Preliminary Design of an Autonomous Armoured Combat Vehicle

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Abstract - *This paper presents the concept of an all-electric small scale unmanned autonomous combat bot which could be further enhanced into an autonomous tank. With the rise of automation in various industrial sectors, Nations like the US and Russia have developed and deployed unmanned ground vehicles for the past decades. Whilst most of these vehicles were meant for surveillance and recon purposes, quite a number of them have been armed with various weapon systems. A few of these combat-capable unmanned ground vehicles include The Russian Uran-9, The Estonian THeMIS, The Turkish UKAP, and many more. Accordingly, we propose a Proof of Concept model of an Autonomous Tank which may be deployed to monitor borders and to carry out operations like Perimeter Scanning, Search and Rescue or Search and destroy missions. An alternative and less-lethal model of the tank could also be employed for crowd controlling and patrolling during the times of a national disaster like the current ongoing pandemic. The model of the proposed idea consists of an autonomous armored vehicle that is capable of perimeter patrolling and detecting threats using computer vision. This vehicle shall also be armed with an automated projectile launcher. This automated gun shall be actuated by a controller that receives inputs regarding a target's position and commands the launcher to shoot accordingly. The detection algorithm shall be able to differentiate amongst targets and nontargets. Thus the prototype shall be able to perform the tasks of moving from one point to another, detecting objects, classifying targets and non-targets, and eliminate the targets by itself.*

Key Words: **Autonomous, Armored Combat Vehicle, Object Detection, Target Classification.**

1. INTRODUCTION

According to South Asia Terrorism Portal, the Indian Armed Forces has lost more than 7000 soldiers, in the past two decades, due to terror attacks; insurgent cross fires; border and cease fire violations; counter-terror exercises etc. Despites the army's best, a significant number of attacks have been carried out regularly by various villainous organizations. These attacks clearly indicate that there exists a flaw, in the country's defensive methods, which still remains as an open wound – unintelligent perimeter scanning and threat evaluation techniques. The repetitive terror attacks also show that the spread of intel during such mishaps and the immediate responses leave a lot to be desired. This has often resulted in escalation of threat levels and has resulted in the loss of many more lives. If a system could identify and eliminate threats as they appear at the borders, or within the borders, most insurgent acts could be stopped before they start. Thus, our proposed model of an autonomous tank would be ideal to convert the nature of the defensive methods into an intelligent system.

The model would essentially consist of an Armoured Vehicle which, could be controlled remotely or be driven autonomously while being capable of following paths or finding new ones. The vehicle could thus be guided towards an area of interest to gain the necessary intel, via a video feed, without needing to risk the lives of security personnel. This would automate the task of border patrolling whilst improving safety of the security forces. The vehicle would also be sufficiently armed to counter any immediate opposition thereby reducing the risks of ambush or crossfire victims. The autonomous control of the vehicle would enable it to scan a region in order identify the presence of enemy elements. The vehicle would then be able to tackle these elements by itself, without any explicit commands.

This would certainly help in the development of a smarter defense system wherein, rapid responses to any sudden attack would be possible without the risk of threat escalations.

1.1 Concept of an Autonomous Tank

While the MUNTRA and DAKSH projects are useful for safeguarding personal from explosives and toxic environments, a concrete automated border scanning system is yet to be incorporated. Also, the unpredictable nature of terror strikes makes immediate tactical responses very difficult. The delay between the onset of an attack and a proper response causes the threat to escalate and result in the loss of more lives. Accordingly, several small scale autonomous bots can be deployed to assist the armed forces in various operations. We thus propose our model of a small scale autonomous tank which shall be suited for the above mentioned tasks.

Our proof of concept model pertains to an all electric bot equipped with the necessary sensors and equipment in order to demonstrate tasks like perimeter scanning search and destroy and search and rescue. The evaluation of the model's performance can certainly pave a path for combat ready bots and UGVs. These vehicles could be deployed in zones too risky for human interventions or for patrolling during odd hours.

