Improving the Mobility Performance of Autonomous Unmanned Ground Vehicles by Adding the Ability to 'Sense/Feel' Their Local Environment

Siddharth Odedra [1], Stephen D. Prior [1], Mehmet Karamanoglu [1]

[1]Department of Product Design and Engineering, Middlesex University, London, N14 4YZ, United Kingdom
Corresponding Author: s.odedra@mdx.ac.uk

Abstract. This paper explores how a 'learning' algorithm can be added to UGV's by giving it the ability to test the terrain through 'feeling' using incorporated sensors, which would in turn increase its situational awareness. Once the conditions are measured the system will log the results and a database can be built up of terrain types and their properties (terrain classification), therefore when it comes to operating autonomously in an unknown, unpredictable environment, the vehicle will be able to cope by identifying the terrain and situation and then decide on the best and most efficient way to travel over it by making adjustments, which would greatly improve the vehicles ability to operate autonomously.

Keywords: Unmanned, Autonomous, Mobility, Situational Awareness, Way Finding, Terrain, Reconfigurable, Intelligent Wheels.

1 Introduction

Robots are fast becoming perceptive, and autonomous systems are already a reality. One class of robot, which has the hardest task in terms of autonomous navigation, is the Unmanned Ground Vehicle (UGV). The main reason for this is the fact that they need to travel over different types of unknown terrain and avoid a number of variable obstacles. An example of how tough it is to negotiate autonomously in an unknown environment was demonstrated at the first DARPA Grand Challenge in 2004, where all the systems failed the course due to not being able to sense and adapt to situational changes [1].

To be able to operate fully autonomously on land, a UGV must be able to know as much as possible about its environment in order to be able to decide the best route from A to B in the quickest and safest way possible. It gathers this information using input sensors, which can include light, ultrasonic, infrared and even 3D scanners such as Laser Radars (LADAR), and the system builds up a picture of the obstacles and terrain ahead using the information received from these inputs.

Sensors are therefore very important, particularly for autonomous UGV's who use them to help build up this picture of the environment in order to make decisions.

Remote controlled or tele-operated robots have the added decision making of human operators who make decisions on what they see from real-time video feedback, whereas UGV's need more information about their local environment to make the same decisions even if this information is as trivial as knowing the difference between hard and soft ground, which a human operator usually determines by sight alone.

This leads onto how we (humans) take it for granted that we can recognise any object or environment and its properties by its appearance, but this isn't true, we only know this information by previously encountering it and remembering its properties, as with any learning experience. Therefore, if this can be added to UGV's it will ultimately create a system which grows more knowledgeable with experience and therefore more capable of being autonomous.

The need to know the difference between terrain types to be able to successfully travel over it is displayed in the latest Land Rover Discovery where a system known as 'terrain response' is available to the driver. This system reconfigures engine, transmission, suspension, brakes and traction settings to improve handling and performance in order to be able to negotiate in the safest and most efficient way over certain terrain types [2]. This also demonstrates that a human driver needs to select the terrain type by sight alone and the vehicle settings adjust to suit, therefore if the vehicle had the ability to detect the terrain type then it would create an autonomous or in this case an automatic system.

1.1 Motivation

Unmanned vehicles technology has advanced a great deal over the last decade and is at the forefront of military capabilities, with current research and development on unmanned systems focused on making them more perceptive and autonomous for use on the battlefield as seen in the U.S Army's Future Combat Systems program [3]. The use of robotics in the military is fundamentally to save the lives of soldiers and the more a system can become autonomous then it lowers the need for human presence on the battlefield.

This paper has been completed as an early part of the research being carried out in this area and will act as a review over the work done in the field of terrain detection for unmanned ground vehicles and breaks up the components to do with terrain sensing in terms of terrain types and available sensors, which will ultimately help ongoing research in the field.

2 Review of Prior Research

Previous work has been done in this area and is known as terrain classification, terrain trafficability or terrain traversability. Most work has been done in the area of terrain classification by using vision systems or 3D radars to build up a map of the terrain by its appearance alone, but how can this represent if the terrain is safe to travel over or how best to tackle it. This paper outlines work carried out in the area of unmanned systems and terrain and is by no means all the work completed in the field, but a selection of a range of methods used to identify terrain.

Lacroix et al [4] use a vision-based system to segment the terrain into four categories, flat, uneven, obstacle and unknown. The system would look at certain areas and segment them into cells, which it then labels as one of the four categories.

