

NC170: Personal Protective Technologies for Current and Emerging Occupational and Environmental Hazards

Multistate Research Project: October 1, 2012 – September 30, 2017

Period of Report: October 1, 2013 – September 30, 2014

Impact Nugget *A concise statement of advancements, accomplishments and impacts. Please add 1-2 sentences of impact nugget per institution. The information appropriate in this section is the achievements that created tangible outcomes (or products), not research findings.*

- CA developed personal use high sensitivity colorimetric sensors that are low cost, easy to use, highly sensitive, and can improve personal protection of workers and residents potentially exposed to fumigants.
- CA developed new farmworker garments that are low cost and could potentially reduce heat stress to wearers.
- CA worked on perspiration and infrared camouflage that could improve personal protection against infrared detection.
- CO developed a new prototype of hospital patient apparel with enhanced physiological and aesthetic attributes, while keeping medical practicality.
- HI developed a methodology for comparing 3D scan data (from Kinect) of the adult female to establish the simulation of drape of fabrics.
- HI, continued in collaboration with Chinese Culture University, conducting Chitosan adsorption of dyes. The data is being compiled, analyzed, and published.
- MN evaluated wearability barriers to consumer and patient adoption of wearable technologies, which is essential to the success and feasibility of long-term monitoring applications and the larger-scale potential of wearable technology.
- MN reimagined existing cut-and-sew apparel technologies for the production of e-textiles and smart garments significantly lowers the barrier-to-entry for new industry and product development.
- MN developed low-cost, comfortable body sensing methods that facilitate pervasive field applications of ergonomic monitoring for manual laborers.
- MD worked with colleagues from other countries to develop a permeation cell to be used to measure permeation of active ingredients in pesticide formulations. MD is responsible for the Inter-laboratory test for the new method. As Project Leader for three ISO standards, the PI is working with experts from several countries to develop/revise ISO standard drafts.
- NY provided biomechanic evidence to improve design of firefighters' PPE through quantification of mobility and body balance that will benefit firefighters' work efficiency and safety and may also be applied to the evaluation of the performance of other protective clothing for first responders.
- NY developed new methods of fit testing for gloves incorporating 3D scan data that will identify areas of misfit for design and sizing of protective gloves for a variety of applications.
- Approximately 175 pesticide applicators from the Amish community in NY increased their knowledge about glove materials, PPE statements on pesticide labels and decontamination methods for households without electricity.

New Facilities and Equipment *Include production areas, sensors, instruments, and control systems purchased/installed.*

- CO established the Human Body Dimensioning Facility in this project period. New research equipment, including a 3D body scanner, a wireless in-shoe plantar pressure system, and physiological monitoring sensors, was purchased for the conduct of biomechanical research. All equipment has been installed and up and running for research.
- NY purchased a 3D foot scanner.
- HI purchased Far Infrared thermal meter to detect surface temperature changes by using different fabrics or materials.

Unique Project Related Findings

- [CA] By selecting proper fabrics and designs, farmworker garments could transport more body heat through but still block UV and infrared irradiation.
- [CA] The work on perspiration and infrared camouflage revealed that the higher a ratio of latent heat flux to sensible heat flux, the better the infrared camouflage effect.
- [HI] HI and Chinese Culture University found different dyes adsorption of Chitosan to explore absorption of dying wasted water.
- [CO] The six foot landmarks that are strongly correlated with BMI, including foot length, ball girth circumference, foot breadth, heel breadth, instep length, and height of top of ball girth. Overweight/obese participants tended to wear improperly fitting shoes to accommodate their wider and thicker feet.
- [CO] While patients strongly believed the current gown design was practical for medical purposes ($\bar{x} = 5.79$ out of 7), healthcare providers did not ($\bar{x} = 3.82$). Also, healthcare providers showed less overall satisfaction with the current gown ($\bar{x} = 4.42$) than patients ($\bar{x} = 4.80$). Both results were significant at a 95% confidence level ($p=.000$, $p=.044$ respectively). This could imply that due to the strong belief in medical benefits of the existing gown, patients tended to be relatively more tolerant of the design and performance of the current gown.
- NY discovered that flexing resistance of the firefighters' boot is a major contributor to impaired gait and body balance. The study also found that significantly greater impact of firefighters' PPE on lower body mobility in female firefighters than in male.
- A firefighter glove study, conducted by NY, showed that 71% of the participants feel that dexterity is the most important characteristic for a glove.
- [MD] Glove permeation tests indicate that the glove requirement for pesticide handlers in the United States could be simplified. Additional research is being conducted to develop a database to be used as the basis for performance standards for gloves.

