candidate for an adaptation is the Monarch MK-V. The Monarch MK-V MIM presents good results in practically all defined metrics. The refitting would focus on two aspects, mobility and adaptation of forest specific attachments to agriculture chassis of this MIM. Fig 3 shows that other MIMs could also be adapted, some with even greater forestry vocation, such as the Bergmann M201, the Raptor 100 or the Milrem Multiscope but they would imply electrification, which could make such a project unfeasible. The development of a electric Unmanned Ground Vehicle from scratch makes sense and is reasonable because there is no fully-electric solution for Forest Clearing with a high degree of autonomy.The metrics for its development were established in this work and are as follows:

- Tracked locomotion
- Skid steer steering mechanism
- Electric power
- Hydraulic actuated
- Weight gross between 2500 and 3500 kg
- Minimum payload of 1000 kg
- Electric plug for electric-powered attachments
- Remote control with supervised autonomy capabilities
- Operating range over 8h
- Charging time $<$4h
- Both opportunity charging and swap battery options
- Standardise communication protocols
- Standardise coupling for attachments
- Selling price below 70k(USD)

Ongoing research and development activities, both by several manufacturers and research institutes, are likely to achieve the required performance in the near future (up to 2025), addressing a very large potential market around the world.

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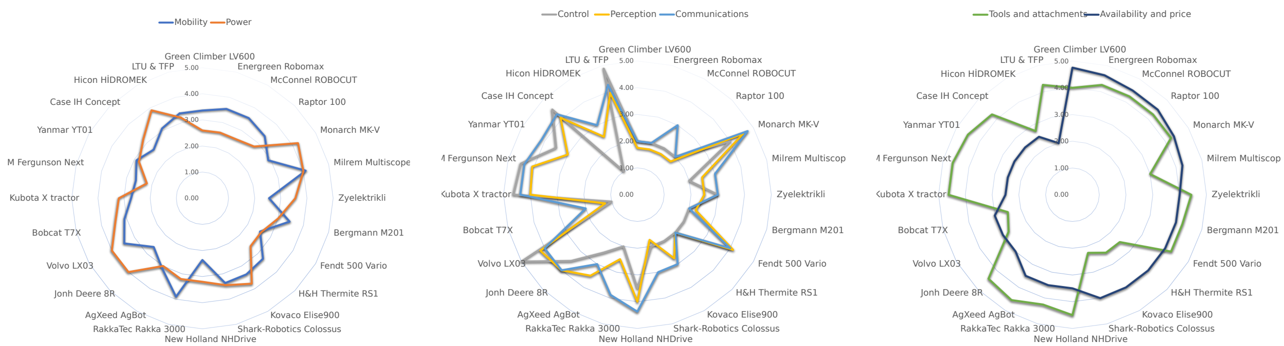
TABLE I

RELEVANT MIM CHOSEN TO SERVE AS TECHNOLOGICAL BASELINE, ITS ORIGINAL FIELD OF APPLICATION, DEVELOPMENT STAGE AND EVALUATION

Model	Field of application	Development stage	Mobility	Power	Control	Perception	Communications	Tools and attachments	Availability and price	Overall
AgXeed AgBot	Agriculture	Commercially available	3.09	3.00	2.50	3.50	3.00	4.55	3.50	**3.25**
Bergmann M201	Forestry	Commercially available	3.45	3.00	2.00	2.25	2.00	4.25	4.00	**2.99**
Bobcat T7X	Construction	Commercially available	3.09	3.44	1.00	1.25	2.00	2.50	3.00	**2.33**
Case IH Concept	Agriculture	Industry concept	2.64	3.20	4.50	4.06	4.25	4.25	2.50	**3.63**
Energreen Robomax	Forestry	Commercially available	3.55	2.60	2.00	1.75	2.00	4.25	4.63	**2.97**
Fendt 500 Vario	Agriculture	Industry concept	2.55	2.60	2.00	4.13	4.00	4.25	4.00	**3.36**
Green Climber LV600	Forestry	Commercially available	3.36	2.60	2.00	1.75	2.00	4.00	4.75	**2.92**
H&H Thermite RS1	Civil protection	Commercially available	3.27	2.60	2.00	2.00	2.00	2.50	4.00	**2.62**
Hicon HİDROMEK	Construction	Industry concept	3.09	3.89	1.00	2.50	3.00	2.75	2.50	**2.68**
Jonh Deere 8R	Agriculture	Industry concept	2.64	4.00	3.50	4.00	4.00	4.44	3.00	3.65
Kovaco Elise900	Construction	Commercially available	3.36	3.78	2.00	2.75	3.00	2.50	4.00	3.06
Kubota X tractor	Agriculture	Industry concept	2.73	3.20	4.63	4.00	4.38	4.63	2.50	**3.72**
LTU&TFP	Forestry	Research and development	3.36	3.20	4.88	3.94	4.25	4.25	2.00	**3.70**
M Fergunson Next	Agriculture	Industry concept	2.64	2.20	4.50	4.06	4.38	4.63	2.50	**3.56**
McConnel ROBOCUT	Forestry	Commercially available	3.55	2.60	2.00	1.75	3.00	4.25	4.50	**3.09**
Milrem Multiscope	Multifunctions	Commercially available	4.09	4.00	2.00	2.50	3.00	3.00	4.25	**3.26**
Monarch MK-V	Agriculture	Commercially available	2.91	4.22	4.00	4.56	4.75	4.25	4.38	**4.15**
New Holland NHDrive	Agriculture	Industry concept	2.36	3.20	3.50	4.00	4.38	4.50	3.50	**3.63**
RakkaTec Rakka 3000	Forestry	Industry concept	3.91	3.20	2.00	2.50	3.88	4.25	3.50	**3.32**
Raptor 100	Forestry	Commercially available	3.36	2.80	2.00	1.75	2.00	4.25	4.50	**2.95**
Shark-Robotics Colossus	Civil protection	Commercially available	3.36	3.44	2.00	1.75	3.00	2.25	4.00	**2.83**
Volvo LX03	Construction	Industry concept	3.45	4.00	5.00	4.19	4.00	2.75	3.00	**3.77**
Yanmar YT01	Agriculture	Industry concept	2.91	2.80	3.50	3.00	4.13	4.50	2.50	**3.33**
Zyelektrikli	Agriculture	Commercially available	2.55	3.56	3.00	2.50	3.00	4.44	4.00	**3.29**



(a) (b) (c)

Fig. 3. MIM overall evaluation: (a) mobility and power KPIs; (b) control, perception and communications KPIs; (c) tool & attachments and availability & price KPIs.