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CONVERSION OF AN ALL-TERRAIN VEHICLE INTO A SIX-CHANNEL WIRE REMOTE CONTROLLED UGV

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ABSTRACT

This paper presents a conversion of an All-Terrain Vehicle (ATV) into a wire controlled Unmanned Ground Vehicle (UGV). The vehicle selected was the Kazuma Gator 250 ATV and the control panel used to communicate with the UGV was a six-channel wired communication. To convert a conventional vehicle into a UGV, four modules needed to be actuated electrically; the accelerator, the steering, the braking and the shifting. The present work illustrates the steps to make such a conversion given two main constraints. The first is not to alter the outer shape and dimensions of the original light vehicle. The second constraint is not to affect the original arrangement of the vehicle controls so that the actuators could be dismantled easily and allows for the normal operation of the vehicle. The deliverable of the work must contain a labeled harness to facilitate further conversion of the wire controlled UGV into a wireless controlled UGV.

KEYWORDS

Unmanned Ground Vehicle (UGV) – All-Terrain Vehicle (ATV) – Wire Controlled

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INTRODUCTION

The concept of wire controlled UGV was first recorded in the early 1940s in WWII when the Germans used the Goliath to bomb Soviet Union targets [1]. Also, the Soviet Union had used a remotely controlled UGV, called Teletank, in their war against Finland in the early 1940s [2]. Both UGVs were named suicide tanks as they were loaded with explosive charges to be ignited remotely when they reach the enemy target units. The UGV had been developed through the following decades until now passing through the Shakey [3-4], which was developed in Stanford Research Institute (SRI) in the 1960s, the Navlab [5], developed in Carnegie Mellon University labs in the 1980s, MDARS [6] developed in U.S. DoD warehouses in the 1990s, and other subsequent UGVs. It was not before 2004 when Defense Advanced Research Projects Agency (DARPA) had launched its major series of competitions between American universities and research centers, named DARPA.

Grand Challenge [7], that the UGV technology had boasted. Since then, a lot of UGVs has been seen around. Stanely [8], developed by Stanford Research Institute, Talos [9], developed by MIT, TerraMAX [10], developed by Oshkash, AnnieWAY [11], developed by University of Karlsruhe, UT Munich, the Fraunhofer Gesellschaft, and the Universitaet der Bundeswehr and many other UGVs. Commercially, we now can see the UGVs leaving the state-of-art to the state-of-mart. They could be sold [12], rented [13] or even converted from conventional vehicles [14].

Application of UGVs in space had started in the 1970s. Since the first successful landing of spacecraft Mars 3 on planet Mars, developed by USSR [15], which lost communication with Earth after 20 seconds of landing, the following decades had witnessed many successful UGVs' landings on planet Mars ended in 2011 by rover Curiosity [16], which is still working until the moment of writing this article.

In this article, a conversion of the conventional light weight vehicle Kazuma Gator 250, Figure 1, into a wire controlled UGV was illustrated. The present work was the first phase out of three phases. The second phase will include transforming the wired control into wireless control, while the third phase will include application of smart control and navigation algorithms into the UGV.



Fig. 1. Kazuma Gator 250 light vehicle before modification.

In order to implement the conversion of a conventional vehicle into a UGV, four control mechanisms needed to be electrically actuated; the accelerator mechanism, the steering mechanism, the braking mechanism and the shifting mechanism.

Several trials to convert similar All-Terrain Vehicles (ATVs) were made earlier by several universities and research centers; Donatello developed by University of Maryland [17], TailGator developed by University of Florida [18], and Autonomous ATV developed by University of Oklahoma [19].

Two main constraints were considered in the present work. The first was to keep the outer shape and dimensions of the original light vehicle unchanged. The second was to keep the original control mechanisms and components unchanged so that the new kit could be dismantled easily to allow for the normal operation of the vehicle. The organization of this article is as follows; the second, the third and the fourth sections of the article illustrate design procedures of the different control mechanisms. The fifth section shows the hardware implementation of the proposed mechanisms and the deliverables of the project. Finally, the sixth section concludes the article.

DESIGN PROCEDURES

In order to satisfy the first constraint, which is keeping the outer shape and dimensions of the original vehicle unchanged, the available cavities under the vehicle body were examined. This was accomplished after dismantling the vehicle body. Figure 2 & Figure 3 show the final cavities' locations for the desired actuators.