Dupont, Moore et al [5] from the Florida State University (also known as FAMU-FSU) offer a system that does not replace the vision detection method but instead compliments it in order to offer a system that can 'see' and 'feel' the terrain just as humans do in order to determine the terrains properties. Sadhukhan's [6] thesis on autonomous ground vehicle terrain classification using internal sensors firstly justifies terrain detection by say that a system can manoeuvre better over a surface that it has more knowledge about and then goes onto say how different terrains require different driving techniques and uses the tendency to get stuck in mud by driving too fast over it, as an example. The main work done by FAMU-FSU is using internal sensors to classify terrain by measuring the robots internal vibration as it travels over different terrain, and also the use of neural networks in terrain identification.

Iagnemma et al [7, 8] from the Massachusetts Institute of Technology (MIT) have done a lot of work on terrain classification especially in the area of space rovers and planetary exploration. Their work includes classifying terrain by measuring internal states such as torque and wheel angular and linear speed to name a few. Their main work is determining soil shear from two key parameters, cohesion of the soil and internal friction angle.

Seraji [9] and Howard [10]of the Jet Propulsion Laboratory (JPL) have developed a system that does not identify the terrain but instead detects its traversability. They used a vision system to create a traversability index using fuzzy rules to detect terrain using four key elements: roughness, slope, discontinuity and hardness. Roughness indicates coarseness and surface irregularity; slope looks at the surfaces incline/decline; discontinuity looks at the end of the surface such as cliffs; and the surface hardness is measured to see how it affects traction. The rules for each are set such as roughness is smooth, rough or rocky and slope is classified as flat, sloped or steep. The system uses this information to detect the terrains traversability and identifies it simply as a low, medium or high risk.

Manduchi, et al [11] are working on the dynamic response of a vehicle on different terrain. They also discuss how the compressibility of obstacles can help to determine whether they should be avoided or traversed and this will greatly reduce the number of unnecessary avoidances. Their work focuses more on obstacle detection/avoidance than terrain detection but the system offers a combined approach. The system uses a contact type sensor on the front of the vehicle in the form of a spring and damper configuration, which tests the compressibility of the object. Their recent work uses a LADAR system to detect obstacles and classify terrain using vision based information.

Thrun [12] and the Stanford Racing team were the first team to complete the second DARPA Grand Challenge in 2005 with their vehicle known as 'Stanley', which won them the $2 million prize. Their system used a combination of camera vision and LADAR systems to learn about what is, and how to select the safest terrain to traverse. Stanley was successfully able to cope with the desert terrain after learning from previous encounters by using machine learning algorithms, which meant Stanley grew smarter with experience and eventually became a master of finding safe paths and avoiding obstacles [13].

3 Terrain

Terrain can be defined as any land surface and is known in geographical terms as the ‘lay of the land’. There are many different types of terrain whether it is indoors or outside, but as yet there is no explicit list of terrain types available. Many researchers have their own classification of terrain types with some as simple as the system demonstrated by Lacroix et al [4], which identifies terrain as: flat, uneven, obstacle, and unknown; as previously mentioned. Table 1 below is an early list of the terrain types we have compiled, with their standard traversable properties which is by no means a complete list of every possible type.

Table 1. Terrain types and their properties.

			Effect of weather		
	Terrain type	**General surface properties**	**Sun**	**Rain**	**Snow/ice**
Harder >>	Sand	sinkage, slippage	hot	hydrocolloid	n/a
	Mud	sinkage, slippage	soft	liquefaction	hard
	Clay	slippage, sinkage	hard	liquefaction	slippage
	Rocks	uneven, hard	dry, hot	slippage	slippage
	Forest	long grass, foliage,	dazzle	marsh	hard
	Short grass	can get tangled	$\mu = 0.35$	$\mu = 0.2$	$\mu = 0.15$
	Gravel	loose, uneven, slippage	dry, hot	slippage	slippage
	Dirt track	dusty, level	dry	liquefaction	slippage
	Paved road	gaps, flat, high friction	$\mu = 0.7$	$\mu = 0.5$	$\mu = 0.08$
	Ashphalt	flat, high friction	$\mu = 0.8$	$\mu = 0.4$	$\mu = 0.06$
<< Easier	Concrete	flat, high friction	$\mu = 0.7$	$\mu = 0.5$	$\mu = 0.08$

3.1 Weather conditions

All the different terrain types change with different weather conditions as seen in Table 1 above. These conditions will change the terrain’s properties therefore certain measurements cannot be taken accurately to be used to identify the terrain. This means that for every different outdoor terrain type there is more than one condition for each weather condition, so the 16 terrain types listed in the table each have 3 different conditions making 48 different types of terrain parameters to identify.

