ARG-US "Traveler" for Tracking and Monitoring Conveyances

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ABSTRACT

Testing and demonstration of ARG-US "Traveler's" ability to track and monitor conveyances carrying risk-significant materials are described, with an emphasis on near real-time satellite tracking and sensor performance, as well as data analytics after the trips. The GPS locations and time stamps of the conveyances allow for strong associations of significant events measured and recorded by Traveler's sensors during the trips.

INTRODUCTION

The ARG-US "Traveler" [1] has been developed under the auspices of the U.S. Department of Energy (DOE) Packaging Certification Program, Office of Packaging and Transportation, Office of Environmental Management. It is the latest innovative product in the family of ARG-US (meaning "The Watchful Guardian") remote monitoring system technologies for risk-significant materials in cargo conveyances during transportation by truck, rail, or ship. Risk-significant materials may include nuclear and other radioactive materials, radiological sources, and/or hazardous chemicals, for which safety, security, and safeguards are major concerns, as the threats of sabotage and theft are real with very serious potential consequences. The Traveler's modular platform, shown in Figure 1, allows sensors to be added or removed (i.e., customized) with relative ease. For example, the Traveler's modular suite of sensors may include

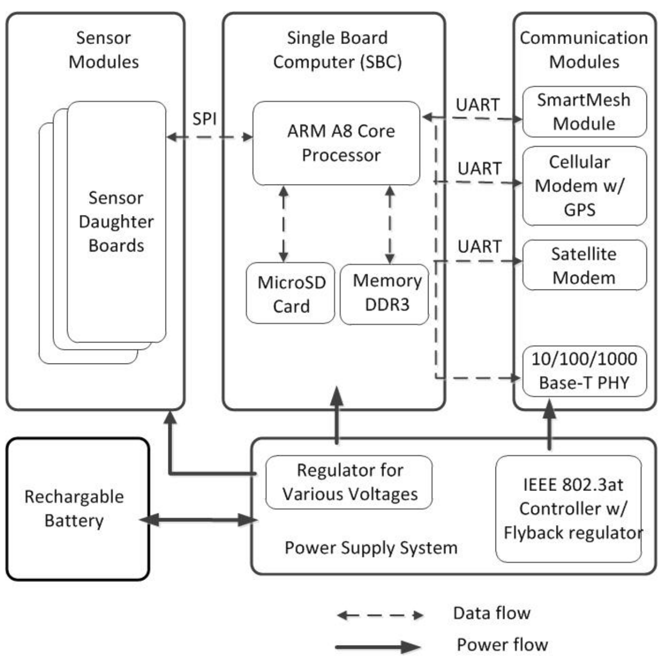
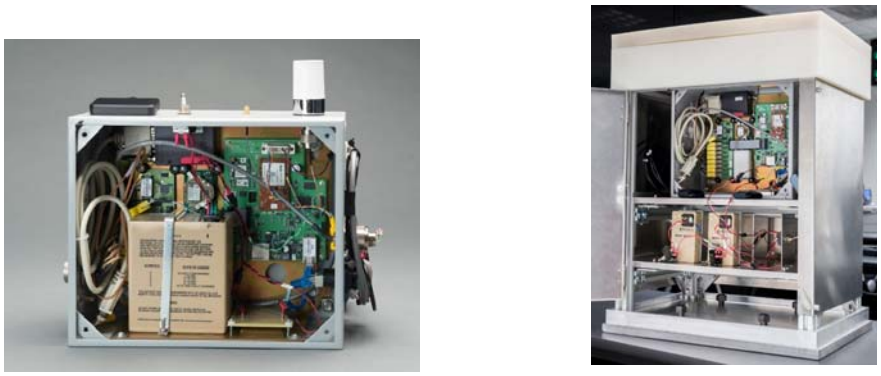


Figure 1. Block diagram of hardware architecture design of Traveler.

temperature, humidity, and radiation (gamma and neutron) sensors, as well as a 3-axis digital accelerometer, an electronic loop seal, and a digital camera, depending on monitoring needs. The Traveler uses redundant methods (i.e., cellular and satellite) for the transmission of sensor data, alarm annunciation when sensor thresholds are violated, and clearance of alarms remotely from a command center. Powered by rechargeable lithium-ion batteries, the Traveler in its current configurations, shown in Figure 2, can support continuous tracking and monitoring for up to 3-6 days. The majority of performance testing and demoing of Traveler to date was conducted using a Traveler prototype shown in Fig. 2(a); the Traveler 2 prototype inside a weather-proof enclosure, shown in Fig. 2(b), was used in a rail shipment during the summer of 2017.