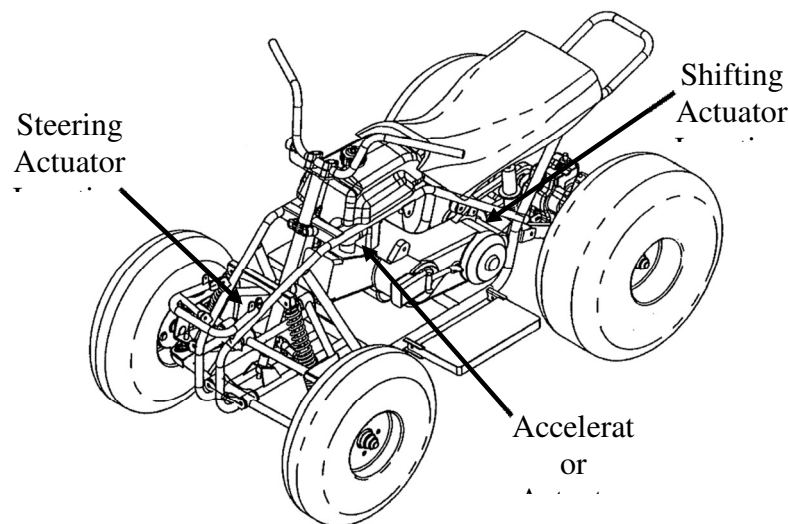


Fig. 2. Selected cavities in the chassis for mounting the steering, accelerator and shifting actuators.

The steering actuator was decided to be mounted on the chassis longitudinal tubes that hold the front suspension upper control arms and linked to the steering column. The accelerator actuator was decided to be placed on the chassis plate that holds the carburetor and wired to the carburetor throttle valve. The shifting actuator was decided to be placed on the vertical chassis rear tubes that hold the rear half of the vehicle and linked to the transmission intermediate shifting link. Finally, the brake

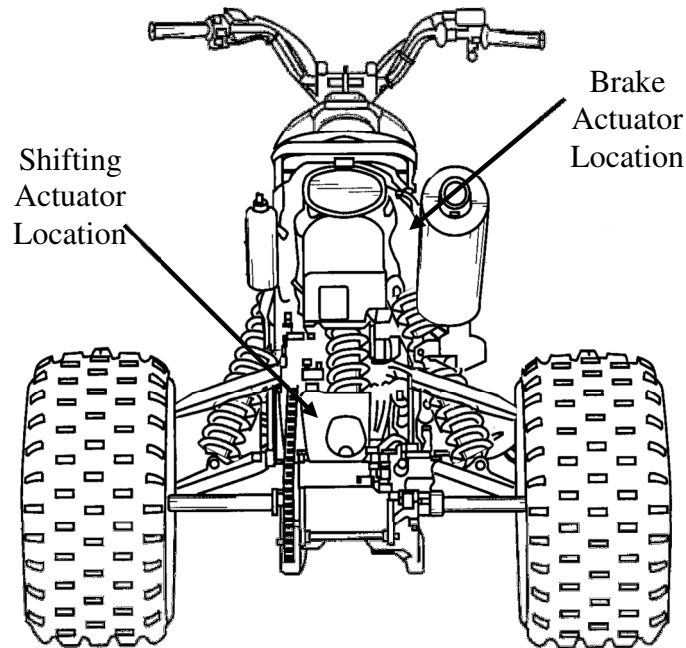


Fig. 3. Selected locations for the shifting and brake actuators.

actuator was decided to be mounted on the longitudinal upper right chassis tube that links the rear and front halves of the vehicle and attached to the brake pedal.

STEERING ACTUATOR

The driver steering force was measured statically throughout the full range of steering angle to address the required actuator force for steering. This measurement included the worst-case condition where the vehicle was fully loaded. To withstand the high torque demand of the steering mechanism in this compact size, a high force linear actuator was used. The angle of the actuator was chosen to follow the kinematic constraint generated by the orientation of the steering column to which the steering lever was fixed. The steering angle range was measured and represented graphically in Figure 4. As seen in the figure, the full steering angle range is 54° which is split into the two angle ranges, $\pm 27^\circ$, for the right and left directions.