3.2 Other factors

Other factors that affect terrain detection are the gradient or slope of the land, and positive and negative obstacles. Positive obstacles include vegetation, rocks, fences and hills; negative obstacles include potholes, cliffs and valleys; and in the case of road driving then drain covers and curbs would pose problems.

4 Sensors

A short review of sensor types and their properties has been conducted to see what is currently used to detect terrain and what types are available (see Table 2).

Table 2. Sensor types and their detection properties in reference to terrain.

Sensor	Type	Properties
Optical - Visible Spectrum	Passive	Range data with stereo pairs. Colour differences. Texture difference.
Optical - Infrared	Passive	Detects water absorption. Detects mineral reflection.
Optical - Infrared (thermal)	Passive	Can differentiate between object types.
Touch - Contact switch	Passive	Feels for solid objects.
Touch - Antennae	Passive	Measures antennae deflection.
Chemical	Passive	Detects certain chemical presence.
LADAR	Active	Range finder, single and 2 axis scanning. Can detect water. Can differentiate objects from one another.
RADAR	Active	Range finder using reflection. Frequency dependant material classification. Can see through weather conditions.
SONAR (Ultrasound)	Active	Range finder using reflection.
X-Ray	Active	Can see through materials.

4.1 What parameters to measure?

The problem with detecting terrain is to firstly select which parameters are best to measure in order to find a distinct difference. The question then arises as to what properties will show a distinct difference in all conditions? Questions have to be asked about what does the system need to know about the terrain it is about to encounter, for example, it will need to know if the wheels will slip or sink; and then the right type of sensor can be sourced

4.2 Current work on touch/feel sensors

There is ongoing worldwide research being carried out on giving robots the ability to feel and mimic human touch.

The first type of feel sensor is being developed for use in minimally invasive surgery. Maheshwari [14] and Saraf [15] have developed these sensors by using metal and semiconducting nanoparticles in a small area which are so precise that they can feel the shape of the head on the back of a coin. Future work with these touch sensors is in detecting cancer cells by feeling their hardness.

Another type of feel sensor is the artificial robotic whisker developed by Schultz et al [16] that can accurately sense different shapes and textures. It has been developed to mimic the way animals, such as rats use their whiskers to build up a picture of their environment and to test the hardness of objects. They work by measuring the 'bending moment' or torque deflection at the base of the whisker using piezoelectric strain gauges. These are then put in an array and can extract an entire shape.

Table 3. DARPA Grand Challenge 2005 top 5 sensor review.

			LIDAR		
Team	Vehicle	Vision	Short Range*	Long Range**	RADAR***
Stanford	Volkswagen Touareg	1	5	0	1
Red Team	M998 HMMWV	1	6	1	1
Red Team Too	H1 Hummer	1	6	1	1
Team Gray	Ford Escape Hybrid	2	3	1	0
Team Terramax	Oshkosh MTVR Truck	2	3	1	0

* Short Range LIDAR type used is typically the SICK LMS (Range <25m).
** Long Range LIDAR type used is typically the SICK LMS (Range <80m).
*** Long Range RADAR is typically <200m.

4.3 Why Sense Terrain?

Terrain is an important element in autonomous driving because if a vehicle cannot travel over a certain terrain type but does not know this, then it will become stuck and ultimately fail its mission. There are a number of ways of looking at this issue as seen in Fig 1. There can be non intelligent systems that are built to cope with a lot of different terrain types, such as 4x4 vehicles that can drive over almost any rough terrain but if it was to become stuck due to sinkage or slippage then it would fail; therefore, for autonomous solutions it is best to give the vehicle the ability to sense the terrain. There are two ways to navigate autonomously over terrain, the first is to have a system which detects that it cannot cope with a certain terrain type and therefore avoid it to prevent getting stuck, but this creates a system which is limited to where it can go. The second solution is a system that can sense the terrain and have the ability to ‘morph’ in order to adapt to changes, which would ultimately create a system without limitations on where it can go.