Accomplishment Summaries

Objective 1: Examine acceptance and barriers to acceptance of PPE products and protective clothing, including hand, foot, and headwear: A. foundation anthropometric and ergonomic research B. user acceptance and barriers to acceptance in domain areas of fire protection, chemical protection and medical environments.

- NY and CA worked on a pesticide protective glove study to gain further information on applicators' knowledge of glove materials and thickness issues. The study has also been designed to examine the relationship between glove knowledge and factors such as main source of glove information and number and type of licenses an applicator has.
- CO determined the impact of foot morphology on footwear fit and comfort, using 3D foot scanning technology. The BMI was positively related with the six identified landmarks of foot anthropometry and showed a negative relationship with footwear comfort. CO further evaluated subjective perception of footwear fit and comfort to supplement findings of the anthropometric approach.
- Four participating institutions –CO, HI, NY (SUNY-Buffalo, BUFF), and NY (Cornell) conducted focus group interviews about firefighters' perceptions about their turnout gear, boots, and gloves.
- MD collaborated with WA to conduct a wear study of disposable/limited use coveralls for applicators in the tree-fruit industry. This study examined whether lightweight, disposable coveralls would be a viable option for those applying products with open-cab, airblast sprayers. Three manufacturers donated a total of four garments for the study in July of 2013. Data and images from this study were analyzed and the findings presented at the IUPAC meeting in August 2014. Reports regarding the respective coverall(s) were sent to the three companies that provided the disposable garments for the study.
- NY conducted an online survey with 516 male and female firefighters in the US and Canada in collaboration with International Association of Fire Chiefs, National Volunteer Fire Council, and National Association of Hispanic Firefighters. NY developed and tested an interactive website to help pesticide applicators more easily interpret PPE statements on pesticide labels.

Objective 2: Assess and improve protection and human factor performance of PPE and protective clothing (including hand, foot, and headwear) through research and product development: A. assessment of HF variables in protective clothing. B. design research and development in domain areas of fire protection, chemical protection, and medical environments.

- CO determined the impacts of poor fit of female firefighters' protective clothing on mobility and firefighting task performance, relative to male counterparts. Joint angles at the waist, knee, and ankle were measured to evaluate the range of motion (ROM), while wearing protective pants. Data demonstrated narrower ROMs in female firefighters than male firefighters, indicating poorer mobility that female firefighters experience.
- MN conducted an experimental evaluation of 4 approaches to transporting and containing body moisture in microgravity environments aboard a simulated microgravity flight. These methods are aimed at reducing the effects of sustained exposure to hand sweat in the EVA space suit.
- A clinical evaluation of a re-designed patient gown was conducted in two clinical settings by patients and clinicians in MN. We found an improvement in psycho-social and physical comfort for patients in the new gown. For clinicians, the design needs improvement in specific areas related to body access. A second design iteration has been completed and a re-evaluation is underway.
- NY conducted a series of human performance test with 12 firefighters to identify the impact of design features of firefighters' PPE. NY is conducting a fit test of firefighter gloves. Firefighters

don the best fitting glove from the size range in each style and assess the fit of the glove. Firefighter hands without gloves, and in the two styles of gloves, (plus the firefighter's current glove style when available) are scanned, and scans have been merged for analysis. Thirty-three firefighters have participated in the study to date, of whom 15% were women. Further testing, hand measurements from the scans, and analysis is underway.

