INTEGRATING HUMAN FACTORS ISSUES INTO CRITICAL PORTABLE DETECTION USAGE

Steven M. Doettl, Patti M. Johnstone, and Meredith McGhee
University of Tennessee Health Science Center
Department of Audiology & Speech Pathology
South Stadium Hall, Knoxville, TN 37996
sdoettl@uthsc.edu; pjohnst1@uthsc.edu; mmghee9@uthsc.edu

Franklin H. DuBose and Jacqueline M. France
InSolves, LLC
1862 Shyville Road, Piketon, OH 45661-9749
dr.f.dubose@insolves.com; jackiemfrance@yahoo.com

Jamie B. Coble, Graham V. Walford, and Laurence F. Miller
Department of Nuclear Engineering
University of Tennessee
Pasqua Engineering, Knoxville, TN 37996-2300
jcoble1@utk.edu; gwalford@utk.edu; lfmiller@utk.edu

ABSTRACT

There are multiple situations where portable detection systems are used to quantify distributed radionuclides. Such applications include holdup measurements in decommissioning activities, other routine usage and safeguards applications.

Human factors dominate equipment deployment and operation and have significant impact upon the resulting data collection and its quality. Equipment use includes simultaneous positioning and targeting the object/region being quantified, observation and reporting of incoming data, often in difficult conditions and often while dressed in protective equipment. We examine the human interface with the equipment and other human factors where balance, perception, situational awareness and personnel health level influence the physical control and positioning of the detector. All these aspects impact both the measurement outcome and the Total Measurement Uncertainty (TMU). In this work, we are developing approaches and solutions to:

1. Initiate an inclusive program to assess and evolve human factors aspects of the interface to provide real time feedback tailored to a specific field operator profile.
2. Develop a measurement system human interface on a “bench top” detection system to allow for both audio and visual I/O for auditory attention and situational (objective and subjective) awareness across varied end-user characteristics.
3. Assess and develop an enhanced health assessment plan to identify and monitor pertinent auditory and balance characteristics for operator(s) interface and physical control of the gamma detector. Use the plan to verify personnel ability for effective deployment.

We take a multidisciplinary approach to maximize accuracy, efficiency, and safety for the end-user to optimize project and measurement performance.

Key Words: radionuclides, detection, human factors, total measurement uncertainty (TMU)

1. INTRODUCTION

Quantification of radionuclides begins with proper detection of pertinent materials. Standard detection equipment requires highly specified usage procedures for efficient and accurate measurement, which must be accompanied with a well understood Total Measurement Uncertainty (TMU). In addition to TMU, the equipment must be able to be used in a wide-variety of environments that allow for proper detection, but also allow the end-user to participate in an efficient and safe manner. Technical factors can be managed through improvements for holdup measurement equipment and techniques with advancing and developing technologies specific for each use such as decommissioning activities and/or safeguard applications. Current measurement systems often separate detection/sensor modules, data collection, and analysis components through wired connections as wireless communication is not an option. Additionally, proper usage requires specific positioning and guided attention throughout the process in varied and even difficult personal (protective equipment) or external (precarious and/or dangerous) physical conditions.

While current techniques allow for sensitive detection, this equipment must be able to translate the detection to the end-user. Current techniques, however, do not include any specific management of human factors that could have a significant impact on the safe and efficient use of the technology at hand. If the goal is to optimize efficiency, and TMU, and increase end-user safety, then technical and human factors must be integrated and dynamic. More specifically, this can be achieved through optimization of the system-human interface in portable measurement systems. This integration begins with identification of integral human factors during measurement applications as well as the development of equipment and techniques that allow for seamless coalescence of the equipment and the end-user across a wide variety of settings and usages.

Integration of human factors which may have a significant effect of the translation of detection to the end-user is critical for optimizing TMU. Many human factors will play a role in the overall efficiency of hold-up measurements. However, the auditory and vestibular systems are uniquely positioned to play integral roles. The human auditory system has the finest resolution for frequency, amplitude, and duration when compared to other sensory systems such as vision or proprioception. Therefore, the system-human interface might be best optimized by exploiting acoustic contrast patterns discernable by operators. Understanding the effect of the acoustic parameters on human attention will allow adoption and development of stimuli that a human operator can exploit to discriminate changes in acoustic patterns. Auditory attention plays a primary role because of the variability in operator audio capability and tolerance to changing audio background interference. Additionally, further development of detection equipment that provides variable auditory output to adapt to both end-user variables (auditory function) and changing acoustic environments (background noise, acoustics, etc.). Improvements in both the addition of auditory output and variable output settings will improve overall TMU as well as the end-user's situational awareness which will increase safety.