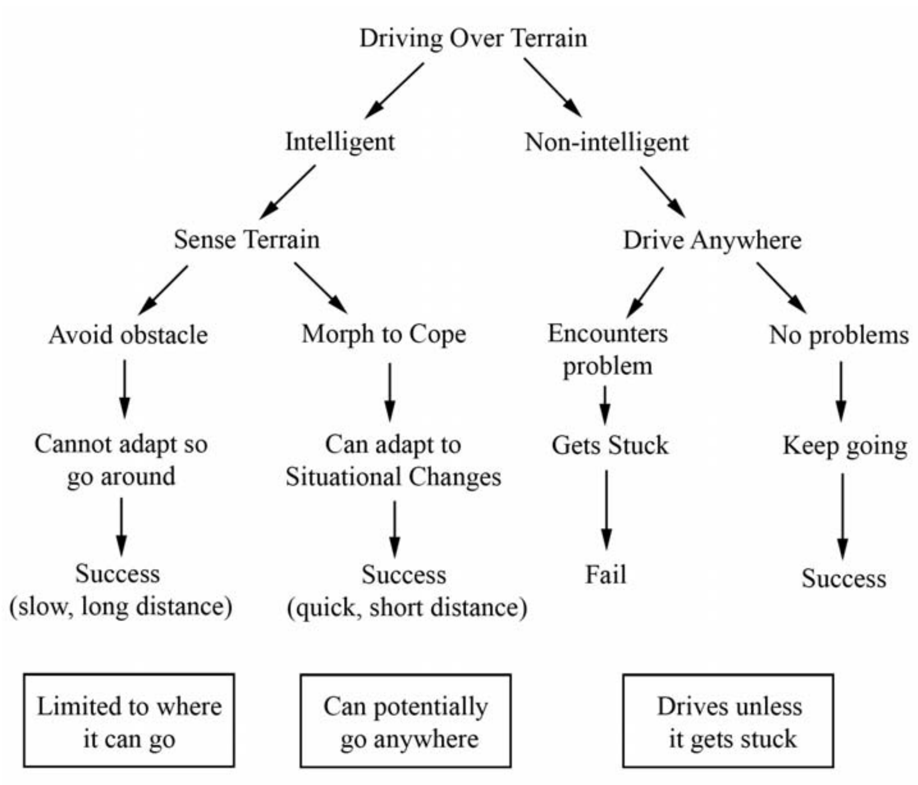

Fig. 1. A flow diagram of driving over terrain, using intelligent and non-intelligent systems.

5 Conclusion

Looking at the terrain types in Table 1, it will be harder to independently class terrain and label each one because of the number of variations and changes in them, therefore only the right parameters must be measured in order to give a distinct difference between types. Another way to tackle the terrain detection issue is to only search for, or sense the relevant attributes to do with traversability such as hardness, sinkage and slippage as well as its gradient and flatness, but this will create a system that is looking for 'safe' rather than a system that can cope with any terrain type, and this is what most current terrain detection systems do by using vision systems and 3D radars to build up maps of areas or analyse terrain by its appearance and surface properties to search for the safe flat ground as done by the winners of the DARPA Grand Challenge 2005 (see Table 3).

The two terrain detection methods discussed earlier not using vision systems are the soil cohesion and internal friction angle work done by Iagnemma et al [7, 8], and internal vibration sensing done by Dupont et al [5]. The problem with internal vibration detection system is that it informs the systems its reaction to the terrain after, or as it travels over it which can be too late. It doesn't tell you if it is traversable, for example if it was stuck in mud, as described by Sadhukhan [6], and the wheels were slipping, then the system would think it is still moving over a smooth surface because there is no vibration. The benefit of this system is that it can assist a system to feel the terrain by measuring its own reaction to it, and if it had the ability it could make changes to adapt to the situation.

Manduchi [11] and JPL's work on contact sensing is more relevant to feel/touch sensing but it then leads onto the issue of the time consuming feeling around at low speeds and has the same issues as SLAM (Simultaneous Localisation and Mapping) in what comes first, testing the environmental properties or actually operating in those environments.

6 Future Work

The concepts discussed in this paper will help ongoing research on reconfigurable mobility systems for UGV's, where the vehicle can use the information about its local environment to be able to 'morph' into the right configuration in order to suit the terrain and environment, therefore adding the ability to take more risks in unstructured, unknown environments.

Earlier work done at Middlesex University [17] on reconfigurable mobility systems include a concept known as intelligent wheels (Fig 2), which can change in size and form to adjust diameter, ground clearance, surface area and traction. The system will ultimately use the embedded sensors to carry out analysis on the local environment and using information learnt from previous experiences, the system could make adjustments to best suit the situation.