- NY is also conducting a fit test of three disposable coverall styles for pesticide protection, two commercial styles and one developed by the research team based on data collected from agricultural workers. Study participants don coveralls, gloves and footwear, and assess comfort and ease of movement with a series of 4 range-of-movement body positions. 3D body scans are taken of each coverall and each position. Data have been collected on 43 participants (30 female, 13 male; 18 to 40 years old, mean age 22. Recruitment efforts for continuation of this data collection are focused on males in larger sizes.

Objective 3: Develop research-based performance guidelines and standards for personal protective equipment and protective clothing: A. establish performance guidelines and/or standards for domain areas of fire protective footwear and glove protection for pesticide handlers B. establish sizing and fit guidelines for fire protective equipment.

- A collaborative project was initiated by MD in 2012 to develop methodology to measure pesticide permeation through glove materials. A new cell was designed with input from colleagues in the United Kingdom. This cell was used to measure the permeation of active ingredients in pesticides through garment and glove materials. Tests were conducted at São Paulo State University – Jaboticabal as part of the MOU with UMES. Two proposed standards are an outcome of the collaborative research on the permeation test. Drafts for the following work items were developed by MD in consultation with experts from several countries.
 - ISO/PWI 18889 "Protective gloves for pesticide operators - Performance requirements" is being balloted as a new project.
 - ISO/PWI 19918 "Protective clothing — Protection against liquid chemicals — Measurement of cumulative permeation of chemicals with low vapour pressure through protective clothing and glove materials" is being balloted as a new project.
- A study was conducted to compare pressure penetration and permeation through multicomponent materials used for Personal Protective Equipment (PPE). The permeation and pressure penetration data were used as the basis for proposing replacement of the pressure penetration test with the permeation test in the ISO 27065 draft.
- As Project Leader for International Standards Organization (ISO) Standards on Protective Clothing for Pesticide Operators, the Project Investigator for Maryland worked closely with the European Committee for Standardization (CEN) WG3 members to address comments submitted by CEN members regarding ISO 27065 "Protective clothing -- Performance requirements for protective clothing worn by operators applying liquid pesticides." CEN/TC 162 has approved activation of the Work Item for revision of the standard as an ISO/EN standard with ISO lead.
- NY is working with International Personnel Protection, Inc. in the development of a technology that could be utilized in the development of a new testing standard for firefighter turnout gear. A sensor garment incorporating parallel electrical conductors sewn into the fabric of a form-fitting hooded coverall to be worn on a manikin is under development. The sensor garment and manikin can be used as part of a standardized test to detect liquid that passes through a protective ensemble to test for protection from liquid challenges. Two prototypes have been developed and are being tested for reliability and durability.

Objective 4: Develop novel functionality in materials for PPE: A. Research on novel environmentally friendly materials and technologies that can provide protective functions.

B. Research on novel textile-integrated sensing techniques C. evaluation of the performance of the materials for personal protective applications.