Due to the spatial limitations of the steering actuator compartment, the actuator needed to be mounted with a 3D angle (the actuator plane of action is inclined to the x-y plane and its axis of action is inclined to the x-axis). Figure 5 shows the 3D angle of the steering actuator and its attachment to the proposed steering actuator plate

The graphical representation of the motion of the candidate steering actuator is shown in Figure 6. The figure shows the general plane motion of the actuator illustrating the locus of the actuator moveable end. The representation was used to guarantee that the selected compartment space could handle the actuator motion during steering.

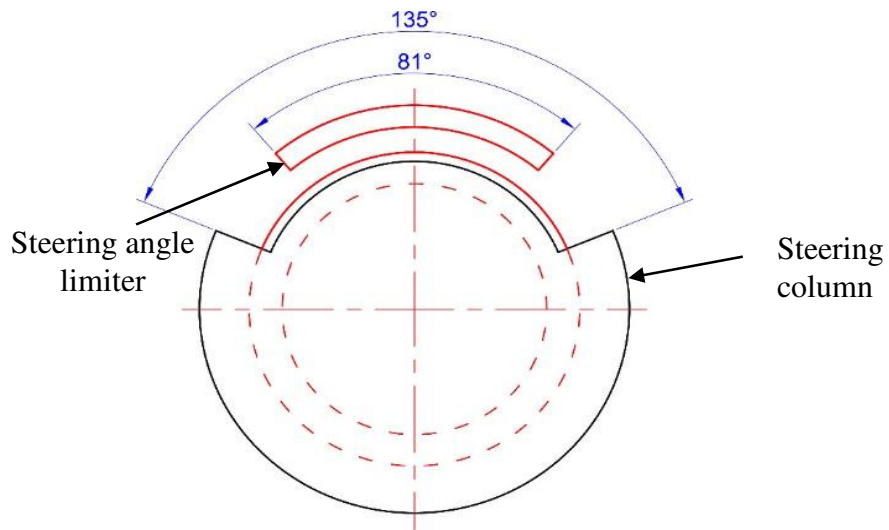


Fig. 4. Steering column angle limiter – TOP VIEW.

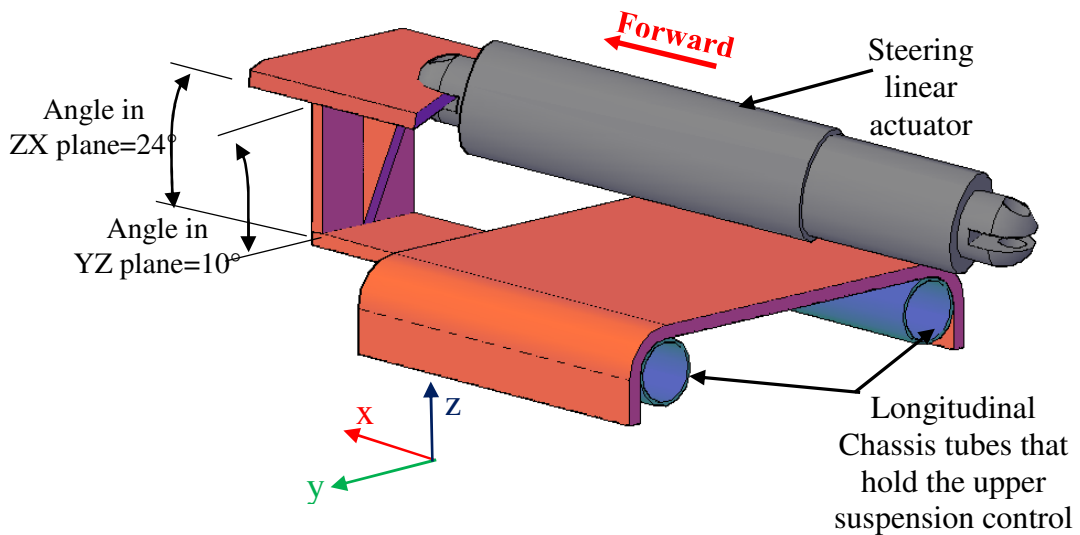


Fig. 5. Steering actuator has a 3D angle to fit in its tight compartment.