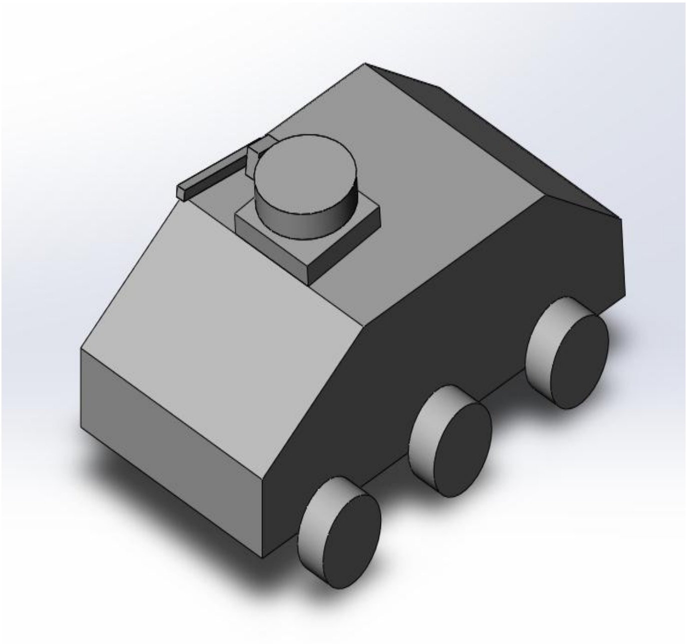

Fig -1: Conceptual model of the Autonomous Tank

1.2 Components of an Autonomous Tank

In order to better elaborate on the construction and working of the model, we have divided the model into its three basic subsystems, classified according to their functions viz:

- The Mobility Subsystem
- The Detection and Tracking Subsystem
- The Shooting System.

The functioning of the proof of concept model and the co-ordination of all subsystems can be expressed as