(a) (b)

Figure 2. (a) Traveler with a rechargeable lithium-ion battery inside a lunchbox-sized unit, and (b) Traveler 2 inside a weather-proof enclosure with two rechargeable lithium-ion batteries in a separate compartment beneath the unit.

The following sections provide highlights of the Traveler's field tests and demonstrations conducted during 2017, including vehicles on both local and interstate highways and the ENSA/DOE transport cask vibration tests [2] during rail shipment from Baltimore, MD, to Pueblo, CO, July–August 2017.

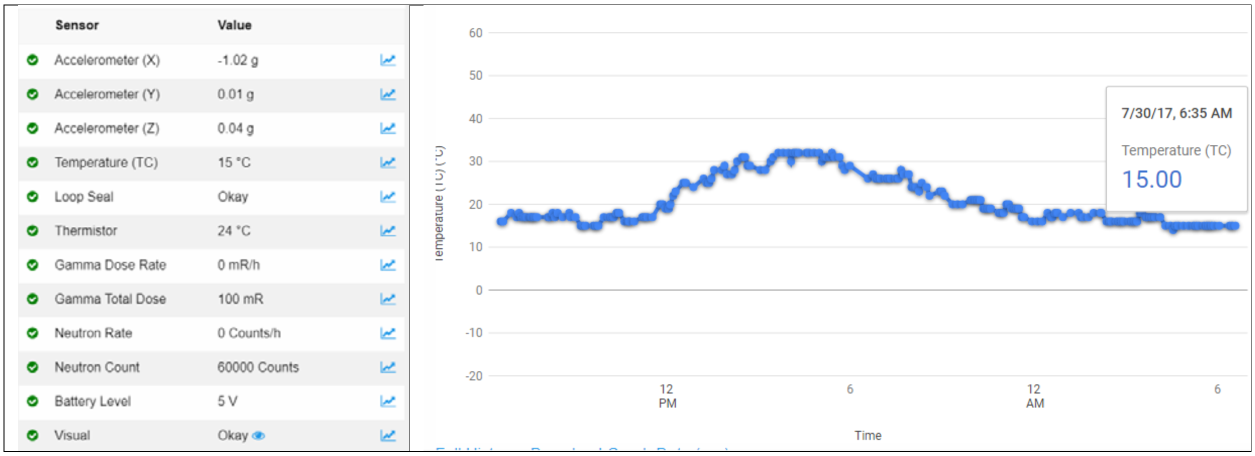
VEHICLE ON HIGHWAYS

Figure 3 shows Traveler Iridium satellite tracking of a vehicle driving on state and interstate highways from Baltimore, MD, to Chicago, IL, on July 29, 2017. The entire trip was summarized and displayed in clusters of aggregated "breadcrumbs" (i.e., satellite transmissions) totaling 185 in 23 hours. The aggregates are single or double-digits—representing the number of individual breadcrumbs aggregated over each segment of the trip. The map scale can be enlarged or reduced by clicking the ± buttons located near the upper left

Figure 3. Traveler Iridium satellite tracking of a vehicle from Baltimore, MD, to Chicago, IL, July 29, 2017.

corner of the webpage, which would alter the number of aggregates and their distributions, accordingly. The map view can be toggled among road view, aerial view, or topographic view by clicking the icon button located near the upper right corner of the webpage, whereas the search box under the ± buttons quickly reveals the location of the vehicle by latitude and longitude.

SENSOR PERFORMANCES



(a) (b)

Figure 4. (a) Traveler's sensors status and values as of most recent update, and (b) ambient temperature history over the last 24 hours.

The icon button (status green) near the bottom left corner of the webpage in Figure 3, when clicked, would display a dropdown box, shown in Figure 4(a), listing all of the Traveler's sensors and their values as of the most recent update, i.e., the latest satellite transmission. Figure 4(b) shows the ambient temperatures measured and transmitted during the last 24 hours. This graph was automatically generated when the icon to the far right of the temperature sensor in Fig. 4(a) was selected. The window in Figure 4(b) popped up after the last data point on the graph was clicked, displaying the date, time, and temperature value—7/30/17, 6:35 AM, and Temperature (TC) 15.00. (The accuracy of the surface-mount, bandgap temperature sensor at room temperature is ±0.4°C, according to the datasheet).