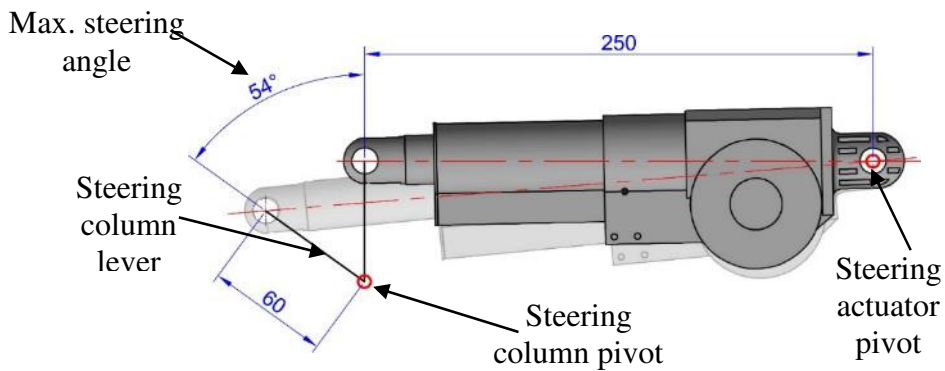


Fig. 6. Steering actuator extreme positions during rotation – TOP VIEW.

ACCELERATOR ACTUATOR

The accelerator actuator was chosen to be a stepper motor as the position of the accelerator (or carburetor throttle valve) needs to be controlled as precise as possible. The accelerator actuator was placed so that it pulls an additional throttle wire attached to the same pulley used to pull the original accelerator wire. When the Remotely Operated Vehicle (ROV) mode is deactivated, the power to the stepper motor is disabled, and hence, the function of the original accelerator is not affected because the pulley will then be returned to the idle position by the torsion spring of the throttle valve. Figure 7 shows the accelerator actuator in its place.

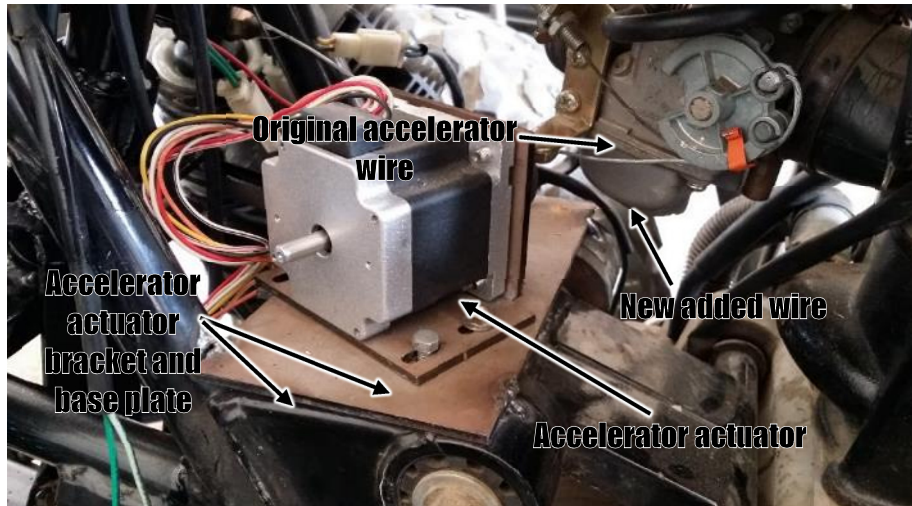


Fig. 7. Accelerator actuator mounted in its compartment.

The controller and the driver of the stepper motor are shown in Figure 8. The function of the program loaded on the controller in the first stage of the project was only to drive the vehicle with a limited speed for the sake of transporting the vehicle between the departments. The wiring diagrams of the stepper motor connections and the remaining actuators will be discussed later in this article.



Fig. 8. Controller and driver of the accelerator stepper motor.

BRAKE AND SHIFTING ACTUATORS

The brake actuator was chosen to withstand the statically measured brake pedal force. The fixed end of the brake linear actuator was mounted directly on the chassis with ease, while its moveable end was mounted on the brake pedal. Figure 9 shows the brake actuator mounted in its compartment.

