PSI-6267

# 10th Quarterly Report – Public Page

Date of Report: *July 10, 2013*

Contract Number: *DTPH56-10-T-000021*

Prepared for: *Department of Transportation/Pipeline and Hazardous Materials Safety Administration*

Project Title: *Advanced Learning Algorithms for PIGPEN*

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For quarterly period ending: *June 30, 2013*

## Work Completed During this Quarterly Period

Task 3.2 – Translate Software to Firmware

*Hardware Assembly and Field Testing*

*Field Test 2 has commenced at the Heath facility in Houston. A set of sensors and a NIB were installed near the end of this reporting period. Data collection has commenced.*

*PSI, Heath, and NYSEARCH members collectively discussed site requirements for Field Tests 3 and 4. Plans were established for two month-long tests starting in late August at sites in NJ and NY.*

*Algorithm Development and Implementation*

*The self-learning and signal processing algorithms have now been configured for real-time processing and are ready for installation and testing. Previously, the algorithms were implemented in MATLAB and tested by post-processing data acquired at prior tests. The algorithms are now written in C code and processes data at the NIB as the data arrive from the sensors.*

*Also, in this reporting period PSI improved the localization subroutine of the self-learning algorithm (SLA) by solving the trilateration problem using a nonlinear least squares method (NSLM). The NLSM was determined to give the most accurate location of*

*a disturbance, when exact distances from the sensors are not known. The subroutine was tested on a blind data set acquired at the PSEG natural gas pipeline in Woodbridge, NJ. The seismic data consists of seismic signals from the background, trains and tamper.*

**Results and Conclusions:**

*We improved the localization subroutine by implementing a nonlinear least squares method (NSLM). The NSLM can make accurate guesses of the location of a disturbance even when the signal data in the sensors is corrupted by discrete noise sources or in scenarios where the sensors are dominated by background noises. Therefore, the NSLM reduces the probability of a false alarm.*

*The ability to correctly pinpoint the location of unauthorized digging in the right-of-way is a key feature of the SLA. This is achieved by trilateration— the intersection of the range estimates of the disturbance for the 3 loudest sensors. In general, the signal power, P, received at a distance, r, from a source signal, $P_0$, follows an inverse square law. i.e.,* $= k\, {}^{P_0}/_{r^2}$ *, where k is a constant. However, for the underground sensors configuration, it was previously determined (experimentally) that a logarithmic function provides the most robust performance in terms of locating the source. The Log function is in the form:* $P_0 - \log_{10} P = Kr$*, where K is a constant. This Log function is more resilient to the variation of disturbance sources, sites, seasons, and other environmental factors affecting the propagation of seismic waves.*

*At the core of the original localization subroutine is the following decision sequence:* ***a)*** *A "guess" of the power of the source, followed by* ***b)*** *an estimate of the range of the source from each of the sensors starting from an initial "guess" of source power.* ***c)*** *Based upon the positions of the possible solutions, as judged by the number of intersections between the range estimates, an iteration of source power estimate (up or down) so that convergence to a single point solution is achieved (if the solution exists).*

*This approach fails for the following scenario: The signal data at one of the three loudest sensors is distorted by an additional discrete noise source such as a car passing by. Also, in the case of large spacing in between sensors, the sensor most distant from the source is often dominated by background noise (i.e., low signal-to-noise ratio) such that localization mostly happens at that sensor. Thus, another method besides the Log function is needed for improved accuracy.*

*In cases where the signals are clearly detected by the sensors, and where there is a real threat, both the Log function and NSLM converge to a single solution. This is shown in Figure 1. The locations predicted by the Log function and the NSLM point are represented by a magenta cross and purple cross, respectively. In Figure 1, the crosses overlap. In the localization plots, the Sx (x=1..6) denote the sensor locations in space, and the asterisks highlight the 3 loudest sensors. The large red, blue and green circles are the range estimates of the disturbance from the 2 loudest sensors.*

