Emergency response robotic platforms

N A Uvarov and V I Syryamkin
Department of Innovative Technologies, National Research Tomsk State University,
Tomsk, Russia
E-mail: Nikotomsk@gmail.com

Abstract. This paper describes the development of an autonomous robotic platform capable of undertaking rescue missions on rough terrain and other unpredictable environments. The key difference of this platform is the lack of LIDAR system and an algorithm that relies primarily on ultrasonic and optical sensors. As a result, two platforms were created, a fully autonomous drone and a scout bot that operate effectively together.

1. Introduction
A relevant problem in robotics is the creation of transport robots capable of evacuating victims from dangerous areas. To create such robots, it is necessary to complete the following tasks:
1. Develop requirements for autonomous platforms used in rescue robots.
2. To develop a universal robotic platform on which navigation and diagnostic equipment can be installed, as well as various sensors, depending on the particular task the platform is facing.
3. Develop a block diagram of platform’s behaviour.
4. Build and test a rescue robot based on the developed platform.

Many companies have already started production of autonomous off-road going mobile platforms. Most of them are wheeled platforms that utilise LIDAR technology to scan the environment around them in great detail. Such a setup is very effective, however cost of LIDAR sensors as well as the processing power required to operate such sensors can be a major downside of such systems. This project aims to recreate the off-road capabilities of LADAR-based systems with much more approachable hardware and simpler algorithmic methods. The algorithms that are used in such platforms are not entirely dissimilar to those used in controlled, or even virtual environments [1]. Let us consider the issues of designing and developing such a platform for the purpose of creating a rescue robot in more detail.

2. Autonomous control system
The platform's control system consists of three key aspects: obstacle avoidance algorithm using ultrasonic sensors, GPS, a compass module, artificial intelligence system that uses video stream processing to recognize obstacles and a manual control system. This section will discuss in detail the features of the algorithm, its fundamental principles and disadvantages, as well as the impact of each component of the system on autonomous navigation of the platform.
The idea for the algorithm used on the autonomous mobile platform arose even before the literature review and research of already existing solutions began. Only after performing some of the platform’s equipment testing using the basic version of the algorithm an existing navigation method using ultrasonic sensors (virtual force field method) [2] was discovered. This method did not fit the goals of the project, but the logic and the main essence of the algorithm in the method coincided with those originally conceived. Based on the virtual force field method, the navigation algorithm has been brought to its final form, described below.

By itself, the obstacle avoidance algorithm is not able to deal with all the challenges facing the platform using only ultrasonic sensors. In contrast to the urban environment, off-road environments have a huge number of different types of obstacles, some of them are completely insurmountable, such as tree trunks and dense vegetation, while some can be scaled by simply driving over them, yet are still registered by ultrasonic sensors as an impassable wall. For such cases, the platform has a visual obstacle recognition system.

The structure of the platform systems is shown in Figure 1.

![Figure 1. Autonomous platform structure block diagram.](image_url)

3. Movement algorithm
The algorithm that the autonomous mobile platform uses is based on the virtual force field method. The method has been significantly modified, and instead of a 3D mesh applied to the surface around the platform and navigating that 3D structure, the algorithm creates a regular 2D vector that the platform must follow when moving.

The essence of the algorithm remains unchanged: any object seen on the platform's path applies a virtual force to the desired direction of movement. In the algorithm, if one of the sensors notices something in the path of the platform, its signal is transmitted to the computer where, depending on which sensor noticed the obstacle and how close it is, a decision is made to change the movement vector. This way the platform "repels" from obstacles in its path, but unlike the virtual force field method, only the values of one vector change, and not the values of a virtual path cells of the whole coordinate grid.

The initial motion vector is determined by the GPS module. All that is needed to start driving in autonomous mode is to indicate the target GPS coordinates. Having received the coordinates of the target,
the platform builds a vector to it and finds the angle of rotation necessary for the platform to turn to the target, that is the default value of the vector. Determining the original vector is perhaps the easiest part.

As the platform moves, the vector will be constantly updated using the default value of the platform's location. This is done to prevent the platform from moving off course due to cumulative minuscule errors in sensors adding up. If the platform takes only one measurement at the beginning of the path and the direction of movement is changed when it encounters an obstacle, then any movement past that point will displace the platform from the path to destination point. To avoid this, the current values of the GPS module are constantly fed into the computer for processing and adjust the default vector value. In this case, if the platform deviates from the vector, it will still be able to arrive exactly to the target (as far as the accuracy of the GPS module allows). The default vector is rather simple to calculate. It is not too dissimilar from a regular “Manhattan distance” heuristic calculation [3]. The algorithm takes a simple equation.