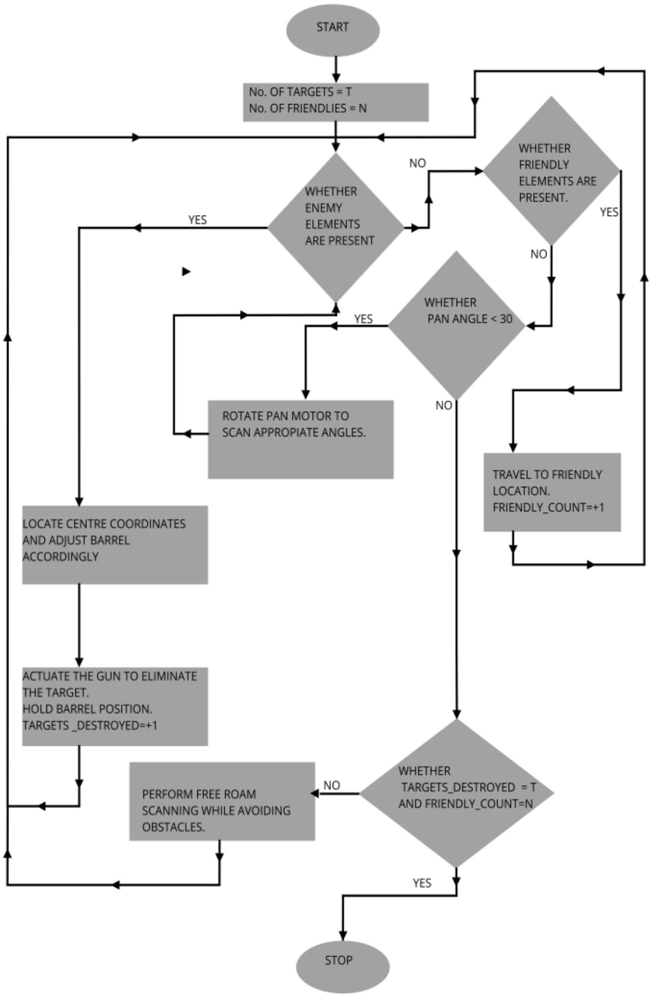

Fig -2: Operation of the Autonomous Tank

2. MOBILITY SUBSYSTEM

This subsystem essentially forms the basis of this autonomous vehicle. It refers to the integrated systems which tend to the functions of propulsion and directional control. The propulsion can be achieved by using I.C engines or electric motors depending upon the scale of the bot. Electric motors, like the B.O. Motors used in the proof of concept model prove to be quite suitable for small scale bots, as they provide a constant speed and torque. This is paired with a near silent and instantaneous operation, which makes them ideal for operations like gathering intel amidst a suddenly arising situation. Alternatively, IC engine based Unmanned Ground Vehicles can be deployed for perimeter scanning purposes along with the BSF and for search and rescue operations. Electrically operated vehicles can also be deployed in regions where charging can be facilitated by isolated independent power generation methods like off-grid solar systems. We preferred the method of electrical propulsion as it would make the integration of the autonomous driving algorithm very convenient. The autonomous driving algorithm to be used must be such that it can avoid collisions with stationary as well as moving obstacles. The subsystem thus ensures that the bot follows the required paths or employs a mapping algorithm to find newer paths. Accordingly search algorithms like the A* algorithm, Robot path planning algorithms like the Potential Field approach and even Special Bug algorithms can be used to dictate the movement of the bot.

Table -1: Selection of Mobility method

Evaluation of Performance of the Mobility Subsystem			
Parameter	*A* Algorithm with BFS*	*A* Algorithm with DFS*	*Potential Field Method*
Components Needed	PIR, range sensors	PIR, range sensor	**range sensors,Camera**
Path definition	Requires a well defined physical path	Requires a well defined physical path	**No need to physically define a path**
Time needed to reach goal state with respect to path length	Short for less than 3 junction paths, exponentially greater for larger paths	Short for less than 3 junction paths, linear growth in time need for larger paths	**Can trace straight paths so time is much more dependent on travel speed.**
Description of motion	Low speed path following. Subjected to backtracking and retracing at every junction.	Low speed path following. Subjected to backtracking at dead ends and no retracing.	**Full speed motion until bot is close enough for braking. Backtracking and retracing are subjected to obstacle conditions**
Need of Trial run	Requires a trial run to find and record the optimal path	Requires a trial run to find and record the optimal path	**No need of a trial run in ideal case.**
Nature of Starting and Goal States	Same for each Trial and Main run	Same for each Trial and Main run	**Can be changed at any time**
Ability to learn and optimize paths	Present but time consuming and buggy.	**Present and smooth**	Can optimize paths to adjust for obstacles but does not learn patterns.

Whilst all of the above mentioned methods shall work with a bit of tinkering, we decided to implement the potential field approach method in association with range sensors and a memory function as it better suited the needs of this proof of concept model as the computational power available is considerably limited.

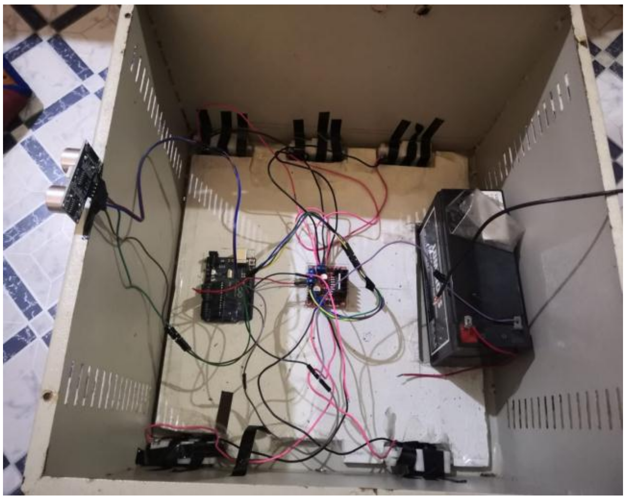

Fig -3: Basic Setup for Mobility System

Using the current setup, we were able to make the UGV patrol a particular irregularly shaped path while avoiding obstacles. This setup, even though is oversimplified, can be used to test and tune various parameters to smoothen out the autonomous driving feature of the model. Later on, it can be configured to obtain inputs from the detection subsystems which would then provide the driving instructions. Finally, on clamping the motors with an improvised suspension system, the azimuth mount, supporting the camera and barrel, can be stabilized and free from vibrations.

3. DETECTION AND TRACKING SUBSYSTEM

While computer vision isn't an entirely new concept, the recent developments in computational capabilities of modern hardware including dedicated GPUs and embedded system boards have caused a surge in the appeal and reliability of computer vision systems for real world applications. Thus computer vision has found countless applications in intelligent vehicles, security systems for both physical and virtual spaces, intelligent transport systems and even crowd monitoring. It has also been extended into the military sector by various organizations and we propose to apply it to unmanned/ autonomous combat vehicles.