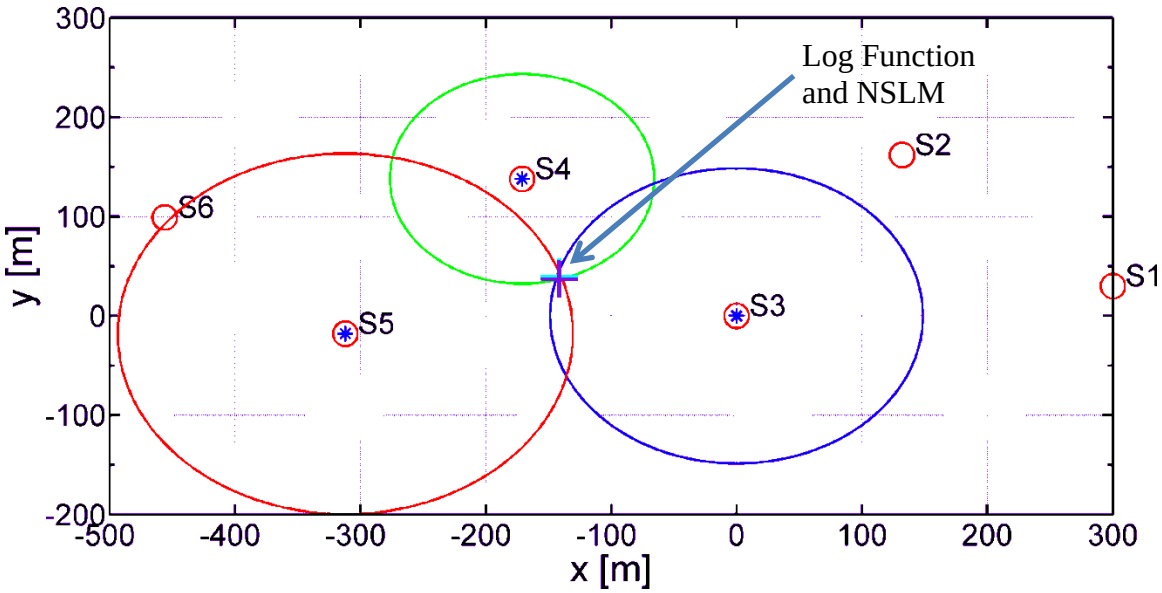


**Figure 1**. Both the Log function and NSLM converge to a single solution. i.e., the crosses denoting the locations overlap.

*Figure 2 is an example of a case where the Log function technique incorrectly predicts the location of the disturbance. Based on the location of 3 loudest sensors (S3, S1 and S5), as shown in Figure 2, it is apparent that the location of the disturbance must be below the y = 0 Cartesian line. If the disturbance was above the y = 0 line, then one of the 3 loudest sensors would have been either S2 or S4, or even both. Although the former localization subroutine has some difficulty in identifying the exact location of the source, it nevertheless indicated that the source was outside the right-of-way.*

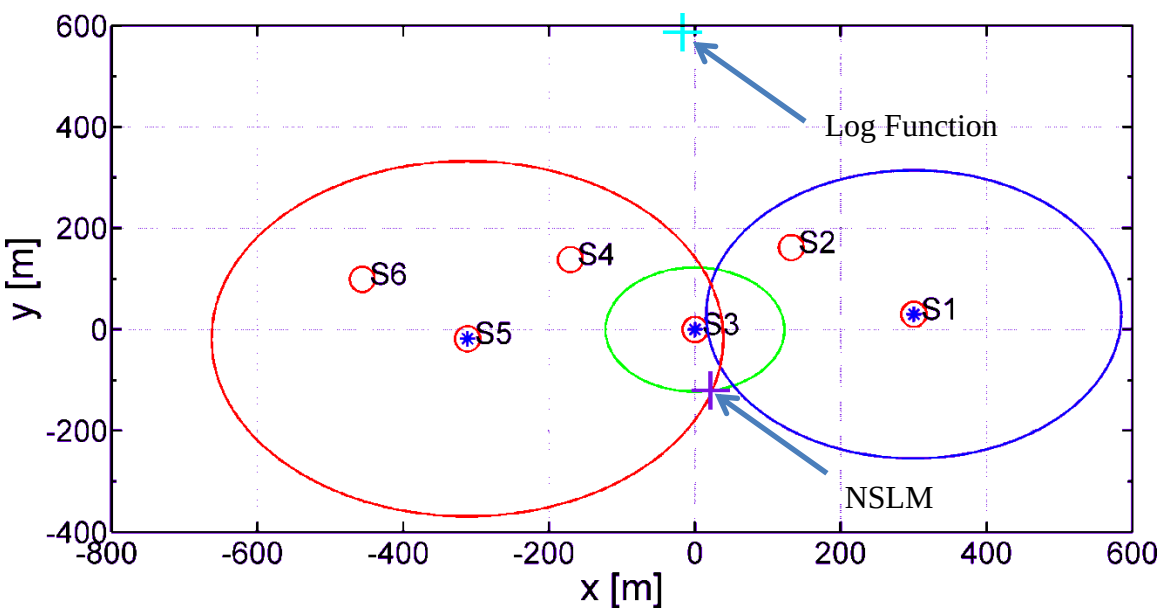


**Figure 2**. NSLM incorrectly predicts the location of the disturbance, while the NSLM converge to a more plausible solution.

