DEVELOPMENT OF A ROBOTIC THERMAL MANNEQUIN FOR EVALUATION OF INDIVIDUAL PROTECTIVE ENSEMBLES

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INTRODUCTION

Personal Protective Equipment (PPE) and Individual Protection Ensembles (IPEs) serve a crucial role in limiting wearer exposure to hazardous environments. In many applications, particularly for warfighters, the in-situ performance of the IPE can make the difference between survival and long-term injury or death.

Ensemble testing is an important element in developing and validating garments, and also to establish standard operating procedures for don/doff, laundering, and service life consideration. Several methods are currently used for design-level and finished garment evaluation. The most prevalent integrated chemical/biological IPE test method is the Man In Simulant Test (MIST)[1], where human subjects don representative garments and perform a series of repetitive tasks within an enclosed chamber. During exercises, the chamber maintains a vapor concentration of methyl salicylate (MeS) at a constant value between 10 and 1000 mg/m^3. The environment conditions are carefully controlled for temperature, humidity, and windspeed. During exposure, sampling devices such as passive adsorbent dosimeters (PADs) are applied to predetermined locations on test subjects' skin to monitor simulant concentration inside the suits. Test data are analyzed using a body region analysis procedure (BRAP) to provide an indication of the protection levels of the suit systems.

While MIST testing remains an important method to characterize IPE performance[2], the protocol cannot be extended to the use of actual chemical agents due to the obvious risk to test subjects. In October of 2009, a US Department of Defense funded effort was undertaken to design and fabricate an advanced capability facility, the Individual Protective Ensemble Mannequin System (IPEMS). IPEMS is comprised of a chemical containment chamber and an integrated robotic thermal mannequin capable of controlled exposure to MeS simulant and chemical warfare agents.

METHODS

The IPEMS program included a 13 month design as Phase I, with the goal to deliver a production-ready system design meeting the program objectives. The team selected for Phase I included Midwest Research Institute (Kansas City, MO) – Prime contractor and chemical systems, Boston Dynamics (Waltham, MA) – Robotics, Measurement Technology Northwest

(Seattle, WA) – Physiological systems, Smith Carter CUH2A (Atlanta, GA) – Facilitiy design, and HHI Corporation (Farmington, UT) – Facility fabrication.

A feasibility report of the program [3] identified either threshold requirements [T], indicating a "must have" capability, or an Objective requirements {O}, indicating a "would like to have" capability. Representative objectives[4] of the Phase I effort are listed below illustrate the technical complexity.

Overall System Requirements

- The IPE Mannequin shall be compatible with current MIST protocols
- The Exposure Chamber shall be capable of disseminating chemical agents Sarin (GB) and Distilled Mustard (HD) vapor, as well as the chemical simulant methyl salicylate (MeS) vapor at a concentration within the range: 2-100 mg/m3 ±10%
- The IPE Mannequin shall be robotic and either tethered or free-standing/self-contained {O}.
- The IPE Mannequin shall be designed to meet a set of body dimensions that is representative of a male soldier in the mid-range of the overall U.S Army body size distribution.
- The IPE Mannequin shall be designed such that IPE can be properly donned (to include selected suits, boots, gloves, masks, all-services' uniforms, helmets, ballistic protection vests, and load bearing equipment)

Motion Requirements

- The IPE Mannequin shall be articulated and robotic such that it looks and moves like a human, to include its proportions, and how the joints respond to sudden movements. All movements shall simulate realistic human control.
- The IPE Mannequin shall be articulated and robotic such that it can simulate the following exercises: Standing, Kneeling, Marching and walking at 4.8 km/hr, Stand-to-prone, Reach arms in all directions, Low and high crawl [O]

Physiology Requirements

- The IPE Mannequin shall simulate skin temperature and perspiration in ten (10) body regions or (18) body regions [O]
- The IPE Mannequin shall simulate a fixed skin temperature over the body regions, or more realistic variability in skin temperature based on body region and the simulated level of physical activity/exertion {O}.
- The IPE Mannequin shall simulate a fixed perspiration rate of 0.4 L/hr over the body regions or locally variable perspiration rates from 0.11 to 1.8 L/hr) {O}

Under-Suit Chemical Sensor Requirements

- The IPE Mannequin design shall incorporate under ensemble sensor technologies, procedures, and equipment to monitor CWA concentration.
- Response Time: Sampling system shall provide CWA concentration measurements in near real-time (less than 10 minute increments) or real-time (1 second increments) {O}.

- Sensitivity: Sensors shall provide measurements within the concentration ranges of: 1.5 mg/m3 – 100 mg/m3 for GB, 0.025 mg/m3 - 100 mg/m3 for HD, and 0.005 mg/m3 – 100 mg/m3 for MeS (T)
- Accuracy: Sensors shall produce measurements within ±10% of the actual concentration.
- Airflow: The sampling system shall minimize any effect on inherent under-ensemble airflow.

RESULTS

The Phase I effort culminated in a comprehensive design for an integrated robotic mannequin system and containment chamber, Figure 1, with supporting software and data integration components. The robotic system design included extensive CAD modeling, biomechanical and dynamic simulation, and fabrication of a working biped prototype to demonstrate and refine dynamic balance capability. The physiological system was fully integrated in CAD, Figure 2, and a full-function heating and sweating leg was fabricated for proof-of-concept.