The detection of a target element and its subsequent tracking forms the backbone of the proof of concept model as it is the primary function which provides inputs to the other systems. It thus dictates the working of the entire model. We believe that the detection system would bear a similar responsibility even in full fledged versions of it, as a combat UGV or a completely autonomous unit. According several computer vision techniques have been developed and tested for their subsequent deployment in the proof of concept and prototype versions.

For this model we have considered the following three computer vision methods for detecting various elements and classifying them as either friendly or foes:

- Haar-like feature extraction
- HSV based classification methods
- Neural Network based image classifiers

All the respective image processing algorithms were developed on a windows based platform power by a quad core 2.5GHz CPU and 8 GB of RAM. They were later deployed on a much smaller single core 1 GHz SOC having 1 GB of memory. Thus the compatibility and effectiveness of the algorithms while running on the smaller board is a major factor. This is because; eventually the smaller board is to be used for the proof of concept model.

3.1Haar-like Feature Extraction:

Haar-like features are rectangular regions, defined within a digital image, such that they can be used to subdivide the image into various components based on the difference of pixel intensities. They were popularized by P.Voila and M. Jones in 2001 by their paper titled "**Rapid Object Detection using a Boosted Cascade of Simple Features**". This paper introduced three major ideas viz: the concept of using Intergral Images, A learning algorithm for extremely efficient classifiers and the concept of Cascading classifiers to reduce computation. These contributions were further worked on and integrated in many Haar-like image classifiers.

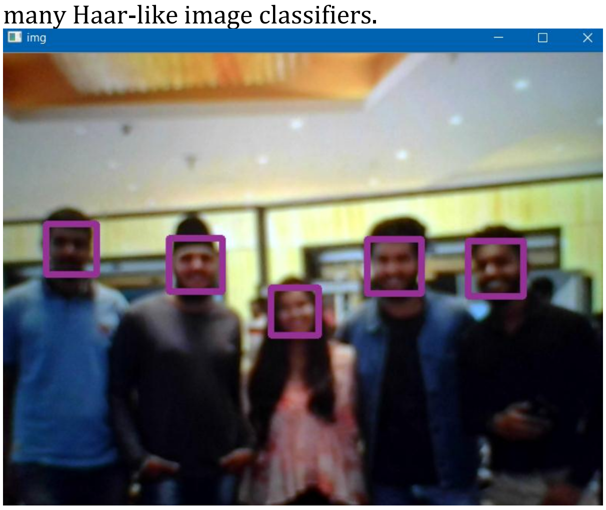

Fig -4: Haar-Cascade Classifier detecting faces

Accordingly, we had built a face detection cascade classifier which was capable to detecting and tracking human faces as they moved around in the image frame. At this stage, the classifier would simply differentiate between faces and other objects. With a little tinkering, faces could be grouped or segregated from each other on the basis of different parameters. This classifier was to be used as the basis of our friendly-foe classifier. Thus with further enhancements, we were able to have a Haar-Cascade classifier capable of detecting a face from the videostream, classifying it as friendly or foe, and continuously updating its position in a Cartesian co-ordinate system.

Performance of the Haar Cascade Classifier:

Using the previously mentioned windows based system; the classifier was developed in Python3. It consumed about 500MB of memory whilst having a 60% load on the CPU. The detection accuracy varied from 0.65 to 0.9. The total data required was 576 positive and 1136 negative images. The algorithm worked well enough at a frame rate of 20fps and a low resolution of 640X480.

However, deployment of the algorithm on the smaller SOC caused it to underperform drastically. This was mainly due to an over defined algorithm which was too much for the SOC to compute. Thus this method was rather unoptimised to be used directly.

3.2 HSV based Method:

The HSV colour model is a digital image processing method which uses three parameters viz Hue, Saturation and Value. It serves as an alternative to the RGB colour model and is a better representation of human colour perception. The three parameters of hue, saturation and value refer to the visual sensation according to which a region is perceived to be similar to either of the three primary colours or a combination of colours. Saturation refers to the amount of colour present in a region. Value simply refers to the brightness or the amount of light present. The model is based on a cylindrical coordinate system wherein the hues of the three primary colours are separated by 120 degrees. Accordingly, a particular colour range can be selected to be detected by the algorithm in order to ease computation needed for object classification. This method would involve extremely cheap computation and would provide an oversimplified detection system. There exist a few flaws like overdependence on colour coded entities and lightening condition but the method is most compatible on smaller hardware.

