

## SYSTEM AND METHOD OF SENSING FORWARD TERRAIN AND OBSTACLES FOR AN UNMANNED GROUND VEHICLE

### FIELD OF THE INVENTION

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**[0001]** The present invention relates to a system and method for helping an unmanned ground vehicle to determine the terrain ahead along a route and, in particular, for deploying an advance vehicle ahead of the unmanned ground vehicle for sensing of route terrain obstacles.

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### BACKGROUND

**[0002]** Obstacle detection capability is very important to an unmanned ground vehicle (UGV) to ensure both platform safety and stability. These obstacles can be classified into two broad categories based on their relative heights to the ground, namely: positive  
15 obstacles and negative obstacles.

**[0003]** A positive obstacle as used herein refers to an obstacle that has a vertical step change in height, upward from the ground. This includes big stones, high bushes, tree trunks, and even moving objects. A negative obstacle as used herein refers to deep  
20 ditches and steep down slopes.

**[0004]** In the event of encountering an undetected obstacle, the UGV may potentially crash into a positive obstacle or fall into a negative obstacle. There are numerous methods to detect positive obstacle with great accuracy and at far distances. However,  
25 negative obstacle detection remains a challenge. This is very true especially for negative obstacle detection at a far distance.

**[0005]** Negative obstacles are very commonly encountered by UGV operating in an off-road or terrain environment. Detecting negative obstacle at a distance is desired to

allow the UGV to travel at a fast speed to reach its destination. However, high speed travel also increases braking distance when encountering an obstacle.

**[0006]** Other than detecting obstacles, it is also desired to measure the terrain conditions such as inclination or pitch angle, side slope angle, roughness, and traction, all of which affect the vehicle safe traveling speed. In extreme cases, the undulating terrain may topple the vehicle.

**[0007]** Existing systems usually mount one or several sensors on the UGV to detect the negative obstacles. **FIG. 1** shows a system **100** having a negative obstacle detector (NODR) and classify obstacles using support vector machine technique. The system **100** has a UGV **102** with fixed NODR to collect data of the obstacle, for example a ditch **104**. **FIG. 2** shows a system **110** that perform negative obstacle detection by thermal signature. The system **110** has sensors that are inclined to better see an obstacle **114** in front and provide obstacle data to a UGV **112**.

**[0008]** **FIG. 3** shows a negative obstacle marking & detection (NOMAD) system **120** having sensors that mounted at an elevated location on a UGV **122** to allow the sensors to “see” distant obstacle **124**. However due to the limitation of the UGV **122** height or the mast height, these sensors cannot be mounted much higher than the vehicle or mast height and hence this limits the sensing distance. To overcome the danger of ditching into a negative obstacle, the UGV **122** has to travel at a slower speed than what it is capable of just to ensure it can apply brakes and stop in time.

**[0009]** Another system **130** shown in **FIG. 4**, employs the concept of a flying vehicle **136** moving ahead of a UGV **132** to provide sensing data of an obstacle **134**. This flying vehicle **132** senses both positive and negative obstacles, and informs the UGV **132** to allow it to plan out a traversable path. Negative obstacles are very commonly encountered by off road or terrain UGV. The ability of detecting negative obstacle at a distant is desired to allow the UGV to travel at a fast speed which directly affects its braking distance.

**[0010]** US 4674590 discloses a driven vehicle of an automatic transport system. The system provides safe operation for unmanned operation of a guiding wire control vehicle at top speed of about 10 km/h. The vehicle comprises a contact feeler mounted on a safety cart, which contact feeler is located ahead of the face surface of the vehicle by a distance exceeding the braking distance. Upon contacting an obstacle, the contact feeler triggers a retracting means which retracts the safety cart against the face area of the vehicle triggering at the same time the braking operation. Accordingly, the vehicle can be brought to a full stop without injuring or damaging as well as bodily contacting the obstacle. This system detects obstacles and bring the driven vehicle to a safe stop but does not provide information of the terrain and feedback to the driven vehicle.

**[0011]** US 5452639 discloses an arrangement for locating below-ground ammunition. In order to be able to automatically locate and map ammunition over a large area without endangering the searching crew, ground-scanning sensors are mounted on a relatively light-weight, unmanned, remote-controlled vehicle which then travels over the area contaminated with ammunition. The controlled vehicle is controlled from, and the sensor signals are evaluated in, a second vehicle which is generally disposed in the immediate vicinity of the area being examined. The controlling vehicle, which is preferably armored, also accommodates the operating crew. This system does not, however, sense the terrain characteristics and does not detect negative obstacles.