The vestibular system plays a key role in the maintenance of upright stance, especially during locomotion, which is important both for the safety of the end-user himself across a wide-variety of environments, but also for efficient use of the detection equipment during hold-up measurements. Protocols for hold-up measurements require end-user guided measurements which will be dependent on a normal functioning vestibular system. Both acute and chronic conditions can affect overall balance function. Identification of potential end-users for hold-up detection could potentially qualify users into a pool of applicable candidates as well as confirm proper balance prior to completion of hold-up detection to ensure maximum efficiency of the measures.

1.1 Human Factors Assessment

Assessment of the auditory factors pertinent for the use of hold-up detection measurement systems begins with the identification and qualification of stimulus factors important for the attention required to complete the measurement task. This assessment begins with evaluation of stimulus conditions and auditory attention as measured by evoked potentials and performance accuracy. Human cortical responses will be measured using contrasting acoustic stimuli patterns to determine those audio signals that best focus attention on the gamma detector response. This incorporates both large and small response shifts, be they small or large. Detection and assessment of signal tones is essential in urgent situations and is crucial to allow for an accurate and timely response.

Long latency evoked potentials (LLEPs) measure the brain's detection of a change in expected stimuli to provoke a response to the deviant stimuli. "The processes that underlie these potential components seem to play an important role in the selection and retention of relevant information while simultaneously keeping the cognitive system accessible for important changes in the environment" (Berti & Schroger, 2001). Multiple LLEP waves are associated with detection of deviant stimuli. N1 is associated with filtering the stimuli and analyzing different attributes of the auditory stimulus (Schwent, et al., 1975a). Known as a weakly-automatic process, N1 occurs without attention to the stimulus, whether auditory or visual, but can be enhanced with attention or a change in frequency, intensity, or duration (Muller-Gass, et al., 2007). Wave P3 is also an automatic process to stimuli but is enhanced with target selection in an oddball paradigm (Schwent, et al., 1975a). Enhancement is also associated with an increase in intensity (Muller-Gass, et al., 2007).

When comparing standard and deviant stimuli in an oddball task, subtracting the average waveforms allows for removal of commonalities in sensory processing to assess negativities associated with the deviant stimulus. Mismatched negativity (MMN), and re-orienting negativity (RON) are often present and can be affected by acoustic parameters. MMN is associated with a detection of change (Berti & Schroger, 2000; Muller-Gass, et al., 2007). The degree of deviance from the standard stimuli has a direct relationship to the degree of negativity. Elicited by a change in tonal frequency, intensity, duration, spatial location or a violation of complex regularity (Sculthorpe, 2008). RON is also known as the deviant related negativity (DRN) and is associated with reorienting back to the original task after a distraction stimulus (Berti & Schroger, 2001; Muller-Gass, et al., 2007; Sculthorpe, 2008).

Changes in waves amplitude and latency can show a change in the way the stimulus was processed (Berti & Schroger, 2001). Acoustic parameters of the deviant stimulus, and study design can affect the amplitude and latency of wave components and negativities. Acoustic parameters include: intensity, degree of deviance, signal to noise ratio, and interstimulus intervals. Study design effects include: attention, type and difficulty of task, and duration of testing. As intensity increases, N1 amplitudes increase. A possible plateau effect is noted so increasing above 60 dB HL does not further affect amplitudes (Schwent, et al., 1975b). DRN amplitudes are increased with an increase in stimulus intensity (Muller-Gass, et al., 2007). Latencies of N2 and P3 were affected by the difficulty of discrimination between standard and deviant stimuli (Oppitz, et al., 2014). White noise presented throughout the Schwent et al. study (1975b) showed an increase in N1 amplitude and show attention effects. The authors also noted an increase in latency when masking noise was present. Faster inter-stimulus intervals (ISI) show more reliable changes on N1 (Schwent, et al., 1975b) however, amplitudes were overall shorter. Conversely, P3 was not affected by ISI (Schwent, et al., 1975a). Interactions between attention and ISI were noted in the short ISI condition but not in the medium and long conditions (Schwent, et al., 1975a). Task irrelevant stimuli can cause an attention change based on task difficulty and novel acoustic stimuli (Mueller-Gass, et al., 2007). The DRN increases with an easy task (Mueller-Gass, et al., 2007). LLEPs are affected by duration of session. N1 showed significant decreases in amplitude as duration of test time increased (Lavoie, et al., 2008). LLEPs are also affected by divided or split attention, a situation that more realistically captures the challenges associated with operating detection equipment like that described in this paper.

