Health Monitoring of Munitions

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When mankind first began to accumulate 'stuff', it became necessary to keep track of 'the stuff', know the condition of 'the stuff' and determine how long 'the stuff' would last. As the quantities of 'stuff' increased these tasks have become more difficult. The 'stuff' is now in excess of 2 million tons. Through the ages various systems have been devised to achieve these goals. Many systems for inventory are labor intensive and prone to error. Once an error in inventory is made, it has a ripple effect to degrade the accuracy of the system. Inventories have the best accuracy the day they are taken and continually degrade until the next time the process is undertaken.

Today I will present a modern approach to reach these goals of accuracy with a low error rate. The United States has a vast array of weapons that spend most or all of their life in storage. Then upon removal from storage are expected of performing with high reliability of their designers. Weapons are made, procured, track, used and destroyed in lots. Lot sizes are statically chosen to posses certain characteristics. Periodically during the life of a lot of weapons a sample is randomly selected for detail destructive analysis. If it fails test requirements the entire lot may have to be modified or destroyed. Once the lot has been identified all its members have to be located for the appropriate action. When weapons leave the factory they are identical and have known life expectancies. It is known that a variety of environmental factors (temperature, humidity, shock, vibration, etc.) affect the weapons' condition and ultimate life expectancies. The older a weapon is the more possible variation in storage condition exist and hence variation in its life expectancies. If individual storage environments could be tracked individual life expectancies could be determined. Weapons reaching near end-of-life could be designated for training and save the cost of de-milling.

The larger the military is the larger the problem. Let's for a minute consider some simple movement of systems. Systems loaded on ships should be simple to track, but in recent years there has been an increase of at-sea transfer. This results in weapons systems leaving on one ship and being transferred to a second ship and so on and so on. Ordnance may be stored at advanced location by one group only to be left for a second group to use later. Locating what is stored and where often becomes a major task.

Solutions to solve these problems are being explored under a tri-service project by the Department of Defense. The goal of the Advanced Technology Ordnance Surveillance or ATOS is to give ordnance managers the ability to accurately locate and continuously determine the status of individual munitions on a near real-time basis while simultaneously updating prediction of their future condition and performance with a high level of confidence. There are three phases to achieving this goal: automated inventory, environmental storage condition monitoring, and insitu analysis of the health of the system. Currently the ATOS program is committed to completion of the first two phases.

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Two technologies (Figure 1) have come together to meet the challenges outlined above: Radio Frequency IDentification (RFID) and low power miniature MicroElectroMechanical Systems (MEMS) sensors. RFID systems are augmenting the standard bar code system with a low power short-range transponder to a local receiver and computer. This enables the timely accurate inventory data. When the RFID standard tag is coupled to an environmental sensor(s) (temperature, humidity, shock etc.) this data can be added to inventory data in a timely manner.