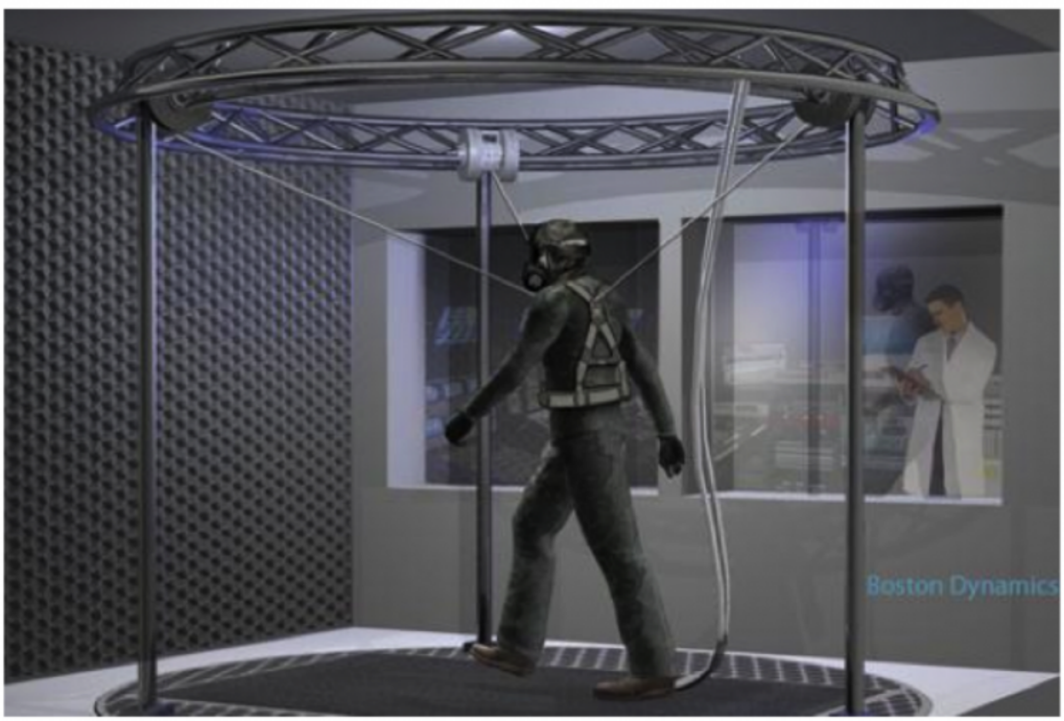

Figure 1 – IPEMS Robot Design Concept Operating on Treadmill

A Phase II effort is now underway to fabricate the fully operational system.

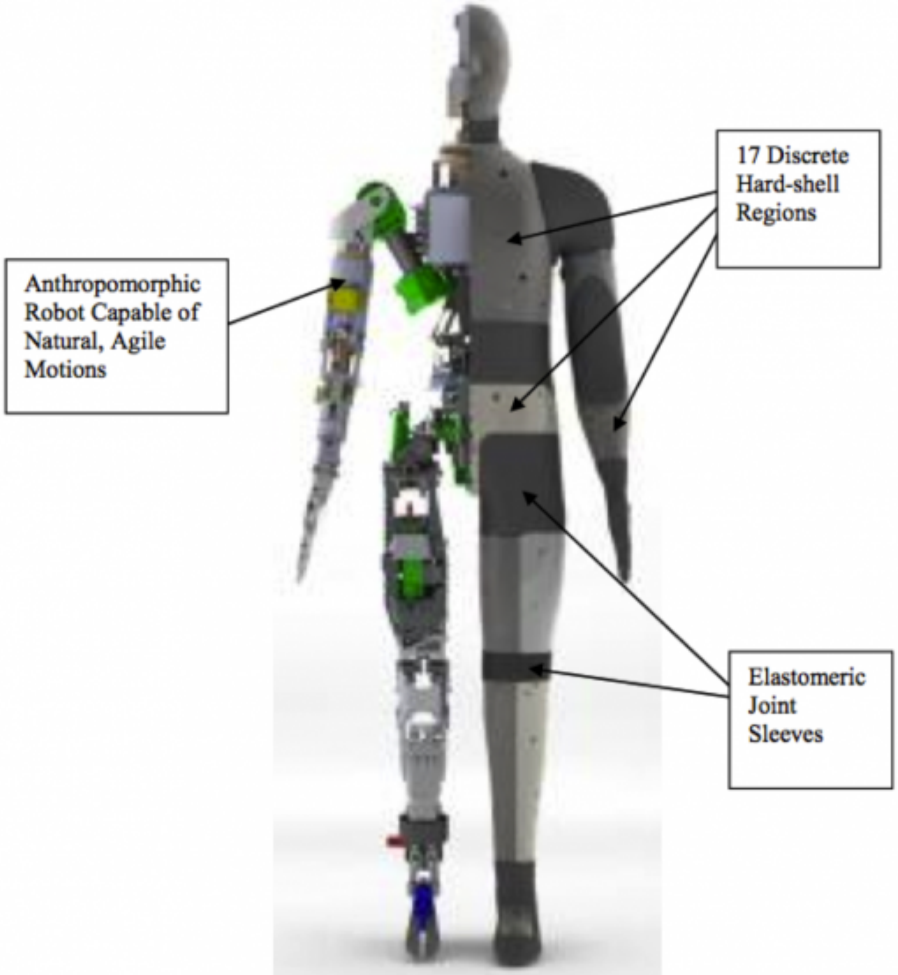

Figure 2 – CAD Integration of Physiological Shell and Robot Structure

CONCLUSIONS

Development and production of the Individual Protection Ensemble Mannequin System (IPEMS) represents a complex engineering challenge, but once completed, the system will provide previously impossible testing capability to improve garments, and ultimately benefit the health and safety of warfighters.

MTNW would like to gratefully acknowledge Midwest Research Institute for subcontracting the development and fabrication of the IPEMS physiological systems to MTNW.

REFERENCES

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