Figure 5 shows the data of the 3-axis digital accelerometer in the Traveler during the Baltimore–Chicago trip. These graphs were plotted from three sets of accelerometer data (X-, Y-, and Z-axis), with each of the 113 data points representing a successful satellite transmission, starting from 7:21 AM to 22:01 PM, July 29, 2017, approximately 14.5 hours from start to finish. The digital accelerometer in Traveler is an integrated-circuit accelerometer consisting of a surface-micromachined capacitive sensing cell (g-cell) and a signal conditioning application-specific integrated circuit (ASIC) in a single package. The sensing element is sealed hermetically at the wafer level, and the g-cell is a mechanical structure formed from semiconductor polysilicon. The ASIC measures the g-cell capacitors and extracts the acceleration data from differences between the capacitors; it also conditions and filters the signal, providing a digital output that is proportional to acceleration. For a vehicle trip on state and interstate highways, a normal range of accelerations is expected in the gravity direction (X-axis), varying between –0.98 and –1.03 g in Fig. 5(a). Vehicle turning caused changes in speed, but the resulting accelerations (Y-axis) were minor, varying between –0.05 and 0.05 g in Fig. 5(b). Relatively large changes in speed occurred in vehicle stops, brakings, or accelerations (Z-axis), which can be as high as 0.3 g or as low as ~0.1 g, as shown by the data points of the Z-axis accelerometer in Fig. 5(c).

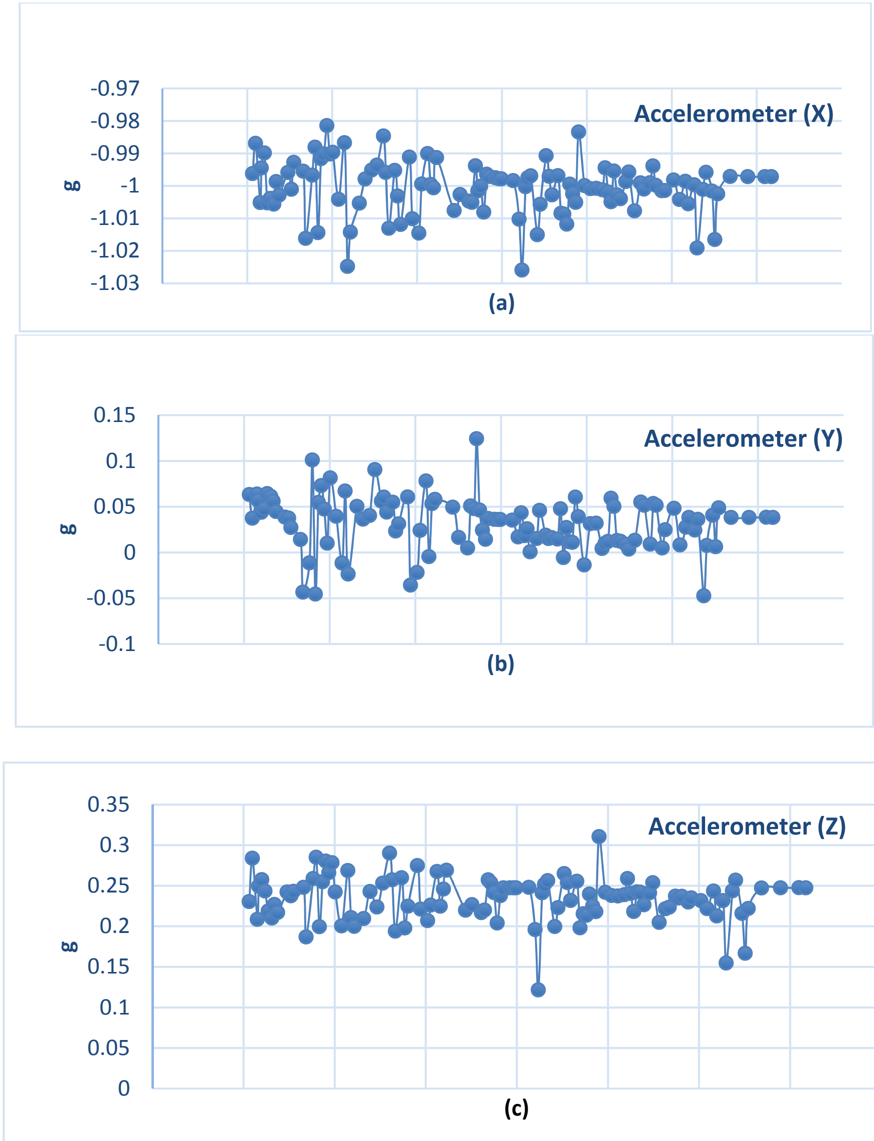
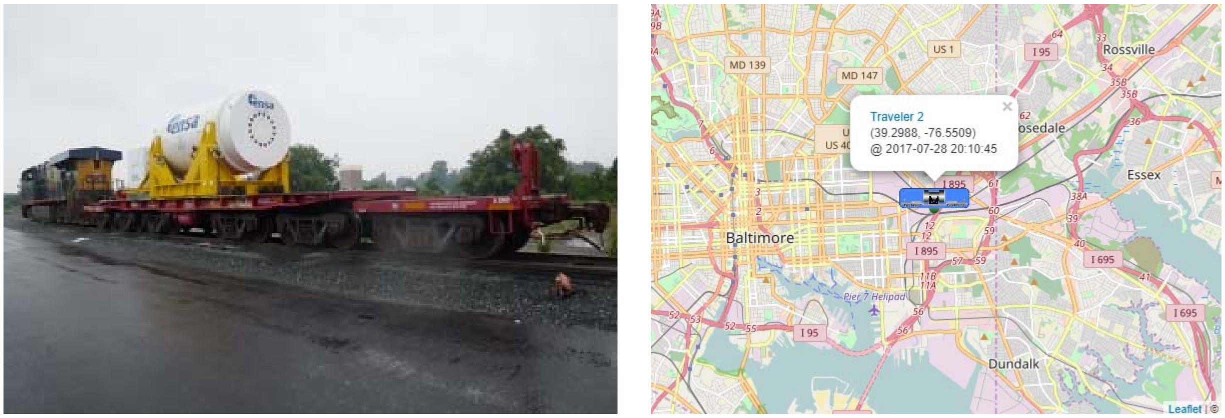