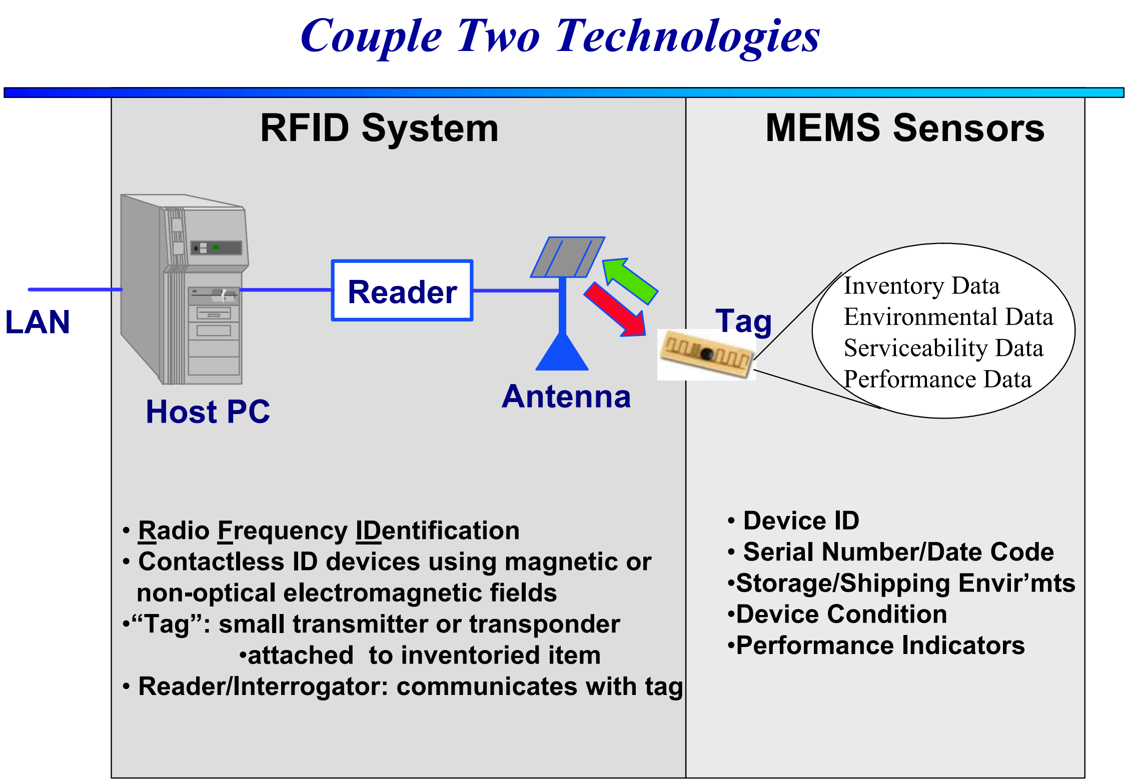

Figure 1.

One of the first challenges is powering the RF tags. RF power scavenging techniques have been developed. These systems have a central medium power level transmitter. The RF energy is received and rectified to produce power required to operate the tag for short periods. RF devices that are safe to be used in and around energetic material must be low power and meet HERO requirements. This precludes the use of current scavenging systems. The tag should be readable in standard magazines and warehouses. A range (open air) of in-excess-of 300 ft is desired. For the near future the tags must rely on battery power. Batteries currently available provide power for a five to ten year life. Battery life can be extended by using non-volatile read/write memory in conjunction with low duty cycle operations. Since the current ATOS tags will be external to ordnance, systems battery replacement is feasible. However, a long-term solution to power source is required for Phase 3 of the project. In addition, to these critical requirements the system must demonstrate better than 99% detect ability in real world environments.

The ATOS tag (Figure 2) has three types of information. First is inventory data (stock control number, serial number etc.) which have been defined by DOD Navy regulations. This allows seamless integration into existing inventory databases. The second type of data is environmental sensor data such as temperature and humidity. The third type of data is performance data. When a threshold has been exceeded a flag is set and during the next inventory interval the flag message is transmitted indicating degraded performance. For example, a locking passive shock sensor would record rough handling (dropping) of the ordnance and set a flag for future interrogation to indicate that the ordnance was not to be used or that further testing was required prior to use.