- CA has continued the development of functional materials and textiles, including photo-induced finishing treatment of fabrics, formaldehyde free wrinkle-free treatment of cotton, rechargeable biocidal polyester microfibers, and farmworker garments with reduced heat stress functions. The preparation of biocidal microfiber wipers is currently supported by Rubbermaid with intention to produce self-decontaminating wipers for healthcare and biological protections. The photo-induced surface modification treatment is using certain textile dyes as photo-initiators for radical graft polymerizations on surfaces of fibers. The environmentally friendly wrinkle free treatment of cotton is supported by Cotton Inc..
- CA has been studying farm worker clothing in order to reduce heat stress illness in California farm workers. This project has been supported by Western Center of Agricultural Health and Safety with a grant from NIOSH. The graduate student (Amy Nowicki) designed and prepared some new garments, and evaluated the wearing acceptance by a group of student farmers. In addition, CA has successfully developed high sensitivity colorimetric sensors for two popular fumigants, methyl bromide and chloropicrin, with financial support from California Department of Pesticide Regulation.
- Rather than resorting to extrinsic aids, like using additional heat insulation/storage or phase change materials or surface coatings as in other current infrared camouflage technologies, a new scheme of perspiration based infrared camouflage and a corresponding multi-layer cloth prototype were proposed recently by us. In this work, several experiments were conducted on a three-layer system based on the proposed prototype, and the original theories were modified to suit the experimental system.
- MN has continued our development and characterization of a novel stitched stretch and bend sensor, fabricated using an industrial coverstitch machine. MN has established a method of insulating the sensor using a fusible polymer film, which was found to reduce noise in the sensor response as well as inhibiting long-term drift during washing and drying.
- MN has also begun development of an alternative technique for sensing in-plane body geometries through clothing, by using magnetic field sensors.
- Work continues on developing industrial production techniques for integrating standard electronic component packages into textiles by blending technologies and techniques standard to electronic manufacture and those standard to apparel manufacture. We have experimented with two CNC-capable embroidery machines, and research into an improved stitching solution is underway. We have successfully completed surface-mount reflow soldering of simple (2-pin) and complex (8-pin SOIC) packages, and durability and washability testing is underway.
- MN has also developed a single-handed typing glove for wearable text input. The glove has been pilot-tested, but thorough evaluation has not yet been completed.
- A method was developed to immobilize Cu-BTC metal-organic framework (MOF-199) particles by enmeshing them in nonwoven polyacrylonitrile (PAN) nanofibers creating a fibrous membrane with the potential ability to remove chemical warfare agents or pesticides from solution. These membranes were shown to effectively adsorb methyl parathion, an organophosphate pesticide.

- Based on solubility theory and experimental results, partitioning was determined to be the main mechanism of removal. After 2 hours, the PAN/MOF-199 membranes removed 88 % more methyl parathion than the unmodified PAN membranes and 62 % as much as the MOF-199 crystal powder. Since the MOF particles were enmeshed in the PAN fiber mats, the MOF particles were in a workable and flexible substrate. Potential applications of these functionalized fibrous membranes include protective clothing for agricultural workers or military personnel as well as filtration media.
- Degradation of methyl parathion (MP) adsorbed in metal-organic framework (MOF)-199 cages was studied using solid-state ³¹P nuclear magnetic resonance (NMR), Raman spectrometry, and solvent extractions. MP degradation was confirmed to be occurring when adsorbed in CuBTC MOF (MOF-199).
Over 67 days of treatment, results show that constitutional isomerization is an early mechanism of methyl parathion degradation with smaller amounts of oxidation (methyl paraoxon) and direct hydrolysis of MP followed by hydrolysis of these early degradation products. Raman spectrometry after 5 days and water extractions after 5 and 35 days supported this conclusion. 4-nitrophenyl, a common MP degradation product, was observed with the amount increasing with exposure time or higher MP loading. Degradation of organic compounds such as methyl parathion, in addition to the selective physisorption, demonstrates the usefulness of MOF-199 for potential applications in protective materials for occupational and military protective clothing.
- A method to create fluorescent metal-organic frameworks using rare earths was developed and it is being optimized to use these materials as sensors for detection of leaks of methane and other toxic and flammable gases. These new frameworks can be used in protective clothing and flexible sensors inside mines and other buildings where natural gas may be present.
- The antibacterial properties of MOF-199 were studied and found to be highly effective. These discoveries are of great importance as it is possible to tailor MOF-199 to capture gases, work as a sensor as well as antibacterial agent in a true multifunctional capability.
- An improved method using covalent bonding has been developed to graft POM onto cotton and electrospun cellulose acetate nanofibrous membranes. Experiments have also been conducted using an electro-static method to graft POM on these membranes. It has been determined that higher loads of POM particles can be grafted on cellulosic materials (whether covalent or electrostatic methods are used). Polycotton samples enable only small/limited amounts of POM particle grafting (whether covalent or electrostatic methods are used.) Higher surface area substrates enable the highest amount of POM grafting. Higher loads of POM on these substrates correspond to higher amounts of methyl parathion decontamination. Further analysis is being conducted to determine which grafting method gave the optimal decontamination results (highest decon to POM loading ratios).