Figure 5. Accelerations (g) recorded during the vehicle trip from Baltimore to Chicago on July 29, 2017. (start 7:21 AM and finish 22:01 PM)

RAIL SHIPMENT

Figure 6(a) shows the railcar with the ENSA/DOE transport cask and Traveler 2 in its weather-proof enclosure [see Fig. 2(b)] welded to the railcar behind the transport cask at the CSX Bayview Yard, Baltimore, MD. Figure 6(b) shows the Global Positioning System (GPS) location (latitude, longitude) of the railcar with a time stamp shortly after Traveler 2 was activated ~4:15 PM (20:10 45 GMT) on July 28, 2017. (The train did not leave the railyard until the evening of July 28.) Shortly after the train left the railyard, a password-controlled, public-accessible webpage was made available to monitors who followed the rail shipment in real time from various locations across the United States and in Europe for 6 days.



(a) (b)

Figure 6. (a) Railcar with the ENSA/DOE transport cask at the CSX Bayview Yard, Baltimore, MD (the weather-proof enclosure containing Traveler 2 is welded to the railcar behind the transport cask); (b) GPS location (latitude, longitude) of the railcar after Traveler 2 was activated in the railyard.

Figure 7 shows the Traveler 2 Iridium satellite tracking of the railcar during the six-day journey from Baltimore, MD, to Pueblo, CO, July 29 to August 3, 2017. The total number of breadcrumbs is 1,108; the journey was marked by arrows in the map view showing the direction of travel from east to the west.