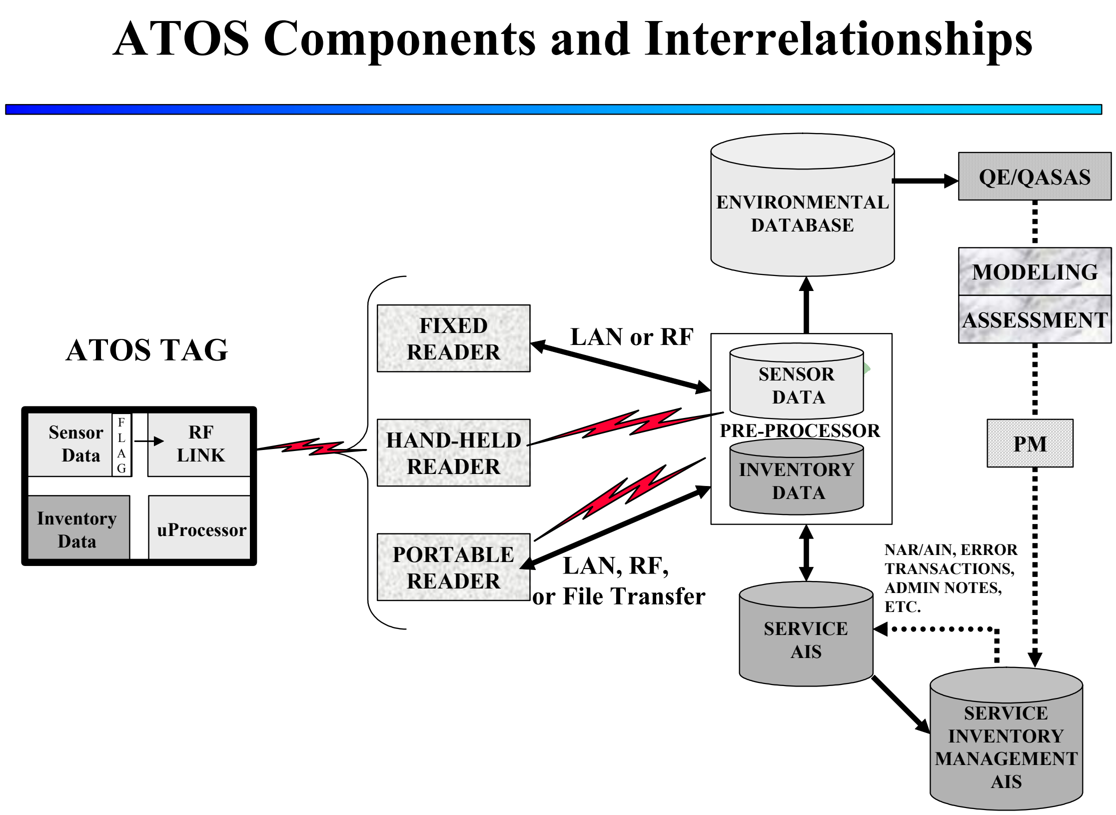

Figure 2.

Three methods of reading the tag data are envisioned. A fixed tag reader that is located in a warehouse or magazine. Or a portable reader to be used at a temporary field storage locations. And finally, a hand-held reader to be aid in shipping and receiving invoicing of ordnance. Once the data (inventory, sensor) is uploaded into a central computer system it would be split into environmental data and inventory data. The environmental data would be examined by QE for life expectancy models for updating predicted performance model. Preventive maintenance schedules for individual weapons would be drawn up. The data coding system has been selected. For temperature data, there are a series of 60- three degrees temperature bins ranging from –20°F to 155°F. Once an hour, the temperature is read and the appropriate bin is incremented. If data tags are read daily, a twenty-four data point profile is uploaded and the daily averages are calculated. Present plans are to read the tag once an hour.

As the project proceeds there have been a series of test to demonstrate features of the system. The RF energy levels must be kept low for explosive safety considerations. One of the initial questions was the RF performance in the presence of a number of metal storage containers that would preclude direct line-of-sight transmission between the reader and a tag. In the test, a typical magazine was filled with eighty-four containers representing six ordnance systems and a single reader. Two types of tags were tested. Five commercial backscatter or scavenger tags were tested. The RF system power of the reader was limited to meet explosive safety considerations. They were able to reliably read about 40 % of the inventory. Their free-space ranges were 6 to 70 feet. These types of tags are best suited for a portal type inventory system. The second class of tags (six) was emitter-type tags (i.e. battery). Two types were able to reliably read 100% of the inventory. The remaining four tags were able to reliably read 85 % of the inventory. When multiple readers were used results improved to 100%. In a second test, six tags (vendors) were chosen for a test aboard the USS Truman aircraft carrier. Located in the bow of the ship on the maintenance deck is a spare parts storeroom. The room has 190 metal storage bins containing 456 tags. During the two-week test, the tag system tracked spare parts being issued. Its performance was evaluated during normal shipboard activities (degaussing, radar operations, radio operations, etc.). The test was very successful and data is being evaluated. A vendor has been selected and is under contract for an upcoming system demonstration.