Impact Statements

- The rechargeable biocidal microfiber wipers and mops could potentially improve prevention of transmission of infectious diseases. The work on farmworker clothing supported by Western Center of Agricultural Health and Safety (NIOSH) revealed that by using simple optimization process and improved design, the new farm worker

garments could provide reduced heat stresses. The work in the area of fumigant sensors supported by California Department of Pesticide Regulation could significantly improve sensitivity of detection limits on these fumigants at very low prices and could potentially improve health and safety of farmworkers or residents living close to crop fields.

- The experimental results compared well with the theoretical predictions in verifying the principle of proposed perspiration based infrared camouflage, and in examining the effects of such factors as layer thickness and layer sequence. More importantly, through a heat flux analysis, it was found that the ratio of the latent heat flux to the sensible heat flux (q_l/q_s) can be used as a general criterion in designing the comfort performance of a cloth system. For the perspiration based infrared camouflage: the higher the ratio, the better the infrared camouflage effect.
- HI developing low-cost body scanning methods with Kinect to personal avatar and facilitate fabric simulation.
- An evaluation protocol for footwear fit and comfort was developed and its validity was evaluated. The protocol adopted both subjective and objective evaluation methods, and data were collected from 3D scanning and participant surveys.
- A new prototype of hospital patient apparel was developed and a provisional patent application has been filed.
- Low-cost, comfortable body sensing methods were developed to facilitate pervasive field applications of ergonomic monitoring for manual laborers.
- Development of permeation cell provides a relatively simple method to measure permeation of active ingredient of pesticide through garment and glove materials.
- Data and comments have been submitted to EPA docket for consideration in revising the Worker Protection Standard. The performance requirement standard for protective clothing and gloves can be used to quantify and thus define chemical resistance of materials against pesticides.
- Microdenier, electrospun webs and self-decontaminating materials were developed to increase chemical protection. These findings are useful in improving product development to enhance health and safety of the population.
- Gender specific fit issues, size issues and compatibility issues of firefighters' equipment designs were addressed. Suggestions for improved design were made based on online survey and focus group interview. Biomechanic data indicating the impact of flexibility of firefighters' boot and weight of PPE on their body balance and mobility will provide practical implications to improve designs.
- Early analysis of firefighter glove fit suggests that the crotch alignment and length of the thumb of the glove are not well proportioned for the majority of firefighters.
- Early analysis of coverall fit suggests that the coverall developed by the research team can be sized smaller and closer to the body and still have good range of motion.

Published Written Works

Book Chapters

Dunne, L.E., Profita, H., & Zeagler, C. (2014). *Social Aspects of Wearability*. In Sasznov, and Neuman (Eds.), *Handbook of Wearable Sensing*. New York: Elsevier.