For effective autonomous navigation, it is not enough to know only the location of the platform. Movement solely using the GPS sensor is, of course, possible, but it greatly complicates the task, for this it would be necessary to constantly calibrate the direction of movement according to changes in the GPS sensor data, but this would only be possible while moving and would also require a much more accurate GPS module. Instead, the compass module is responsible for determining the orientation of the platform.

The compass exerts the greatest “pressure” on the direction of movement of the platform. When launching the platform, the compass adjusts the direction of the platform precisely to the desired vector, this is possible thanks to the nature of tracks on the platform, they allow the platform to turn in place slowly and accurately. After the platform has matched its direction to the vector, the sensors start to the influence the motion vector, the platform now begins to move. If there are no significant obstacles in the way of the platform, then it can achieve its target coordinates using only these two modules, but of course, that is unlikely in a realistic off-road scenario and sooner or later the platform will stumble upon some object. When the ultrasonic sensors detect an obstacle that is in the path of the platform, they will apply virtual pressure on the motion vector. This will cause the platform to change direction. As soon as the obstacle disappears from view, the virtual pressure of the sensors on the vector will disappear, and the influence of the compass remains the same, thus the platform keeps the direction of movement according to the compass.

After the sensor values have been collected and processed, they are fed to the on-board computer. If the space in front of the platform is free, then no virtual pressure is exerted on the vector other than the desired default direction determined in the first stage. If one of the sensors detects an obstacle, the pressure will begin to act on the vector in the opposite direction, thus diverting the platform away (Figure 2).
Each sensor affects the vector differently, with their values multiplied by a constant coefficient depending on the sensor’s location. Sensors monitoring the area directly in front of the platform exert more virtual pressure on the motion vector than sensors monitoring the sides of the platform. This is done so that the platform responds faster and sharper to the appearance of obstacles in the center of its vision cone, while the data from the side sensors changes the vector much less allowing for smoother movement.

As a result, having a target set by GPS coordinates and a current location, the platform moves directly to the final point, changing the direction of movement depending on obstacles detected by ultrasonic sensors and returns to the default vector value using a compass. This system is extremely effective when used on a surface where there are no sudden changes in elevation, however, the algorithm may have problems with overcoming ditches, pits, hills and other similar obstacles, due to which the platform can tilt downwards so that ultrasonic sensors can see the ground. The program is not yet able to distinguish in any way the surface of the earth from obstacles on it. Despite this, the algorithm will still continue to operate and will be able to avoid such obstacles, but depending on the nature of such obstacles, it may cause the platform to tilt too much or even flip over, which can be dangerous to sensitive equipment. This problem can be solved by adding a second row of ultrasonic sensors located above the existing ones for detecting tilted obstacles, or by integrating a gyroscope into the system to accurately measure platform tilt. The algorithm diagram is shown in Figure 3.
4. Obstacle video recognition
The idea of installing a video stream processing system on the platform for detecting obstacles was suggested at the very beginning of the project. Then, in TSU laboratory of computer vision, experiments were carried out to recognize human faces in a video stream. For face recognition, the OpenCV library was used. This is a very common practice often used as the first step in mastering pattern recognition systems. In the course of this practice, a system was created that can recognize a person’s face without identifying the person’s identity. Meaning, the program was able to recognize the face of a person in the video stream, build a frame of the boundaries of the face, but was not able to determine who exactly is in the picture. In future, the same solution will be applied to identifying obstacle types in front of the platform to aid the algorithm in plotting its course.

**Figure 3.** Platform movement logic.
5. Similar solutions
At the moment, there are already quite a lot of ready-made solutions for autonomous mobile platforms designed to move over rough terrain. Some of them are focused on very narrow applications and also have very low load capacities. Basically, these are various reconnaissance vehicles designed to work in various conditions dangerous to humans, but there are also specimens that go beyond these limits. Several companies have already created working prototypes of autonomous ATVs, such as the Honda autonomous work vehicle and the Aion Robotics autonomous ATV, which are basic 4 wheel ATVs that have been retooled to accommodate sensors and carry cargo. Other companies have followed a similar path and retooled off-the-shelf mobile platforms for autonomous travel (T-ATV2000). This approach to the design of platforms is popular due to the simplicity of their production, since there is no need to produce your own chassis and power plant for an autonomous platform, but it should be noted that the price of such platforms, even before the conversion is very high.