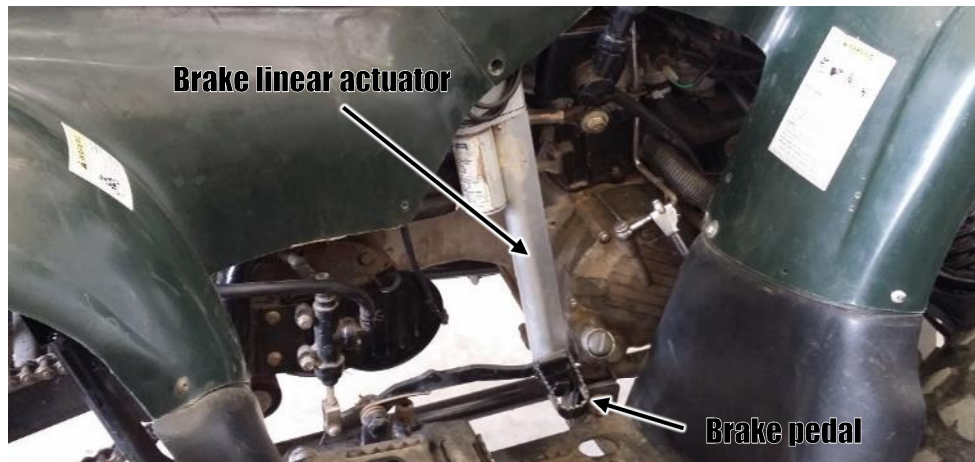


Fig. 9. Brake linear actuator in its compartment.

The shifting linear actuator was placed in the rear side of the chassis. Figure 10 shows the shifting linear actuator in its compartment. The orientation of the linear actuator axis was chosen so that the line of the push and pull actions of the actuator coincides, as close as possible, with the original main shifting tie rod axis.



Fig. 10. Shifting linear actuator in its compartment.

PROJECT DELIVERABLES

The vehicle was equipped with an emergency stop button mounted on the rear side of the vehicle body so that it is handy and reachable during the operation of the UGV, Figure 11.

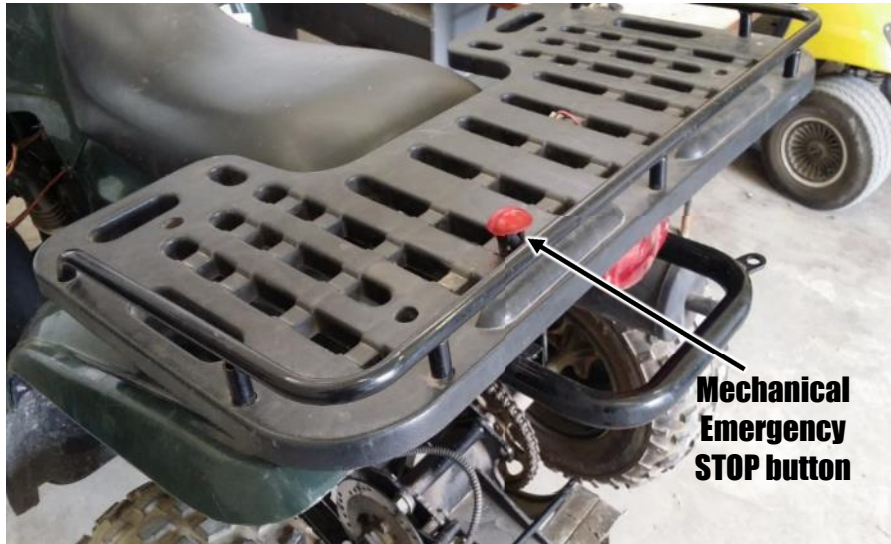


Fig. 11. The Emergency STOP button is located at the top of the rear side of the vehicle body.

The steering actuator was mounted on the steering actuator plate as indicated earlier. Figure 12 shows the assembled steering actuator mounting system.