Referred Journal Articles

- Barker, J., Boorady, L., Lee, Y-A., Lin, S., Cho, E., & Ashdown, S. (2013). Exploration of firefighter turnout gear part 1: Identifying male firefighter user needs, *Journal of Textile and Apparel, Technology and Management*, 8(1), 1-13.
- Black, C., Shaw, A., Harned, C., & Coffman, C. (2014). A survey of chemical resistant glove use practices and preferences of pesticide applicators. *Journal of Pesticide Safety Education*, 16, 17-26.
- Boorady, L., Barker, J., Lee, Y-A., Lin, S., Cho, E., & Ashdown, S. (2013). Exploration of firefighter bunker gear part 2: Assessing the needs of the female firefighter, *Journal of Textile and Apparel, Technology and Management*, 8(2). 1-12.
- Curwen, L., & Park, J. (2014). When the shoe doesn't fit: Female consumers' negative emotions. *Journal of Fashion Marketing and Management*, 18(3), 338-356.
- Chen, S., & Sun, G. (2013). High sensitivity ammonia sensor using a hierarchical polyaniline/poly (ethylene-co-glycidyl methacrylate) nanofibrous composite membrane. *ACS applied materials & interfaces*, 5(14), 6473-6477.
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- Gioberto, G., & Dunne, L.E. (2013) Overlock-Stitched Stretch Sensors: Characterization and effect of fabric property. *Journal of Textiles and Apparel Technology and Management*, 8(3), 1-14.
- Hou, A., & Sun, G. (2013). Multifunctional finishing of cotton with 3, 3', 4, 4'-benzophenone tetracarboxylic acid: Functional performance. *Carbohydrate polymers*, 96(2), 435-439.
- Hou, A., & Sun, G. (2013). Multifunctional finishing of cotton fabrics with 3, 3', 4, 4'-benzophenone tetracarboxylic dianhydride: Reaction mechanism. *Carbohydrate polymers*, 95(2), 768-772.
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- Sun, G., & Hong, K. H. (2013). Photo-induced antimicrobial and decontaminating agents: Recent progresses in polymer and textile applications. *Textile Research Journal*, 83(5), 532-542.
- Lange, L. (2014). *Incorporation of metal-organic framework and polyoxometalate with fibrous materials and their effectiveness in removal and degradation of an organophosphate* (Doctoral dissertation). Retrieved from: <http://hdl.handle.net/1813/36114>.
- Lange, L.E., Ochanda, F.O., Obendorf, S.K., & Hinestroza, J.P. (2014). Development of Polyacrylonitrile-metal organic framework (MOF) composite fibers designed to remove chemical warfare agent simulants from a solution, *Fibers and Polymers*, 15(2), 200-207.
- Lu, A., Ma, Z., Zhuo, J., Sun, G., & Zhang, G. (2013). Layer-by-layer structured gelatin nanofiber membranes with photoinduced antibacterial functions. *Journal of Applied Polymer Science*, 128(2), 970-975.
- Li, J., He, B., Pan, N., & Pan, Z. J. (2013). Study on taylor cone and trajectory of spinning jet by altering the properties of negative electrode. *Advanced Materials Research*, 796, 317-322.

- Li, M., Wang, D., Xiao, R., Sun, G., Zhao, Q., & Li, H. (2013). A novel high flux poly (trimethylene terephthalate) nanofiber membrane for microfiltration media. *Separation and Purification Technology*, 116, 199-205.
- Lin, S., Chang, C., Chang, J., & Memmal, K. (2014). Comparison of dye adsorption of three forms of Chitosan, *Advances in Chemical Engineering and Science*, 4, 319-326.
- Pan, N. (2014). Exploring the significance of structural hierarchy in material systems—A review. *Applied Physics Reviews*, 1(2), 021302.
- Park, J. (2014). Development of an integrative process model for universal design and an empirical evaluation with hospital patient apparel. *International Journal of Fashion Design, Technology and Education*, 7(3), 1-10.
- Park, J. (2013). Gauging the emerging plus-size footwear market: An anthropometric approach. *Clothing and Textiles Research Journal*, 31(1), 3-16.
- Park, H., & Hahn, K. (2014), Perception of firefighters' turnout ensemble and level of satisfaction by body movement, *International Journal of Fashion Design, Technology and Education*. 7(2), 85-95.
- Park, H., Kim, S., Wu Y., & Allen, N. (2014), Beyond protection: Technology and design moving toward human factors of fire gear, *AATCC Review*, 14(5), 40-45.
- Park, H., Park, J., Lin, S-H, & Boorady, L. (2014). Assessment of firefighters' needs for personal protective equipment. *Fashion and Textiles*, 1(8), 1-13.
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- Rodríguez, H. S., Hinestroza, J. P., Ochoa-Puentes, C., Sierra, C. A., & Soto, C. Y. (2014). Antibacterial activity against *Escherichia coli* of Cu-BTC (MOF-199) metal-organic framework immobilized onto cellulosic fibers. *Journal of Applied Polymer Science*. 131(19), 40815-4020.
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- Yin, X., Chen, Q., & Pan, N. (2014). A more comprehensive transport model for multilayer-cloth for perspiration based infrared camouflage. *Applied Thermal Engineering*, 68(1), 10-19.
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- Zhang, X., & Zhu, S. (2014). Preparation and properties of natural cellulose fibres from *broussonetia papyrifera* (L.) Vent. Bast. *Fibres & Textiles in Eastern Europe*, 22(4), 24-28.