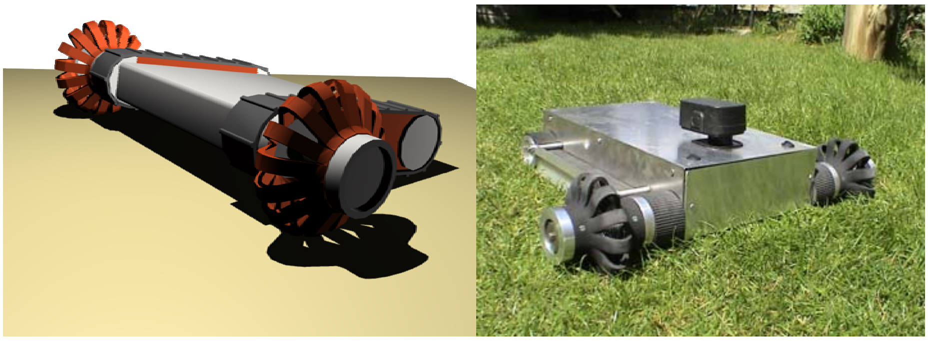

Fig. 2. Intelligent wheels conceptual model and prototype.

References

1. Vance, A. *DARPA's Grand Challenge proves to be too grand*. 2004 [cited; Available from: http://www.theregister.co.uk/2004/03/13/darpas_grand_challenge_proves/.

2. Vanderwerp, D. *What Does Terrain Response Do?* 2005 [cited; Available from: http://www.caranddriver.com/features/9026/what-does-terrain-response-do.html.

3. Shachtman, N. *Undead Warrior*. 2006 [cited; Available from: http://www.defensetech.org/archives/cat_fcs_watch.html.

4. Lacroix, S., Chatila, R., Fleury, S., Herrb, M., Simeon, T., *Autonomous Navigation in Outdoor Environments: Adaptive Approach and Experiment.* IEEE International Conference on Robotics and Automation, 1994.

5. DuPont, E.M., Moore, C.A., Roberts, R.G., Collins, E.G., Selekwa, M.F. *Online Terrain Classification for Mobile Robots*. in *ASME International Mechanical Engineering Congress and Exposition Conference*. 2005.

6. Sadhukhan, D., *Autonomous ground vehicle terrain classification using internal sensors*, in *Department of Mechanical Engineering*. 2004, The Florida State University.

7. Iagnemma, K., Dubowsky, S. *Terrain Estimation for High-Speed Rough-Terrain Autonomous Vehicle Navigation*. in *SPIE Conference on Unmanned Ground Vehicle Technology IV*. 2002.

8. Iagnemma, K., Shibly, H., Dubowsky, S. *On-Line Terrain Parameter Estimation for Planetary Rovers*. in *IEEE International Conference on Robotics and Automation*. 2002.

9. Seraji, H., *Safety measures for terrain classification and safest site selection.* Autonomous Robots, 2006(21): p. 211-225.

10. Howard, A., Seraji, H, *Vision-based terrain characterization and traversability assessment.* Journal of Robotic Systems, 2001. 18(10): p. 577 - 587.

11. Manduchi, R., Castano, A., Talukder, A., Matthies, L., *Obstacle Detection and Terrain Classification for Autonomous Off-Road Navigation* Autonomous Robots, 2005. **18**(1): p. 81-102.

12. Thrun, S., Montemerlo, M., *DARPA Grand Challenge 2005 Technical Paper*. 2005, Stanford Racing Team

13. Orenstein, D. *Stanford team's win in robot car race nets $2 million prize*. 2005 [cited; Available from: http://news-service.stanford.edu/news/2005/october12/stanleyfinish-100905.html.

14. Maheshwari, V., Saraf, R.F *High-Resolution Thin-Film Device to Sense Texture by Touch* in *Science* 2006. p. 1501 - 1504.

15. Saraf, R.F., Maheshwari, V, *Nanodevice for Imaging Normal Stress Distribution With Application in Sensing Texture and Feel' by Touching*. 2004, NEBRASKA UNIV LINCOLN.

16. Schultz, A.E., Solomon, J.H., Peshkin, M.A., Hartmann, M.J. *Multifunctional Whisker Arrays for Distance Detection, Terrain Mapping, and Object Feature Extraction*. in *2005 IEEE International Conference on Robotics and Automation* 2005.

17. Gaspar, T., Rodrigues, H., Odedra, S., Costa, M., Metrolho, J.C., Prior, S. *Handheld devices as actors in domotic monitoring system.* IEEE International Conference on Industrial Informatics, INDIN '04, 2004: p. 547-551.