Using the HSV method, we were able to simplify the elements to be detected on the basis of color and shape. Accordingly, using a specific colour range for enemy and friendly entities helps streamline the detection and tracking process. Thus the HSV range of (150 150 100) to

(255 255 255) was selected for target units and (45 150 100) to (90 255 255) was selected for friendly units. A threshold area of 6000 pixels was selected in order to have a detection range of 2 meters. This range can be varied by the provision of an illumination feature and by decreasing the threshold area.

Fig -5: HSV method to detect targets and friendlies

Performance of the HSV Method:

This method was directly developed into the SOC after the colours had be identified using a different algorithm. The classifier consumed about 200mb of the board's memory resources whilst detecting objects at 640 X 480 with a consistent frame rate of 32 fps. The frame rate and resolution were inversely proportional and thus this was the best compromise for rapid and accurate detection. The deployment of the HSV method of classifying elements was the most favourable with almost no detection or mishit issues. The Test subjects, balloons, were classified flawlessly and the tracking system could easily be built upon this for the demonstration purposes.

3.3 Neural Network based Image Classifiers:

A neural network is a deep learning technique which is modelled after the functional biological neural network and is composed of layers of artificial neurons. The inter-neural connections are modelled as weights which may reflect an excitatory or inhibitory connection. The algorithm requires well defined and segregated images of the required classes. These input images are scanned for features. Activation functions are employed to set the output of the layers based on the input from the raw data or the previous layer. After this, down sampling is done to condense the activation feature. Neural networks also use weights and biases to identify the patterns in the provided images. These enable the model to make decisions faster or with better confidence, when certain conditions are met. Neural networks are machine learning method which involves a few different forms like CNNs, DNNs, and ANNs etc. Convoluted Neural Networks (CNNs) are the most commonly used deep learning algorithms which are deployed for visual computation. CNNs are essentially neural networks with a convolution and pooling layer for feature extraction and weighing. Convolution and Pooling help to reduce image matrix sizes thereby reducing computation. They also include a series of hidden layers which perform back propagation to obtain enhanced accuracy.

Performance of the CNN image classifier:

Two neural networks were developed to compare their performance and relevance for this model. The first was a double layer CNN, with a learning rate of 0.6 and 25 epoch. Relu was selected as the activation function and an accuracy of about 0.75 was achieved. This accuracy could be enhanced by increasing the sample size, number of layers and a few more tweaks. The second network was built on the VG16 model and reused the earlier parameters. This network, however, yielded an accuracy of over 0.95 for every test sample. However this method is extremely unoptimized even for a quad core CPU platform with dedicated GPU. Deploying the network in the SOC caused it to overheat and shutdown. Thus severe optimizations would have to be done for this method to be successful.

Table -2: Selection of Detection System

Evaluation of Performance of the detection systems			
Parameter	*Haar-Cascade Classifier*	*HSV Method*	*CNN*
Accuracy	0.75-.9	0.6 - 1	**.95 and above**
Frame Rate on RasPi board	Max 10.2 fps Avg 8.3 fps	**Max 32 (programmed limit) Avg 32**	Not directly deployable
Data Needed (Sample/Test Images)	500+ positives 1000+ Negatives	**Not needed**	200+ per class
Training Time	10 minutes	**Not Needed**	25-30 minutes
Consistency with Moving Objects	Poor	**Undeterred**	Can detect Moving objects at high

			framerates.
Drawbacks	Highly dependent on lighting conditions and stability of Camera. Does not work with moving or tilting objects	**Highly dependent on lighting conditions. Does not incorporate any learning mechanism.**	Requires large processing power, unavailable on the Smaller Pi board.
Suitability	Cannot be used in current state as it severely underperforms. Optimizations may be possible	**Best suited for the scope of the model.**	Cannot be used due to computation limitations.

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4. SHOOTING SYSTEM

For the proposed model, the shooting system would be mounted along with the main video feed camera such that the centre coordinates of the camera's frame are coincident or as close as possible to the barrel. This is required so that the camera and the barrel can be mounted on a common tracking mechanism which is capable of panning and tilting. However, the entire shooting mechanism cannot be supported on an azimuth mount due to space and weight constraints. Thus, the shooting system has to be designed such that the heavier portions are situated inside the body, while the propulsion unit and the barrel are on the mount. This would enable the bot to change the barrel's direction as per the detection and tracking system's inputs. While it is completely possible to develop a chemical propelled projectile launcher for the given constraints, we decided to develop an launcher powered by electromagnetic propulsion. This was done to make the integration of the shooting system with the other systems much more convenient. In this case, all the systems could easily be controlled by a central SoC.