**[0012]** WO 2007143756 discloses a system and method for autonomously convoying vehicles. The system comprises a lead autonomous vehicle and at least one follower vehicle following the lead vehicle; wherein one of the at least one follower vehicle is a master vehicle, and the lead vehicle is a slave vehicle; and wherein the master vehicle sets at least one convoy control parameter. Accurate autonomous navigation requires the ability to evaluate terrain and identify obstacles. Each vehicle is equipped with environmental sensors which are used to evaluate the terrain through which the autonomous vehicles are about to travel in order to identify terrain variations, obstacles,

road deviations, or any other significant environmental factors that could impact the stability of the autonomous vehicle. The environmental sensors are also used to provide a measure of vehicle separation. This system focus on creating a convoy of vehicles each having similar capability to traverse the terrain in any line-up sequence, but fails to focus on forward sensing of the terrain characteristics and negative obstacle detection.

**[0013]** WO 2007141795 discloses an unmanned air vehicle (UAV) system. The system is provided with a ground station, and includes a platform configured for carrying a payload and having a propulsion system for enabling the platform at least to selectively sustain a predetermined altitude above the ground station when in flight mode, and also including a tether operatively coupling the ground station with the platform, the tether providing electrical communication between the platform and the ground station. This system focus on creating a flying platform to provide vicinity terrain information to the ground station. Contactless sensing techniques are used. This system does not elaborate on any details on how to maintain the airborne platform in a horizontal position ahead of the ground station and yet traverse across the terrain successfully without collision with the environment. This is important since at low height there will be many more obstacles as compared to flying higher.

**[0014]** CN 204515537 discloses a radar monitoring system comprising an unmanned car, an unmanned plane body, and monitoring devices. 360-degree cameras may be provided on both sides of the unmanned car, linked firmly to a railway carriage on the unmanned car, and/or be provided with the unmanned plane body in the railway carriage. Monitoring devices are installed at the unmanned plane body top, the monitoring devices including a fixed base, an articulated seat, and detection radar. The fixing base is installed on a main screw duct frame of the unmanned plane body, linked to the articulated seat on the shell of detection radar. The system uses a flying vehicle with radar to detect the environment, and can fly upward to avoid the terrain and obstacles on the ground.

**[0015]** The above prior art systems fail to accurately detect negative obstacle at a far distance to allow a fast moving unmanned vehicle ample time to react to the ambient

environment.

**[0016]** A need, therefore, exists for an improved system and method of sensing forward terrain and obstacles for unmanned ground vehicle.

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## **SUMMARY OF THE INVENTION**

**[0017]** The following summary is provided to facilitate an understanding of some of the innovative features unique to the disclosed embodiment and is not intended to be a full description. A full appreciation of the various aspects of the embodiments disclosed herein can be gained by taking into consideration the entire specification, claims, drawings, and abstract as a whole.

**[0018]** It is, therefore, one aspect of the disclosed embodiments to provide for a system for safely operating an unmanned ground vehicle (UGV). The system comprises the unmanned ground vehicle comprising a deploy-and-retrieve system and at least one run ahead vehicle (RAV). The deploy and retrieve system deploys the run ahead vehicle ahead of the unmanned ground vehicle using a tethered cable spool system, to safely operate the unmanned ground vehicle moving at high speed. The run ahead vehicle is initially stowed onto the unmanned ground vehicle and comprises one or more obstacle and terrain sensors for sensing the obstacle and terrain conditions in its path and for communicating the sensed data to the unmanned ground vehicle. By, using the sensed data, the unmanned ground vehicle traveling behind the run ahead vehicle accurately detects the terrain condition and obstacles at a far distance to allow the fast moving unmanned ground vehicle ample time to react to an adverse environment.

**[0019]** It is, therefore, another aspect of the disclosed embodiments to provide for the system wherein a tethered cable spool system is installed in the run-ahead ground vehicle or the unmanned ground vehicle.