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- Berglund, M.E., Coughlin, J., Gioberto, G., & Dunne, L.E. (2014, September). Washability of e-textile stretch sensors and sensor insulation. *Proc. of the 18th ACM International Symposium on Wearable Computers*. Symposium conducted at the meeting of ACM International Symposium, Seattle, WA.
- Coffman, C. (2014, January). PPE selection, use and maintenance for pesticide applicators, pesticide applicator training, fingerlakes produce auction. Penn Yan, NY.
- Coffman, C. (2014, January). Understanding PPE statements on pesticide labels, pesticide applicator training, seneca produce auction. Romulus, NY.
- Dunne, L.E., Profita, H., Zeagler, C., Clawson, J., Gilliland, S., Do, E. Y.-L., & Budd, J. (2014) The social comfort of wearable technology and gestural interaction. *Proc. of the Engineering in Medicine and Biology Conference*, Chicago, IL.
- Zhuo, J. & Sun, G. (2013, October). Multiprotective functions on cellulose materials introduced by Anthraquinone Vat Dyes. Symposium conducted at the meeting of Fiber Society Meeting Fall, Clemson SC.
- Sun G., Zhao, C. & Greenson, K. (2014, April). A study of direct esterification of cotton cellulose with an aromatic acid, Symposium conducted at the meeting of AATCC International Conference, Asheville, NC.
- Sun G. (2014, April). Fabrications and functionalizations of thermoplastic nano-fibers and nanofibrous membranes. Symposium conducted at the meeting of NETInc, Nashville, TN.
- Sun, G. (2013, October). Fabrications and applications of thermoplastic nano-fibers and nanofibrous membranes. Symposium conducted at the meeting of Asia Textile Conference, Shanghai.
- Sun G. (2013, October). Emerging environmentally friendly multifunctional dyeing and finishing approaches. Symposium conducted at the meeting of Asia Textile Conference, Shanghai.
- Gioberto, G., Min, C.-H., Compton, C., & Dunne, L.E. (2014, September) Lower-limb goniometry using stitched sensors: Effects of manufacturing and wear variables. *Proc. of the 18th ACM International Symposium on Wearable Computers*. Symposium conducted at the meeting of ACM International Symposium, Seattle, WA.
- Lange, L.E. & Obendorf, S.K. (2013, October). *In situ synthesis of a Polyoxometalate-CuBTC metal organic framework on cellulose and reactivity*. Poster session presented at the meeting of Fiber Society, Clemson, SC.
- Lin, S., Johnson, R. R., Kan, J., Stricker, D., & Cui, Y. (2013, January). *Virtual avatar from Kinect in the class room*. Oral presented at the meeting of Hawaii International Conference on Education Proceedings, Honolulu.
- Lin, S., Johnson, R. R., Stricker, D., & Cui, Y. (2013, November). *Fitting simulation evaluated on self body scanned and programmed avatars*. Poster session presented at the meeting of 4th International Conference on 3D Body Scanning Technologies Proceedings, Long Beach, CA.
- Obendorf, S. Kay, lecture on protective materials, PMI short course, October 16, 2013.
- Peshock, A., Duvall, J., & Dunne, L.E. (2014) Argot: A wearable one-handed keyboard glove. *In Adjunct Proceedings of the 18th ACM International Symposium on Wearable Computers*. Symposium conducted at the meeting of ACM International Symposium, Seattle, WA.