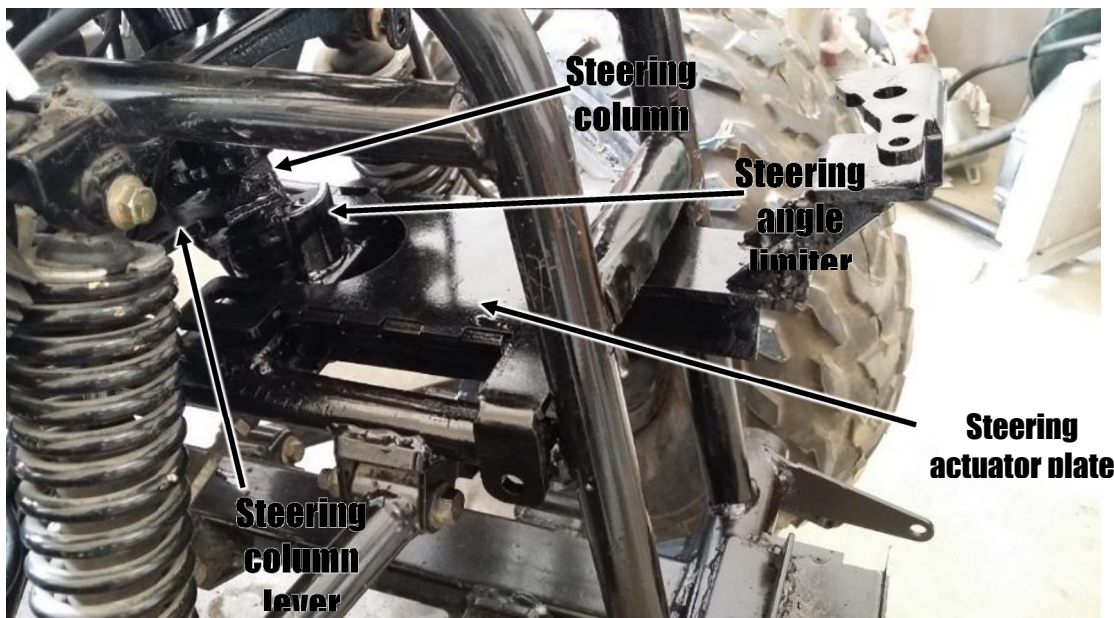


Fig. 12. The steering actuator base plate in its compartment.

For the sake of transporting the vehicle between departments during the first stage of the project, a wired control panel was implemented, see Figure 13. The control panel was designed to contain a wired six-channel connection to the UGV harness. This is

because the control panel contained six control switches; three momentary Double Pole Double Through (DPDT) switches, a momentary Single Pole Single Through (SPST) switch and two ON/OFF switches. The three momentary DPDT switches are to control the steering, brakes and shifting (direction) actuators. The momentary SPST switch is for starting the engine. One of the ON/OFF switches is for turning the ignition ON and OFF which also could be used to remotely bring the vehicle to a complete stop in case of an emergency. Finally, the second ON/OFF switch is used to energize the accelerator actuator control program which is set-up previously to a limited throttle valve position as mentioned earlier.

The control panel was designed and connected so that, when detached, the remaining harness plugs match the connections required for extending the control work of the vehicle in the second stage of the project, see Figure 14. Each of the linear actuators needs a pair of terminals (collected in one plug) to control the polarity of the input voltages to the actuators.



Fig. 13. Wired control panel.



Fig. 14. Labeled plugs of the new harness to facilitate the extended control work.

The main wiring diagram of the new developed harness that connects the actuators to the control panel and the power source is shown in Figure 15. An auxiliary 12V 12Ah battery was added to the system just to operate the actuators separately. There is no concern about using the vehicle OEM battery for powering the actuators though. The figure shows the components on the vehicle side which are, basically, the actuators, the controller and the emergency stop button. Also, the control panel side components are shown in the figure. In between, the connecting harness is shown in the figure. It is worth mentioning here that the connection taken from the primary coil ignition circuit could give a good indication about the engine r.p.m. which could be used as a feedback indicating the engine starting in the second stage of the project when a wireless control will be used. This signal is a pulsating signal with an amplitude of 140 mV and its frequency is proportional to the engine r.p.m. The availability of this signal in the remote control station facilitates the acknowledgement of the engine remote operation to the UGV operator.