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**[0020]** It is, therefore, another aspect of the disclosed embodiments to provide for the system wherein the tethered cable spool system comprises a tethered cable connecting the unmanned ground vehicle and the run ahead vehicle. The UGV can transmit electrical power to RAV for extended operation endurance. The tethered cable can also be used to transmit information between the UGV and the RAV.

**[0021]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the system wherein the run-ahead ground vehicle comprises a logic processing system for processing the sensed data to determine the terrain condition ahead.

**[0022]** It is, therefore, another aspect of the disclosed embodiments to provide for the system wherein the tethered cable spool system maintains the slackness of the tethered cable to prevent over tension of the tethered cable or dragging of the tethered cable on the ground.

**[0023]** It is, therefore, another aspect of the disclosed embodiments to provide for the system wherein the run-ahead ground vehicle is an unmanned vehicle used to detect the terrain and obstacles in the travel path and inform the UGV about the obstacle and terrain condition, such that the UGV may have sufficient time to apply brakes.

**[0024]** It is, therefore, another aspect of the disclosed embodiments to provide for a method for safely operating an unmanned ground vehicle. The method comprises initially stowing at least one run ahead vehicle onto the unmanned ground vehicle, deploying the run ahead vehicle ahead of the unmanned ground vehicle, such that the unmanned ground vehicle travels behind the run ahead vehicle in same direction, sensing the obstacle and terrain conditions in the path of the run ahead vehicle using one or more obstacle and terrain sensors and communicating the sensed data to the unmanned ground vehicle. By, using the sensed data, the unmanned ground vehicle traveling behind the run ahead vehicle accurately detects the obstacle at a far distance to allow the fast moving unmanned ground vehicle ample time to react to the obstacle without

ditching.

**[0025]** It is, therefore, another aspect of the disclosed embodiments to provide for the method further comprising installing a tethered cable spool system comprising a tethered  
5 cable.

**[0026]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the method wherein the unmanned ground vehicle and the run ahead vehicle are connected using the tethered cable. The UGV can transmit electrical power to RAV for  
10 extended operation endurance. The tethered cable can also be used to transmit information between the UGV and the RAV.

**[0027]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the method further comprising maintaining the slackness of the tethered cable to prevent  
15 over tension of the tethered cable.

**[0028]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the method of further comprising recovering the run ahead vehicle when ditched into the obstacle.  
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**[0029]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the method further comprising removing the run-ahead vehicle when damaged after ditching into the obstacle.

**[0030]** It is, therefore, yet another aspect of the disclosed embodiments to provide for the method further comprising replacing the run ahead vehicle with another run ahead vehicle.  
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**[0031]** It is, therefore, yet another aspect of the disclosed embodiments to provide for

the system and method that senses the terrain characteristics and detects negative obstacles. Both the UGV and RAV are moved along a path during the operation. The RAV regularly transmits the terrain information to the UGV while travelling ahead of it. When encountering a negative obstacle, it quickly alerts the UGV to allow it to stop in time to prevent ditching into the obstacle. As both the vehicles are moving, the UGV has to directly or indirectly locate the RAV position and maneuver it actively to ensure the RAV travel ahead of the UGV in accordance to the UGV intended path.

**[0032]** Other aspects and advantages of the invention will become apparent from the following detail description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0033]** The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

**[0034]** **FIG. 1** shows a side view of a prior art system with a negative obstacle detector and support vector machine;

**[0035]** **FIG. 2** shows a side view of another prior art system that perform negative obstacle detection by thermal signature;

**[0036]** **FIG. 3** shows a side view of another prior art system that use negative obstacle marking & detection technique;

**[0037]**     **FIG. 4** shows a side view of another prior art system that perform forward sensing for UGV with a fly ahead vehicle;

5     **[0038]**     **FIG. 5** shows a perspective view of a system that deploys a run ahead vehicle (RAV) connected to the UGV by a tethered cable for forward sensing of obstacles for the behind unmanned ground vehicle (UGV), in accordance with the present invention;

10     **[0039]**     **FIG. 6** shows a side view of the system depicted in **FIG. 5** having the RAV in a stowed position;

**[0040]**     **FIG. 7** shows a side view of the system depicted in **FIG. 6** that deployed the RAV;

15     **[0041]**     **FIG. 8** shows a side view of the system depicted in **FIG. 7** in which the RAV extends itself from the UGV while maintaining connection via the tethered cable at a suitable distance from the UGV, and shows a cross section detail of the tethered cable;