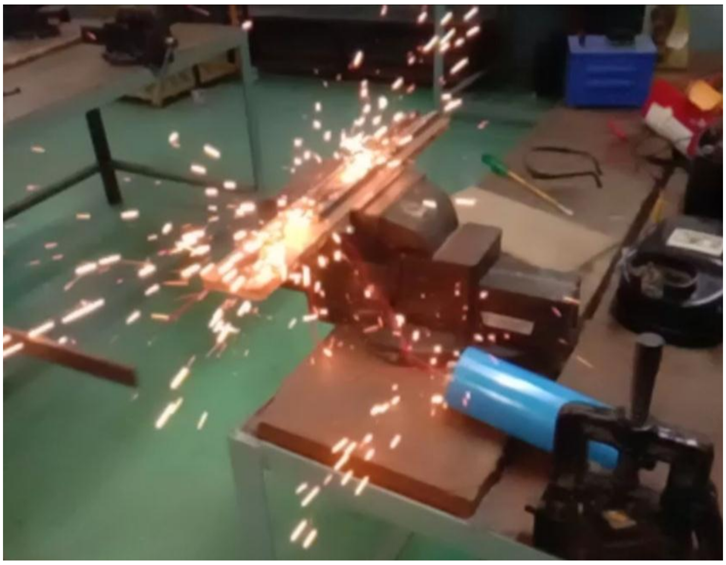

Fig -6: Testing of rail gun

Correspondingly, we designed and developed an improvised rail gun which was powered by a large capacitor. Using metals of medium conductivity, we were able to manufacture the rails and the projectiles of the required dimensions. In order to avoid weld spots, a pneumatic launch mechanism was used to provide an initial velocity to the projectile. With this method, the projectile was expected to have a theoretical velocity of 10m/s but due to various losses, had an actual velocity of about 6m/s.

An alternative shooting mechanism consisting of a gauss rifle was also developed. It consisted of a dual copper coil barrel, powered by a high capacity capacitor. A set of sensors and relays was also used to ensure smooth functioning of the gun. The current arrangement was capable of launching ferromagnetic projectiles with a velocity of about 10m/s.

Even though this velocity was enough for validation purposes, other methods of launching the projectile are also being looked into.

5. CONCLUSIONS

We have thus designed a small scale proof of concept model of an all electric Unmanned Ground Combat Vehicle or an Autonomous Tank, and have been able to demonstrate its working.

Such small scale all electric autonomous UGVs can be used for intel gathering purposes in localized areas especially where silent motion is required.

We were thus able to develop various bug algorithms for the bots movements and were able to study their performance comparatively in order to deploy the best possible algorithm for the Mobility system. Whilst methods which have a potential to adapt to changing paths and can calculate optimal paths on the fly may seem appealing, their computational requirements cause them to be shadowed by a simpler Potential Field approach.

A similar analysis for the detection system was also done, which enabled us to use an improvised HSV method for detected the target and friendlies. This was the most suitable method considering the existing constraints. Accordingly, a more linear concept of friendly and foe targets. Subsequently, the use of better hardware can assist in the development of learning methods like CNNs to detect real enemy elements.

We also developed a gauss gun, to be controlled by the central SoC, having full autonomy and with less explosive ammunition along with no compromise of accuracy. Two potentially serviceable guns were developed, experimentally tested and the more efficient system- the coil gun was used for this system.

5.1 Scope for Future Work:

As we have used general purpose hardware along with low cost materials, a smaller intel gathering version of the tank can be build by using specialized components.

Accordingly, a multicamera arrangement can be used instead of the monocamera method in order to collect more information.

The use of a processing board with a dedicated GPU would enable the tank to run much more advanced image processing methods like multiple neural networks. It could also benefit from different human action monitoring methods like skeletal tracking and abnormal activity detectors

Full scale, I.C engine powered UGVs can also be equipped with a similar threat classifier and be used for long distance or remote operation under supervision or in autonomous modes.

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