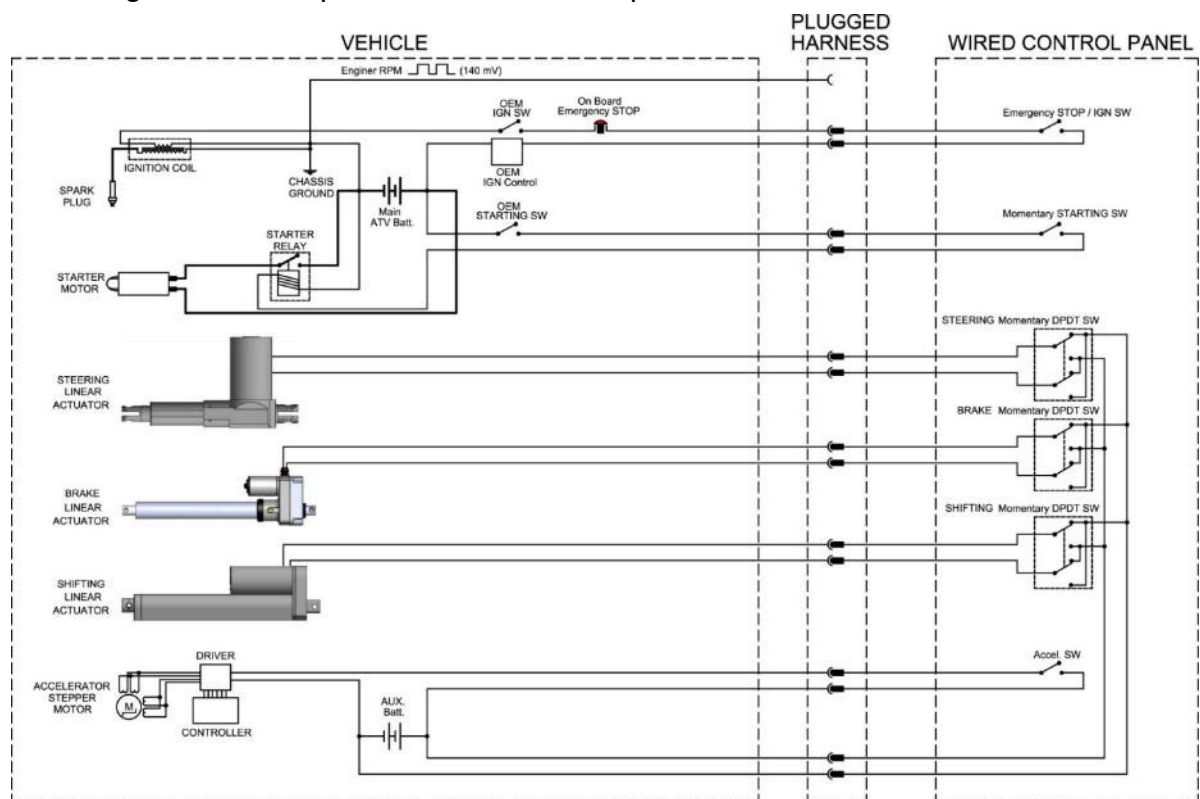


Fig. 15. Wiring diagram of the new developed UGV system.

Figure 16 shows the complete wire controlled UGV at the end of the first phase of the project. The UGV operation was tested. All the control mechanisms were functioning properly with ease including the remote engine starting, stalling, and acceleration, steering, shifting and braking. The emergency stop button operation was tested repeatedly and it was functioning properly. Also, the time duration of the easy deactivation and reactivation of the UGV mode was recorded to be less than 5 minutes for each case with a minimal tool count.



Fig. 16. The successfully modified ATV into a UGV with its wired control panel as delivered at the end of the first stage of the project.

CONCLUSIONS

In the present work, a conversion of a light weight vehicle into a UGV was carried out. Two main design constraints were imposed to the proposed solution. The first is to keep the outer shape and dimensions of the original vehicle unaltered. The second is to maintain the deactivation and reactivation of the UGV mode as simple as possible to facilitate the normal operation of the vehicle. The main four actuation mechanisms; steering, accelerator, braking and shifting, were electrified. The design procedures were illustrated and the hardware implementation was explained. The UGV was tested experimentally and showed successful operation in all actuation commands including deactivation and reactivation of the UGV mode. The developed UGV and the documentation of the harness wiring diagram, accelerator control program and complete design drawings were presented as the deliverables of phase I of the project. The project future phases will include converting the UGV into wireless mode and implanting smart control and navigation algorithms.