20     **[0042]**     **FIG. 9** shows a side view of the system depicted in **FIG. 5** in which the deploy and retrieve system stowed the RAV onto the UGV;

**[0043]**     **FIG. 10** shows a side view of the system depicted in **FIG. 5** in which the deploy and retrieve system deployed the RAV on the ground;

25     **[0044]**     **FIG. 11** shows a schematic view of the RAV showing the essential components;

**[0045]**     **FIG. 12** shows a side view of the system depicted in **FIG. 5** in which a tethered cable is too slacked and drags on ground;

[0046] FIG. 13 shows a side view of the system depicted in FIG. 12 in which the tethered cable is too taut;

5 [0047] FIG. 14 shows a side view of the system depicted in FIG. 12 in which the tethered cable has sufficient tension;

[0048] FIG. 15 shows a side view of the system depicted in FIG. 5 in which the tethered cable spool system will control the slackness of the cable depending on the  
10 distance between the UGV and the RAV;

[0049] FIG. 16 shows a side view of the system depicted in FIG. 5 in which the RAV relative position sensor system measure the RAV's position and compute the distance between the UGV and the RAV;

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[0050] FIG. 17 shows a side view of the system depicted in FIG. 5 in which the RAV distance measurement sensor system measures the RAV distance from the UGV directly via wired or wireless means;

20 [0051] FIG. 18 shows a side view of the system depicted in FIG. 5 in which the RAV ditched into a negative obstacle;

[0052] FIG. 19 shows a side view of the system depicted in FIG. 5 in which the UGV retrieves the RAV by spooling back the tethered cable which also acts as a recovery line;  
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[0053] FIGS. 20-21 show a flow chart pertaining to a process of detecting and controlling the tethered cable based in the distance between the UGV and the RAV.

**DETAILED DESCRIPTION OF THE INVENTION**

**[0054]** The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate at least one embodiment and are not intended to limit the scope thereof.

**[0055]** Negative obstacles are very commonly encountered by off-road or terrain unmanned ground vehicle (UGV). The ability of detecting negative obstacle at a distance is desired to allow the UGV to travel at a fast speed while providing for an adequate braking distance. The present invention is a suitable system configuration design that allows accurate sensing of the terrain condition and negative obstacle detection at a far distance to allow a fast moving UGV ample time to react to an adverse environment.

**[0056]** **FIG. 5** shows a perspective view of a system **200** that deploys a RAV **208** for forward sensing of obstacles for a trailing UGV **202**, in accordance with the present invention. The UGV **202** and the RAV **208** are connected using a tethered cable **206** for transmitting information between the UGV **202** and the RAV **208**. When the UGV **202** is traveling at high speed in an off road or terrain environment **204**, the UGV **202** deploys the RAV **208**. By gaining the extra sensing distance with the RAV **208**, the UGV **202** can detect and avoid obstacles or adverse terrain while traveling at its nominal speed. In the event when an obstacle is unavoidable, the UGV **202** will be able to stop in time without crashing or ditching into the obstacle.

**[0057]** **FIG. 6** is a side view of the system **200** depicted in **FIG. 5** showing the RAV **208** in a stowed position, in accordance with the present invention. Before deployment, the RAV **208** is typically stowed within the UGV **202**. In the stowed position, the RAV **208** can be compacted to reduce the storage requirement on or within the UGV **202**. In this configuration, the UGV **202** performs normal operation without any interference or consideration of the stowed RAV **208**.

**[0058]** **FIG. 7** shows a side view of the system **200** depicted in **FIG. 6** with a deployed

RAV **208**. When the UGV **202** far distance obstacle and terrain sensing capabilities are desired, such as when traveling at a high speed in an off road or terrain environment, the UGV **202** deploys the RAV **208**. Upon deployment, the RAV **208** can be expanded to provide a larger footprint for better cross-terrain capability, if desired.