Projects for which their own platforms were designed are most often designed for very small weight carrying capacity and are not able to carry the weight of an adult. Such platforms are reconnaissance vehicles with autonomous movement function. Examples of such platforms are small tracked platforms. Having a low carrying capacity, such platforms most often gain in mobility and off-road capability due to their low weight and often used caterpillar tracks. Comparison of these platforms can be seen in Table 1.

| Platforms                                           | Off-road ability | Weight | Cargo capacity | Maximum speed | LIDAR | Price   |
|-----------------------------------------------------|------------------|--------|----------------|---------------|-------|---------|
| Honda autonomous work vehicle (Japan) [4]           | Average          | 350 kg | 450 kg         | n/a           | Yes   | High    |
| Aion Robotics autonomous ATV (USA) [5]              | Average          | 385 kg | 454 kg         | n/a           | Yes   | High    |
| T-ATV 1200 (Switzerland) [6]                         | High             | 236 kg | 380 kg         | 120 km/h      | Yes   | Very High |
| MAPC (Russia) [7]                                    | Very High        | 950 kg | 500 kg         | 35 km/h       | Yes   | Very High |
| Warthog (Canada) [8]                                 | Very High        | 280 kg | 272 kg         | 18 km/h       | No    | Average |
| Compact tracked platforms (N/A) [9–11]               | Very High        | 10-100 kg | <100 kg       | <8 km/h       | n/a   | Low     |

6. Standout characteristics
Unlike all analogues listed in the table above, our developed platform (Figure 4) does not use LIDAR sensors, instead relying on video stream analysis and ultrasonic sensors. This can significantly reduce the cost of the platform. The system is very capable off-road and is able to move on a thick layer of snow without any problems at any speed. The platform is also designed to integrate additional systems at the request of the customer without the need for major changes in the structure of both the program and the platform itself. This allows you to adapt the platform for practically any task or terrain.
In addition to the rescue platform a separate bot can function together with the rescue platform for carrying out engineering, chemical or radio reconnaissance. The scout robot can work in both remote controlled and automated modes as well (Figures 5, 6).

The scout bot is controlled by the same control station as the rescue platform, it’s equipped with high-definition video cameras with a 24x optical zoom and a night vision camera. Optionally, it can also carry: a thermal imager, gamma particle sensor, video camera of high radiation resistance, ASKRHO system (automated system for monitoring radiation and chemical conditions), directional antenna with auto-corrector, brushes, grabs. Also, it is possible to install other equipment necessary to solve the task at hand, provided that it is suitable in size and electrical load on the platform’s network.

The idea behind the scout bot is to conduct engineering radio and chemical reconnaissance, remote deployment of ASKRHO system in obstructed or contaminated and hazardous environments. Patrolling the controlled area around guarded objects, examining internal premises after emergency situations, as well as examining questionable and explosive objects.

7. The performance characteristics of the scout robot
Dimensions (length / width / height) – 1000mm / 500mm / 400mm. The platform can move at speeds up to 10 km / h. The carrying capacity of the additional equipment is 30 kg. Overcoming vertical obstacles - 20cm. The robot is capable of scaling stairs with an incline of up to 45 degrees and a width of at least 0.6 meters. The maximum slope of the scalable surface is 50 degrees. The depth of powdered snow that the platform is capable of navigating with no issues is 10 cm. Moving over rough summer terrain, as well as indoors, does
not present any difficulties to the platform. The operating range of the remote control system is 1 km without an auto tracker, with an installed digital data transmission system - up to 20 km. The range of the course without recharging is up to 10 hours. The robot also has an autonomous system.

8. Summary
During this research a mobile all-terrain autonomous robotic platform was developed. The algorithm used for its navigation is a heavily modified virtual force field method. The platform utilizes GPS, compass, ultrasonic sensor and cameras to navigate itself through practically any reasonably rough terrain. The platform is also usable with a previously developed scouting robot which greatly increases the range of operations the rescue platform can operate in as well as provides valuable operational information.

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