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REFERENCES

- [1] Chamberlain, P., Doyle, H. L., “Encyclopedia of German Tanks of World War Two”, ISBN-13: 978-1854095183, Cassell, 1999.
- [2] Irincheev, B., “War of the White Death: Finland against the Soviet Union 1939-1940”, ISBN 978-0-8117-1088-6, Stackpole Books, 2012.
- [3] Rosen, C. A., Nilson, N. J., “Application of Intelligent Automata of Reconnaissance”, Stanford Research Institute Report, 1966.
- [4] Nilson, N. J., “Shakey the Robot”, Stanford Research Institute Technical Notes, 1984.
- [5] Thrope, C., Hebert, M., Kanade, T., Shafer, S., “Toward Autonomous Driving: the CMU Navlab. Part II – Architecture and Systems”, IEEE Intelligent Systems, vol. 6, no. 4, pp. 44-52, August 1991.
- [6] Everett, H. R., “Sensors for Mobile Robots: Theory and Applications”, ISBN 1-56881-048-2, A. K. Peters, 1995.
- [7] Behringer, R., Sundareswaran, S., Gregory, B., Eley, R., Addison, B., Guthmiller, W., Daily, R., Bevely, D., “The DARPA Grand Challenge – Development of an Autonomous Vehicle”, IEEE Intelligent Vehicles Symposium, DOI: 10.1109/IVS.2004.1336386, June 2004.
- [8] Thrun, S., Montemerlo, M., Dahlkamp, H., Stavens, D., Aron, A., Diebel, J., Fong, P., Gale, J., Halpenny, M., Hoffmann, G., Lau, K., Oakley, C., Palatucci, M., Pratt, V., Stang, P., Strohband, S., Dupont, C., Jendrossek, L. E., Koelen, C., Markey, C., Rummel, C., Niekirk, J., Jensen, E., Alessandrini, P., Bradski, G., Davies, B., Ettinger, S., Kaehler, A., Nefian, A., Mahoney, P., “Stanley: The Robot That Won the DARPA Grand Challenge”. The 2005 DARPA Grand Challenge. Springer Tracts in Advanced Robotics. 36. p. 1. DOI:10.1007/978-3-540-73429-1_1. ISBN 978-3-540-73428-4, 2007.
- [9] Leonard, J., How, J., Teller, S., Berger, M., Campbell, S., Fiore, G., Fletcher, L., Frazzoli, E., Huang, A., Karaman, S., Koch, O., Kuwata, Y., Moore, D., Olson, E., Peters, S., Teo, J., Truax, R., Walter, M., Barrett, D., Epstein, A., Maheloni, K., Moyer, K., Jones, T., Buckley, R., Antone, M., Galejs, R., Krishnamurthy, S., Williams, J., “A Perception Driven Autonomous Urban Vehicle,” Journal of Field Robotics, vol. 25, no. 10, pp. 727–774, 2008.
- [10] Ozguner, U., Redmill, K.A., Broggi, A., “Team TerraMax and the DARPA Grand Challenge: A General Overview”, IEEE Intelligent Vehicles Symposium 2004, pp. 232–237, Parma, Italy, June 2004.
- [11] Soren, K., Zeigler, J., Pitzer, B., Moritz, W., Gindele, T., Jagzent, D., Schroder, J., Thuy, M., Goebel, M., Felix, V. H., Pink, O., Frese, E., Stiller, C., “Team AnnieWAY’s Autonomous System for the 2007 DARPA Urban Challenge”, Proceedings of Journal of Field Robotics, vol. 25, no. 9, pp. 615–639, 2008.
- [12] Roboteam Inc. products: online website: www.robo-team.com/products/, accessed November 2017.
- [13] Hawkins, A. J., “You can Hail a Self-Driving Uber in San Francisco Starting Today”, online article: <https://www.theverge.com/2016/12/14/13921514/uber-self-driving-car-san-francisco-launch-volvo-xc90>, December 2016.
- [14] Solon, O., “Almotive Aims to Convert Regular Cars into Driverless Ones Inexpensively”, The Guardian, online article: <https://www.theguardian.com/technology/2017/mar/05/aimotive-driverless-cars-artificial-intelligence-cameras>, March 2017.

- [15] Perminov, V. G., "The Difficult Road to Mars; A Brief History of Mars Exploration in the Soviet Union", Monographs in Aerospace History, NASA Headquarters, July 1999.
- [16] Welch, R., Limonadi, D., Manning, R., "Systems Engineering the Curiosity Rover: A Retrospective", IEEE 8th International Conference on System of Systems Engineering, DOI: 10.1109/SYSoSE.2013.6575245, Wailea-Makena, HI, USA, June 2013.
- [17] Martins, N., Busalacchi, A., Garvey, J., Hedinger, L., Holub, D., McElhinney, S., Mukherjee, R., Ramesh, R., Thomson, R., Tossell, K., Walsh, M., Winter, S., Yang, A., "Donatello Design Report", 7th Annual Intelligent Ground Competition (IGVC), 2009.
- [18] Crane, C., Ahmed, M., Galluzzo, T., MacArthur, D., Solanki, S., Zawodny, E., "A Technical Report on TailGator", 12th Annual Intelligent Ground Competition (IGVC), June 2014.
- [19] Beainy, F., Commuri, S., "Development of an Autonomous ATV for Real-Life Surveillance Operations", 17th Mediterranean Conference on Control and Automation, DOI: 10.1109/MED.2009.5164660, Thessaloniki, Greece, 2009.