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**[0059]** FIG. 8 shows a side view of the system **200** depicted in FIG. 7 in which the RAV **208** has deployed from the UGV **202** and is maintaining a predetermined distance from the UGV **202** so as to provide the UGV **202** with advance warning of potential terrain obstacles. Once deployed, the RAV **208** accelerates and travels ahead of the UGV **202** in one direction, and maintains a suitable distance from the UGV **202**. A suitable distance ranges from, but is not limited to, 20 m to 40 m. However, distances shorter than 20 m or longer than 40 m are possible with the system **200**. As seen in the cross sectional view denoted as Detail 'A' the tethered cable **206** includes a structural cable **226** or reinforced cable **226** and at least two signal lines **228**. The reinforced cable **226** supports the weight of the RAV **208** when it is necessary to pull the RAV **208** out of a ditch, as described below. In an alternative embodiment, structural cable **226** in the form of an aluminum cable, a composite cable, or a plastic cable, and the reinforced cable in the form of steel reinforcement, aluminum reinforcement, composite reinforcement or plastic reinforcement. can be used such that sufficient cable strength is maintained to support the weight of, and enable physical retrieval of, the RAV **208**. The signal lines **228** are used to conduct signals or power between the RAV **208** and the UGV **202**. In an exemplary embodiment, the signal lines **228** may be copper conductors, a coaxial pair, or other electrical or optical signal conductors, as is well-known in the relevant art.

**[0060]** FIG. 9 shows a side view of the system **200** depicted in FIG. 5 in which a deploy and retrieve system **210** is stowed with the RAV **208** on the UGV **202**, in accordance with the present invention. The RAV deploy and retrieve system **210** can be a ramp, a robotic picking arm, or a combination of the ramp and robotic picking arm. The RAV deploy and retrieve system **210** may consist of other suitable RAV deploy and retrieve means that serve the need of retrieving the RAV **208** into the stowed position or deploying the RAV **208** for forward sensing. FIG. 10 shows a side view of the system

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**200** depicted in **FIG. 5** in which the RAV deploy and retrieve system **210** has deployed the RAV **208** on ground.

**[0061]** **FIG. 11** is a schematic view of the RAV **208** showing the essential components. The RAV **208** has a tethered cable spool system **218**, a logic processing system **214**, and an obstacle and terrain sensors **216**. The RAV **208** is a mobile ground platform capable of traversing the terrain in which the UGV **202** operates. The RAV **208** can be a wheeled vehicle, a track vehicle, or a combination of wheeled and tracked vehicle or any terrain traversal mechanism that is compatible to the UGV, and may carry suitable terrain sensors **216** for obstacle and terrain sensing. Although the RAV **208** is capable of carrying numerous sensors to perform its task, the primarily sensors comprise at least one of an accelerometer, a gyroscope, a forward obstacle distance sensor and a tilt sensor. These are typical sensors used for vibration, rotation and inclination measurement. The sensors enable the RAV **208** to send terrain and obstacle data to the UGV. The forward obstacle distance sensor is used to detect any obstacle that is in front of the RAV **208** during its movement, so that it can avoid if any obstacles that is along the path and it can inform the UGV **202**. The forward obstacle distance sensor comprises at least one of an ultrasonic sensor, a laser sensor, a lidar or an Infra Red (IR) sensor without limitation.

**[0062]** The RAV **208** matches the terrain cross capability of the UGV **202** to a large extent so that the UGV **202** does not impede on the UGV **202** performance when the RAV **208** is deployed. To achieve such cross terrain capability, the wheel or track of the RAV **208** is designed to have a footprint width comparable to the wheel or track of the UGV **202**. This is in contrast to the desired compact stowed configuration. As such, the RAV **208** can have expansion features for deployment purposes, where the RAV **208**, as well as the wheel or track sprocket diameter of the RAV **208**, can be laterally expanded after being deployed, to provide a bigger obstacle clearance than the track of the RAV **208** when stowed. The wheel or track sprocket diameter of the RAV **208** is thus changeable between a first wheel or track sprocket diameter or dimension smaller than the wheel or track sprocket diameter of the UGV **202** to a second wheel or track sprocket diameter

similar in dimension or slightly smaller than the wheel or track sprocket of the UGV **202**.

**[0063]** While the RAV **208** is traveling ahead of the UGV **202** for terrain sensing, the logic processing system **214** processes the obstacle and terrain sensor data, and determines the terrain condition ahead. This data and terrain determination is sent to the UGV **202** over the signal lines **228**. Coupling this information together with the UGV **202** sensing capability, the UGV **202** can maneuver the RAV **208** to avoid obstacle while traveling forward. The tethered cable spool system **218** controls the slackness of a cable depending on the distance between the UGV **202** and the RAV **208**.