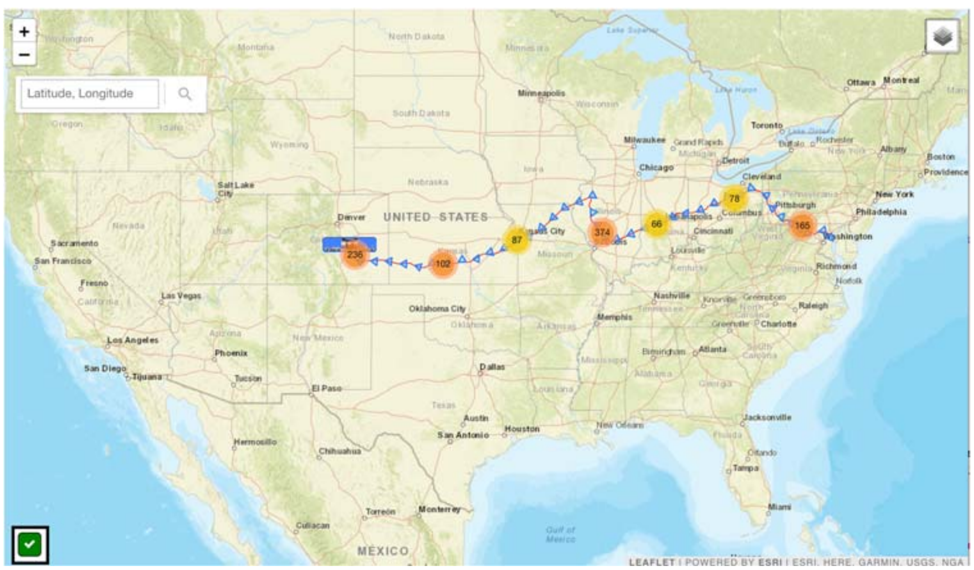


Figure 7. Traveler 2 Iridium satellite tracking of rail shipment from Baltimore, MD, to Pueblo, CO, July 29–August 3, 2017.

Figure 8 shows the aerial map view of Traveler 2 Iridium satellite tracking of the railcar at Transportation Technology Center, Inc. (TTCI) near Pueblo, CO. The railcar was parked at the TTCI rail track for the hours shown by the spiral of breadcrumbs—all have the same geographical location (latitude, longitude), but different time stamps—the last one being 2017-08-03 21 02:59 (GMT).

Figure 8. Traveler 2 Iridium satellite tracking of railcar at TTCI, Pueblo, CO, August 3, 2017.

DISCUSSION AND SUMMARY

Remote tracking and monitoring of potential risk-significant materials in conveyances using the ARG-US Traveler has been demonstrated in vehicles travelling on local and interstate highways and in a rail shipment from Baltimore, MD, to Pueblo, CO, July 28 to August 3, 2017. Real-time tracking performance of the Traveler, measured by the GPS locations of a vehicle and/or train and manifested in webpage displays, was deemed satisfactory over a sustained period of hours to days. The Traveler's Iridium satellite tracking capability, therefore, should achieve a similar level of performance to those demonstrated in this paper in other parts of the world. The service life of the lithium-ion battery in the Traveler imposes a limit on use; however, various means and schemes of power management can be incorporated into the Traveler, including use of additional rechargeable batteries, adjustment of the duty cycles of the data transmission intervals, use of hybrid satellite and cellular communications, and energy harvesting from the environment.

Understanding Traveler's sensor performance necessitates a focus on the primary functions of each sensor that affect data collection frequency, communication, and energy consumption. For example, the data collection frequency for the 3-axis digital accelerometer in Traveler can be set as low as 1.5 Hz and as high as 800 Hz, which may result in a large amount of data of little value and create an unnecessary burden on data storage, while draining batteries due to the energy cost associated with data transmission. Perhaps only the peak values of the accelerometer data are of interest, as in transportation accidents involving vehicle collisions and/or train derailments. These types of accidents will cause sudden changes in velocities in all three axes, which can be identified by thresholds set for the 3-axis digital accelerometer. Alerts/alarms will be sent automatically when data exceed the thresholds, along with the GPS locations and times of such events for immediate response and for post-accident management, assuming the Traveler remains functional after the accidents.

Specialty sensors in the Traveler include radiation sensors for gamma radiation and neutrons, an electronic loop seal, and a digital camera; each of which has its own characteristics, primary functions, and data transmission and storage requirements. Remote control of these sensors would be desirable with an on-off switch capability, for example, activating the digital camera in the Traveler only when necessary, and clearance of the electronic loop seal alarm remotely from a command center after the cause of the alarm has been investigated to be benign and the loop seal is reengaged. More effort will be required to optimize the use of the digital camera because the images are data-intensive, which affect data processing, communication, and storage. Progress in using the digital cameras in the Remote Area Modular Monitoring

(RAMM) systems in Argonne's Alpha-Gamma Hot Cell Facility is described in a companion paper by Craig et al. [3].

Major improvements have been made in the Traveler's Web application user interface during the course of field testing and the demonstrations in 2017. New webpage functions and analytics are also being developed, including average vehicle speeds, segmented terrain videos, weather maps, algorithms for the implementation of geo-fencing, and alert/alarm annunciation. These features will be validated in future conveyance shipments using Traveler for tracking and monitoring, with potential industry partners in the United States and other countries in the world.

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