*In this last scenario, shown in Figure 3, the Log function erroneously indicates that the threat is located 6 km away from the center of the right-of-way. This shows that the subroutine becomes utterly confused when the power registered by the 3 sensors is distorted. In this case, the power detected by the 3 loudest sensors was about the same strength, as shown in Figure 4. In Figure 4, we see that the NSLM can make a more accurate guess, even though the signal is corrupted.*

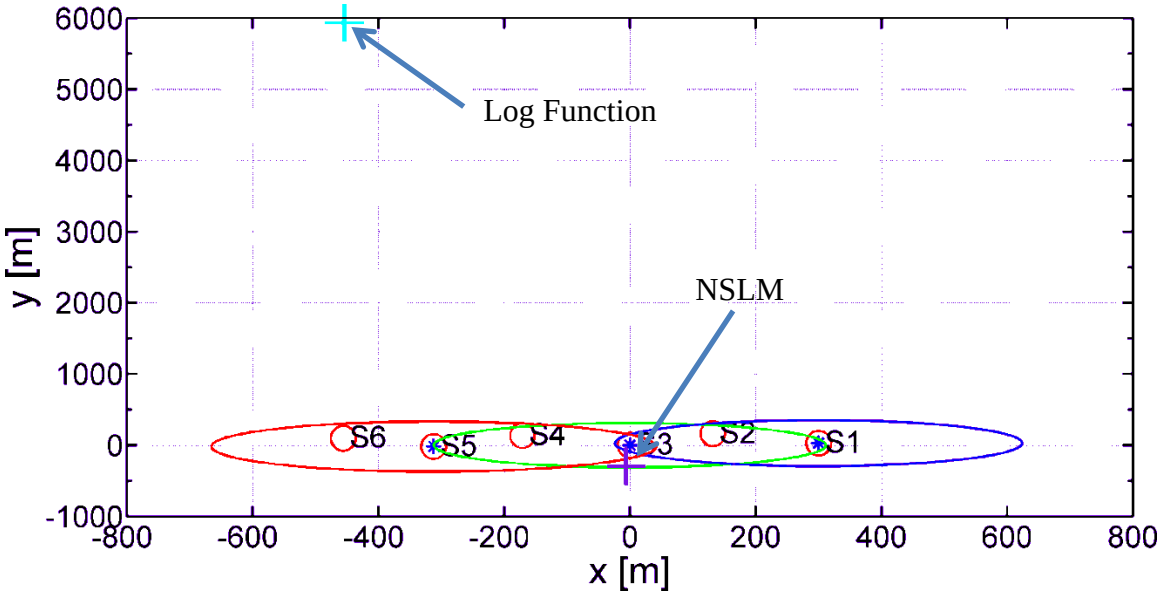


**Figure 3**. Log function yields highly erroneous location when the data from the sensors are distorted.

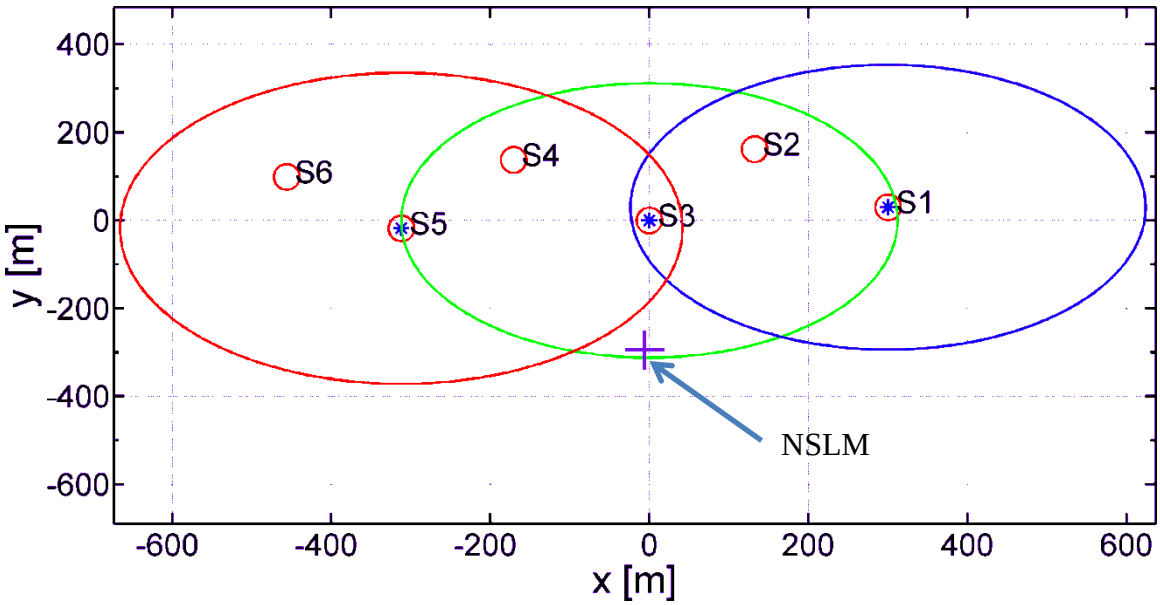


**Figure 4.** NSLM provides improved localization, even when the data on the sensors is corrupted.

**Plans for Future Activity:**

*Field tests of the system with the improved algorithms operating in real time has commenced and will continue throughout the next reporting period.*