**[0064]** FIG. **12** shows a side view of the system **200** shown in FIG. **5** in which a tethered cable **206** is too slack and drags on ground. Excessive dragging on the ground will wear out the cable **206** prematurely and affect the operation of the system **200**. Accordingly, the tethered cable spool system **218** functions to maintain the tension in the tethered cable **206** within specified limits, as explained below.

**[0065]** FIG. **13** shows a side view of the system **200** depicted in FIG. **12** in which the tethered cable **206** is too taut. It can be appreciated that an overly tensioned tethered cable **206** will hinder the RAV **208** mobility as the UGV **202** is typically moving slower so as to be able to anticipate the forward terrain and respond accordingly. As can be appreciated by one skilled in the art, an overly tensioned tethered cable **206** would cause the RAV **208** to skid and lose control. The tethered cable spool system **218** thus functions to maintain the tension in the tethered cable **206** below a specified upper limit.

**[0066]** FIG. **14** shows a side view of the system **200** shown in FIG. **12** in which the tethered cable **206** has sufficient tension to ensure that it does not drag on the ground, but is not under too much tension such that the RAV **208** is in danger of skidding. The ideal slackness of the tethered cable **206** keeps the tethered cable **206** hanging above the ground, while not interfering with the movement of the RAV **206**. The tethered cable spool system **218** thus also functions to maintain the tension in the tethered cable **206** above a specified lower limit.

**[0067]** It can be appreciated that there are various techniques to maintain the proper tension in the tethered cable **206** so as to: (i) prevent excessive tension in the tethered cable **206** and adversely affect operation of the RAV **208**, and (ii) prevent excessive slack in the tethered cable **206** so as to keep the tethered cable **206** from dragging on the ground. In one embodiment of the invention, relative positioning of the UGV **202** to the RAV **208** is used to maintain the slackness of the tethered cable **206**. **FIG. 15** shows a side view of the system **200** in which the tethered cable spool system **218** controls the slackness of the tethered cable **206**, depending on the distance between the UGV **202** and the RAV **208**. Based on the absolute positions of the UGV **202** and the RAV **208**, the distance from the RAV **208** to the UGV **202** can be computed and the tethered cable **206** is thereby lengthened or shortened by the tethered cable spool system **218** to the desired slackness. This tethered cable spool system **218** can be housed in the RAV **208** or in the UGV **202** or in both. **FIG. 15** shows the tethered cable spool system **218** housed in both the RAV **208** and in the UGV **202**.

**[0068]** **FIG. 16** shows a side view of the system **200** in which the relative position sensor system **220** of the RAV **208** determines the position of the RAV **208**, and computes the distance between the UGV **202** and the RAV **208**. The UGV **202** has a RAV **208** relative position sensor system to determine the relative position of the RAV **208** with respect to the UGV **202**. The distance between the UGV **202** and the RAV **208** can be computed and the tethered cable **206** is lengthened or shortened by the tethered cable spool system **218** to a desired tension.

**[0069]** **FIG. 17** shows a side view of the system **200** in which the RAV **208** distance measurement sensor system **222** measures the RAV **208** distance from the UGV **202** directly via the signal lines **228**, or via wireless means **221**. It should be noted that the system **200** includes the logic processing system **214** to determine or computed directly or indirectly the distance of the RAV **208** from the UGV **202** and hence adjust the tension of the tethered cable **206** accordingly to maintain a desired slackness. The techniques described above are not exhaustive; hence, other possible means can also be used.

**[0070]** FIG. 18 shows a side view of the system 200 in which the RAV 208 has “ditched” into a negative obstacle 224. When the RAV 208 encounters a negative obstacle or very steep slope 224 at fast speed, the RAV 208 may be ditched and trapped inside the negative obstacle or on the very steep slope 224. Once such abrupt changes in the terrain trap or incapacitate the RAV 208, the UGV 202 receives adverse sensed data from the RAV 208 and, because of the adequate distance from the RAV 208, has sufficient braking distance to avoid ditching into the negative obstacle or onto the very steep slope 224.