1.2 Development of the Measurement System Human Interface

It has been suggested that human perception may not be sensory modality specific (Levy-Tzedek et al., 2012), the idea being that the human brain can substitute one type of sensory input for another. The auditory system specifically has been documented both with behavioral and electrophysiological models to have a high degree of discriminatory capabilities for sound (Weir et al., 1977; Nelson et al, 1983; Kidd, 2002). Regarding gamma ray detection, the human auditory system parallels responses from other differing sensors where frequencies and amplitudes comprise a complete received input.

For example, a gamma ray detector with spectroscopic capability generates an energy spectrum where the higher energies represent the higher received gamma ray frequencies. A complete energy spectrum comprises a combination of mono-energetic events (full energy peaks) and lower energy scatter events. The scatter continua and fractions often represent the surroundings in which the radionuclides of interest are situated. For example, concrete walls, shields, other materials will generate that scatter. If the gamma ray energy spectrum were translated to an appropriate audio response, the pure tones would represent the receipt of mono energetic (peak) events and scatter fractions would translate to lower tonal frequency ranges. The human auditory system can simultaneously receive these inputs to “hear the orchestra” and to make consequential deep and intense analysis.

Where field personnel and others are searching for radionuclides in a “heads up” situation, the properly translated audio response could direct them to source presence, targeting the higher tones and minimum scatter (shielding and other scatter generators). This intelligent response approach would guide personnel most effectively to materials of interest. Similarly, color is represented as a visible region frequency range. It is well understood that various chemical forms of contaminants exhibit color profiles that suitable cameras can assess well beyond the visible region. The eye, compared with hearing, has less dynamic range so that visual observation is much more limited compared with those suitable cameras. A suitable camera/audio interface could enhance sensitivity to surface contaminants of several types to act as suitable audio alarm and potential identification.

A model for this translation, regarding gamma ray detection, exists in the translation of visual information to auditory output for use in individuals with severe visual deficits. Sensory substitution devices (SSDs) have been developed and evaluated for the use of translating visual input such as color into auditory output for translational to the individual. Studies have validated the use of these SSDs and the ability of the auditory system to translate this coded non-auditory information from auditory signals

(Bologna et al., 2008; Hamilton-Fletcher & Ward, 2013). The purpose of this project is to investigate the translation of gamma ray spectral measurements with the supporting sensors into auditory spectral output to be translated by the end-user.

Our benchtop development and test system will be expanded for use in the project development and is as shown schematically in Figure 1. A scintillation detection system is utilized with existing software to produce a gamma ray spectrum reflective of the mono energetic full energy peak events and continua which comprise those through incomplete collection and external scatter fractions. The computing interface enables the combination of the spectral inputs and other sensor inputs. The I/O control enables the generation of signal responses and output and modification of the response to the operator panel. This then enables emphasis to be placed accordingly for various conditions to optimize the operator understanding and his response. This system has a basis of gamma ray detection as this can consequently address various types of survey work both for applications including holdup detection but also safeguards type applications.