Now let us focus on the health monitoring aspect of the system. Critical parameters (Figure 3) such as stabilizers concentration are tightly grouped for a lot of ordnance when it is manufactured. Lot to lot variations results in some small additional scatter in the parameter values. Total scatter of a critical parameter diverges with time. Variations within a single lot are due mainly to environmental factors. If environmental factors and critical parameters are modeled, service life and performance can be predicted. The failure and ageing mechanism must also be understood, quantified and modeled. If individual weapon environmental data is available individual life expectancy can be predicted. As oppose life expectancy of the entire lot. Finally, there needs to be a surveillance program to validate models and identify shortfalls. Once such a system is in place, performance can be predicted and safe service life extensions can be evaluated.

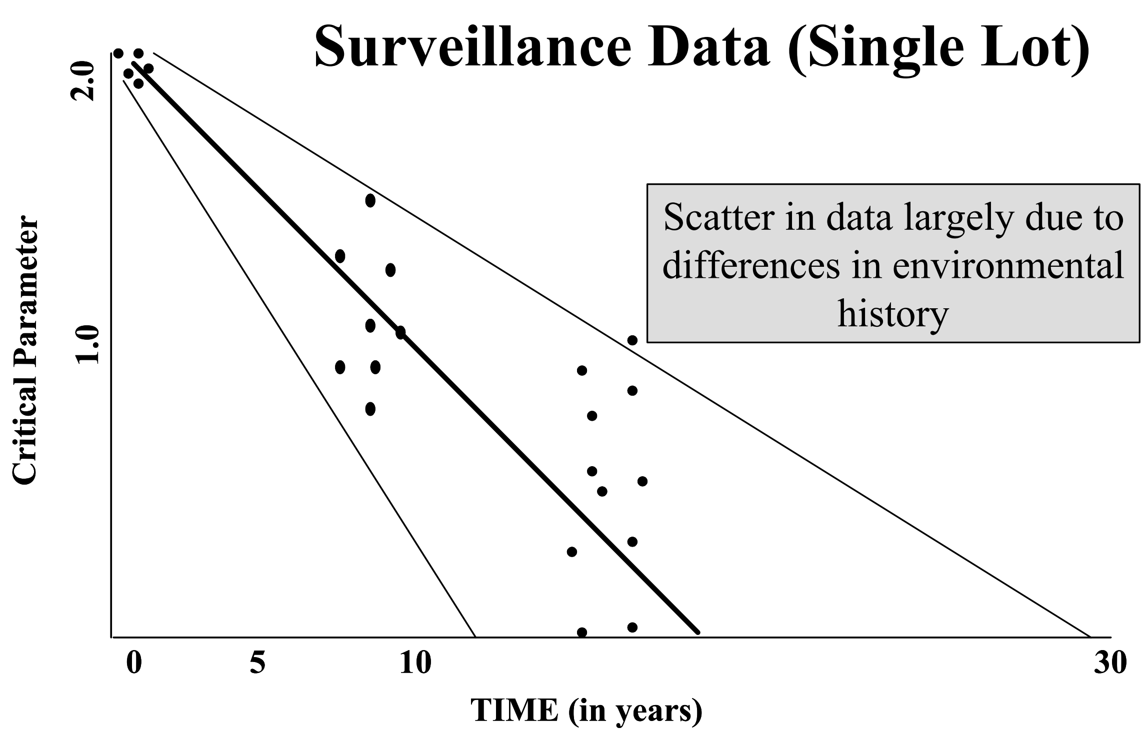

Figure 3.

In an earlier paper I spoke of integrating energetic in to MEMS to produce future Safety and Arming (S&A) systems. To complete the third phase of health monitoring, it is necessary to integrate MEMS into energetics- that is explosive and propellants. It is envisioned that in the near future MEMS technology will produce a "Chemistry Lab on a Chip". Initially these devices will be placed adjacent to energetic material and monitor the health of chemical compounds. The long-term goal is to embed this capability in new weapon systems at the time of manufacturing. Thus, allowing chemical/mechanical measurement in addition to environmental data for high fidelity models. Each of these phases will build upon the infrastructure develop by previous phases.

The goal is give ordnance managers the ability to accurately locate and continuously determine the status of individual munitions on a near real-time basis while simultaneously updating predictions of their future conditions and performance with a high level of confidence. In simple words, the age-old questions:

- What 'STUFF' Do I Have ?
- Where Is My 'STUFF' ?
- Does The 'STUFF' Still Work ?
- How Long Will The 'STUFF' Last ?