**[0071]** FIG. 19 shows a side view of the system 200 in which the UGV 202 retrieves the RAV 208 by spooling back the tethered cable 206, here acting as a recovery line. The UGV 202 performs a recovery process to “rescue” the RAV 208 by pulling the RAV 208 up and back to safety with reinforced cable 226 in the tethered cable 206.

**[0072]** It should be noted that, if the RAV 208 has been damaged after ditching into a negative obstacle, the damaged RAV 208 can be detached and replaced with an intact RAV 208. In an exemplary embodiment, the UGV 202 may have the capacity to carry two or more RAV 208 units for forward sensing purposes.

**[0073]** FIGS. 20-21 show a flow chart describing a process of detecting and controlling the tethered cable 206, in accordance with an aspect of the present invention. As at step 300, the RAV 208 is stowed onto the UGV 202 using the RAV deploy and retrieve system 210. When the UGV 202 far distance obstacle and terrain sensing capabilities are desired, such as traveling high speed in an off road or terrain environment, as at step 302, the UGV 202 deploys the RAV 208 as at step 306. In case when the UGV 202 is not traveling at a high speed, the RAV 208 remains stowed in the UGV 202 itself, as at step 304. Upon deployment, as at step 308, the RAV 208 travels ahead of the UGV 202, and the wheel or track of the RAV 208 can then be expanded or widened to provide a larger vehicle footprint for better cross terrain capability. As at step 309, the UGV 202 and RAV 208 share the control, sensing and navigation information to facilitate the

movement of the RAV **208** ahead of the UGV **202**.

**[0074]** As at steps **310** and **312**, the RAV **208** senses obstacle and terrain conditions and sends sensed data to the UGV **202**. The UGV **202** can react to the obstacle and terrain based on the sensed data, as at step **314**. In one aspect of the invention, the UGV **202** maintains appropriate slack in the tethered cable **206** to prevent either excessive tension or dragging on the ground, based on the distance between the UGV **202** and the RAV **208**, as at step **316**.

**[0075]** In another aspect of the invention, when the RAV **208** is ditched into a negative obstacle, as at steps **318** and **320**, the RAV **208** can be spooled back using the reinforced cable **226** in the tethered cable **206**. Further, in another aspect of the present invention, as at step **322** and **324**, in case the RAV **208** is damaged during ditching, the UGV **202** can deploy a new RAV **208**. As described above, the UGV **202** can have two or more stowed RAVs **208**. When the RAV **208** that currently operating is damaged, the UGV **202** can disconnect the damaged RAV **208**. Then as at step **306**, the UGV **202** can deploy a new RAV **208** and continue to step **308**. When the RAV **208** is not ditched or not damaged, as at steps **318** and **322**, the RAV **208** can continue sensing the obstacle and terrain conditions for the UGV **202**, as at step **310**.

**[0076]** Thus, the system **200** and method are directed to sense the terrain characteristics and detect negative obstacles. Both the UGV **202** and the RAV **208** are moved along a path during the operation. The RAV **208** regularly transmits the terrain information to the UGV **202** while travelling ahead of the UGV **202**. When encountering a negative obstacle, the RAV **20** quickly alerts the UGV **202** to allow the UGV **202** to stop in time to prevent ditching into the negative obstacle. As both the vehicles are moving, the UGV **202** has to directly or indirectly locate the position of the RAV **208** and maneuver the RAV **208** actively to ensure that the RAV **208** travels ahead of the UGV **202** in accordance to the intended path of the UGV **202**.

**[0077]** It will be appreciated that variations of the above disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently  
5 made by those skilled in the art which are also intended to be encompassed by the following claims.

**[0078]** Although embodiments of the current disclosure have been described comprehensively, in considerable detail to cover the possible aspects, those skilled in the  
10 art would recognize that other versions of the disclosure are also possible.