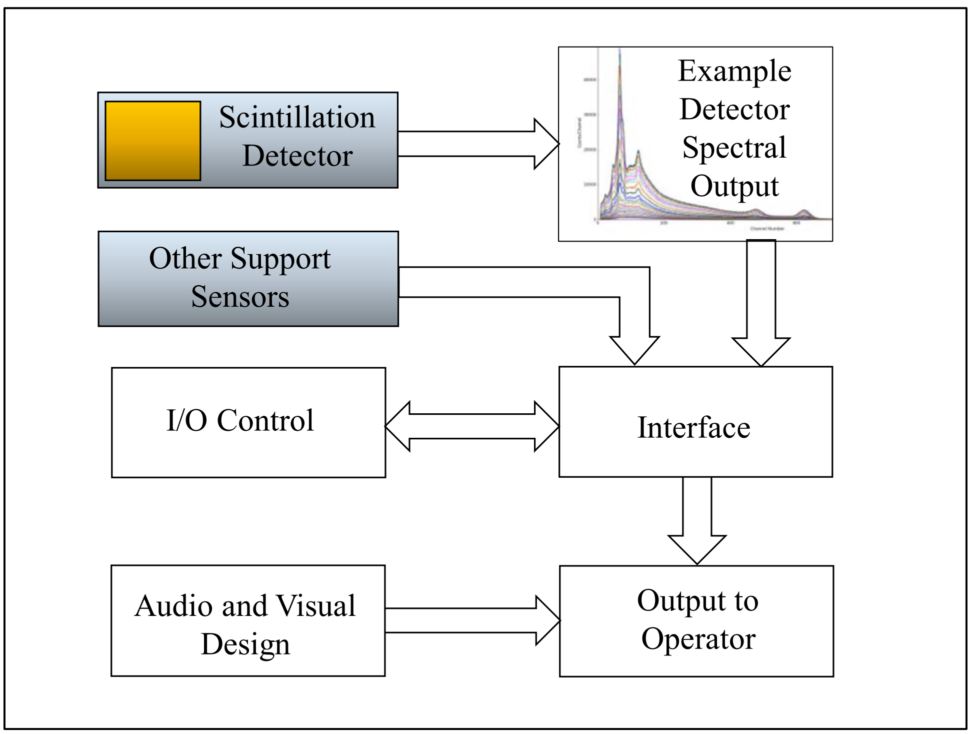

Figure 1: System Functions for Development Interface

The system also will have capability to listen and have adjustable audio I/O communications, both optical and audio. Figure 2 shows a more detailed layout of system equipment. The system customization is based upon the availability of existing software packages. Use of the system will enable the development of data bases to provide detection and measurement output and the associated total measurement uncertainty (TMU). Where interface development provides effective communication and a better understanding to the operator then both measurement performance and TMU will be favorably affected.

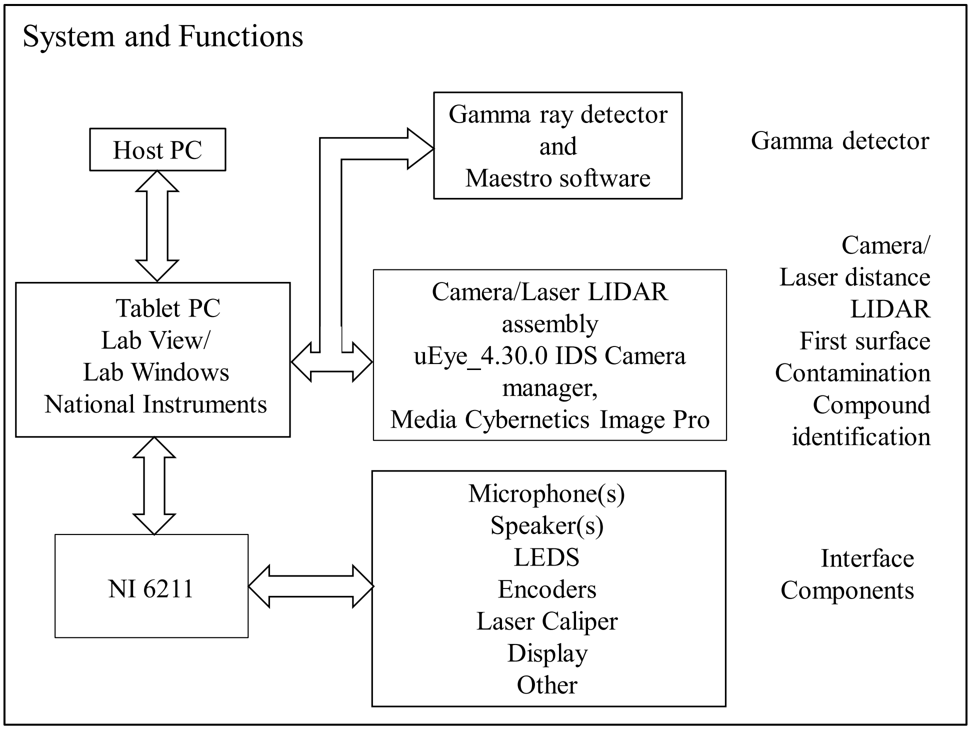

Figure 2: System Physical Aspects

1.3 Enhanced Health Assessment Plan

Radiation detection personnel health status can vary widely across age, health status, training, and background. Specially, health status regarding auditory function and postural control are of specific interest for hold-up detection. As mentioned previously auditory attention and demands on the end-used can be varied due to internal factors such as hearing and discrimination abilities as well as external factors such as acoustic environment and protective gear. Minimal functions for both auditory and balance function ability for holdup detection and quantification efficiency and overall safety in varied environment can be evaluated using a baseline evaluation (see Appendix A). Audiometric evaluation should consist of otoscopic, tympanometric, and audiometric threshold evaluation. These criteria will be useful to identify any auditory impairments to qualify potential end-users for use with hold-up detection equipment.

Operators must be able to adequately receive, perceive, and react appropriately to acoustic signals in a variety of situations, including face-to-face communication, radio communication and/or telephone conversations. One might also assume that these essential job-related hearing tasks involving speech comprehension, sound localization, sound detection, and sound recognition will occur in a wide range of acoustic environments (Goldberg, 2001). Certainly, factors other than background noise and unfavorable acoustics can affect performance of workers involved in the decommissioning and detecting of nuclear sites. These might include: heat stress in summer, coldness in winter, musculoskeletal disorders, and fatigue (Hiraoka et al. 2015). These factors may affect worker ability to concentrate, sustain attention, or process auditory information. Given the importance of these hearing functions, it would seem necessary to require candidates to have normal sensory abilities. While this is a reasonable assumption, it is not necessarily the case that minor degrees of functional hearing impairment would impair job performance or create safety risks. This is an important and relevant issue to the extent that these functional abilities can be assessed clinically, and those with only minor impairment reliably identified. At the present time, this is possible only for pure tone detection in quiet and speech discrimination/recognition in quiet and noise

Efficient and safe usage for hold-up measurements also require normal functioning vestibular system. Age and both acute and chronic conditions can affect overall balance function (Johnnson, 1971; Su et al, 2004). Hearing loss, specifically noise-induced hearing loss (NIHL), has been specifically linked with vestibular dysfunction (Xu, et al. 2016; Li et al, 2015; Tseng et al, 2013; Sazgar et al, 2006; Wang et al, 2007; Kumar et al, 2010). Identification of potential conditions involving potential end-users for hold-up detection will qualify the pool of users and ensure proper balance prior to completion of hold-up detection to ensure maximum efficiency of the measures. Postural and vestibular evaluation will include measurement of postural control to assess gait, balance, and fall risk. Postural assessment will be completed using the Timed Up and Go Test (TUG) to provide a baseline measure of overall balance function (Whitney, et al 2004; Kear, Guck, & McGaha, 2016). Baseline vestibular evaluation including Videonystagmography (VNG), Video Head Impulse Testing (VHIT), cervical and ocular Vestibular Evoked Myogenic Potentials (cVEMPs, oVEMPs) will provide a baseline measure of peripheral vestibular structures (semicircular canal and oculomotor function) within the inner ear (Ganaca, Caovilla, & Ganaca, 2010; Weber et al, 2009; MacDougall at el, 2009; MacDougall et al, 2013). The combination of TUG, VNG, VHIT, and VEMP testing can provide a full assessment of the postural control and vestibular function of an end-user, which can be used as a baseline evaluation to determine status. Follow-up evaluations with the TUG test could be used at intervals to maintain assessment of the status of an individual end-user to ensure adequate health status prior to hold-up detection.

CONCLUSIONS

To maximize the overall effectiveness of hold-up detection other applications and optimize TMU, human factors, beyond equipment capabilities and protocols, must also be considered. Our current effort begins with audiological studies that will ultimately lead to the identification and qualification of pertinent auditory signals used to direct the operator to critical materials in the environment and provide a meaningful acoustic translation recognized in real time to the operator. Such an approach enhances the potential of providing this capability for a variety of existing systems. Initial sensory data will be presented in what is the beginning of a long-term project. This project also consists of perpetual improvement of existing equipment and protocols as well as development of new techniques that will aid in detection, but also allow for better integration with the end-user taking into account the aforementioned human factors, Finally, the long-term goal of the project is to develop a health assessment plan that will allow for qualification of end-users with tracking and onsite evaluation that will ensure adequate auditory and vestibular function to maximize the end-user's capabilities for hold-up detection.

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APPENDIX A

Health Assessment Plan Guidelines

Auditory Assessment - American Academy of Otolaryngology for factors requiring medical eval uation.

1) Average hearing level at 500, 1000, 2000, and 3000 Hz greater than 25 dB, in either ear.
2) Difference in average hearing level between the better and poorer ears of more than 15 dB at 500, 1000, and 2000 Hz, or more than 30 dB at 3000, 4000, and 6000 Hz.
3) History of ear pain; drainage; dizziness; severe persistent tinnitus; sudden, fluctuating, or rapidly progressive hearing loss; or a feeling of fullness or discomfort in one or both ears within the preceding 12 months.
4) Accumulation of ear wax (cerumen) sufficient to completely obstruct the view of the tympanic membrane or a foreign body in the ear canal.

Balance Assessment

1) Timed Up and Go Test (TUG) as a validated protocol for the measurement of postural control to assess gait, balance, and fall risk.

2) Vestibular evaluation including at least or a combination of Videonystagmography (VNG) and Video Head Impulse Testing (VHIT) to provide behavioral and physiologic evaluation of peripheral vestibular structures (semicircular canal and oculomotor function) within the inner ear.
3) Cervical and ocular Vestibular Evoked Myogenic Potentials (cVEMPs, oVEMPs) also will provide neurophysiological evaluation of the otolithic organs (utricle and saccule) of the inner ear.