**CLAIMS**

What is claimed is:

1. A system for providing forward sensing to an unmanned ground vehicle, said  
5 system comprising:
  - a run ahead vehicle including obstacle and terrain sensors for providing forward sensing;
  - a tethered cable for communicating said forward sensing to the unmanned ground vehicle; and
  - 10 a tethered cable spool system connected to said tethered cable, said tethered cable spool system for maintaining tension in said tethered cable within specified limits.
2. The system of claim 1, wherein the unmanned ground vehicle is configured to stow said run ahead vehicle.
- 15 3. The system of claim 1, wherein said tethered cable spool system is disposed in the unmanned ground vehicle.
4. The system of claim 1, wherein said tethered cable spool system is disposed in said run ahead vehicle.
5. The system of claim 1, wherein said tethered cable comprises one of a structural  
20 cable or reinforced cable and at least two signal lines.
6. The system of claim 1, wherein said obstacle and terrain sensors comprise at least one of at least one of an accelerometer, a gyroscope, a forward obstacle distance sensor and a tilt sensor, to provide a plurality of sensed data to the unmanned ground vehicle.
7. The system of claim 6, wherein said forward obstacle distance sensor comprises  
25 at least one of an ultrasonic sensor, a laser sensor, a lidar or an infra red sensor.

8. The system of claim 6, wherein said run ahead vehicle further comprises a logic processing system for processing said sensed data to determine forward terrain conditions.

5 9. The system of claim 1 further comprising a deploy and retrieve system disposed in the unmanned ground vehicle, said deploy and retrieve system functioning to deploy said run ahead vehicle from the unmanned ground vehicle, and to stow said run ahead vehicle in the unmanned ground vehicle.

10 10. The system of claim 9, wherein said deploy and retrieve system comprises at least one of a ramp, a robotic picking arm, and a combination of a ramp and a robotic picking arm.

11. The system of claim 1, wherein said run ahead vehicle comprises a mobile ground platform capable of traversing the terrain in which the unmanned ground vehicle operates.

15 12. The system of claim 1, wherein said run ahead vehicle comprises a wheel or track sprocket changeable between a first wheel or track sprocket diameter smaller than a wheel or track sprocket diameter of the unmanned ground vehicle to a second wheel or track sprocket diameter essentially of similar dimension or slightly shorter than the same as said wheel or track sprocket diameter of the unmanned ground vehicle.

13. The system of claim 1, wherein said run ahead vehicle upon deployment expands to provide a larger footprint for better cross-terrain capability.

20 14. A method for guiding an unmanned ground vehicle along a predetermined route, said method comprising the steps of:

stowing a run ahead vehicle in the unmanned ground vehicle;

deploying the run ahead vehicle on the predetermined route ahead of the unmanned ground vehicle;

sensing obstacle and terrain conditions on the predetermined route ahead of the unmanned ground vehicle to produce sensed data; and

communicating said sensed data to the unmanned ground vehicle by sharing control, sensing and navigation information between the unmanned ground vehicle and said run ahead vehicle.

15. The method of claim 14 wherein said step of communicating comprises the step of sending said sensed data over a tethered cable connecting the unmanned ground vehicle with said run ahead vehicle.

16. The method of claim 15 further comprising the step of retrieving said run ahead vehicle utilizing one of a structural cable or reinforced cable in said tethered cable.

17. The method of claim 15 further comprising the step of maintaining tension in said tethered cable within specified limits to prevent over tension or excessive slack in said tethered cable.

18. The method of claim 14 further comprising the step of braking the unmanned ground vehicle in response to receiving adverse sensed data from said run ahead vehicle.

19. The method of claim 14 further comprising the step of changing a wheel or track sprocket diameter on said run ahead vehicle from a first wheel or track sprocket diameter smaller than a wheel or track sprocket diameter of the unmanned ground vehicle to a second wheel or track sprocket diameter essentially similar to or slightly smaller than the said wheel or track sprocket diameter of the unmanned ground vehicle.

20. The method of claim 14 wherein said step of sensing obstacle and terrain conditions utilizes at least one of an accelerometer, a gyroscope, a forward obstacle distance sensor and a tilt sensor.

21. The method of claim 20 wherein said forward obstacle distance sensor comprises at least one of an ultrasonic sensor, a laser sensor, a lidar or an infra red sensor.

22. The method of claim 14 further comprising the step of expanding said run ahead vehicle upon deployment to provide a larger footprint for better cross-terrain capability.

23. A deploy and retrieve system comprising:

an unmanned ground vehicle;

5 a run ahead vehicle including obstacle and terrain sensors for providing forward sensing;

a tethered cable connecting said unmanned ground vehicle to said run ahead

10 vehicle, for communicating said forward sensing to said unmanned ground vehicle; and

a tethered cable spool system connected to said tethered cable, said tethered cable spool system for maintaining tension in said tethered cable within specified limits.