Poster Presentations

- Black, C. & Shaw, A. (August, 2014). PPE information on pesticide labels. Poster presented at the 13th IUPAC International Congress of Pesticide Chemistry, San Francisco, CA.
- Dunne, L.E. & Simon, C. (2013, October). *Out of this world: A university partnership model for functional clothing design*. Poster presented at the ITAA Annual Meeting, New Orleans, LA.
- Dunne, L.E., Gioberto, G., Coughlin, J. & Bibeau, K. (2013, October). *Machine-stitched e-textile stretch sensors*. Poster presented at the ITAA Annual Meeting, New Orleans, LA.
- Gordon, L. & Dunne, L.E. (2013, October). *The re-design and evaluation of the patient gown for an integrated healthcare organization*. Poster presented at the ITAA Annual Meeting, New Orleans, LA.
- Harned, C., Black, C., Shaw, A., Borges, O., & Servin, F. (August, 2014). Study of disposable coveralls worn by operators during spray application in orchards. Poster presented at the 13th IUPAC International Congress of Pesticide Chemistry, San Francisco, CA.
- Shaw, A., Coleone, A.C., & Machado-Neto, J.G. (August, 2014). Permeation of pesticides through chemical-resistant gloves. Poster presented at the 13th IUPAC International Congress of Pesticide Chemistry, San Francisco, CA.
- Shaw, A. & Ramos, H. & Machado-Neto, J. (2014, May). Performance requirement for level 3 materials in ISO 27065: Comparison of pressure penetration and cumulative permeation of pesticide. 6th European Conference on Protective Clothing, Bruges, Belgium.
- Zhuo, J. & Sun G. (2014, April). *Light-induced grafting polymerization on dyed cellulose with photo-active anthraquinone derivatives*. Poster presented at the meeting of ACS Spring Conference, Dallas, TX.
- Zhuo, J. & Sun G. (2014, May). *Surface modification and functionalization of cotton fabrics with light-active anthraquinone derivatives*. Poster presented at the meeting of Techtextil, Atlanta, GA.

Funds Leveraged

- Colorado Agricultural Environment Station. “Improving Safety and Health of Wildland Firefighters through Personal Protective Clothing.” \$42,500 (07/01/2013-06/30/2015)
- Research and Creative Artistry Infrastructure Grant. Vice President for Research Office, CSU. “Human Body Dimensioning Facility.” \$69,318 (no indirect) (07/01/2013-06/30/2015)
- CSU Ventures. “Toward commercialization of new patient hospital apparel.” \$13,044 (07/01/2014-06/30/2015)
- Rubbermaid, “Biocidal microfiber wipers.” \$85,000 (01/01/2014-12/31/2014)
- Cotton Inc., “Wrinkle free treatments with new chemistry.” \$34,277 (01/01/2013-12/31/2013)
- Cotton Inc., “Wrinkle free treatments –catalysts.” \$53,117 (01/01/2014-12/31/2014)
- Cotton Inc., “Wrinkle free treatments –novel acids.” \$53,117 (01/01/2014-12/31/2014)
- California Dept. of Pesticide Regulations. “Colorimetric sensors for fumigants.” \$249,907 (04/01/2012—4/15/2-14)
- National Institutes of Health, SBIR. “Smart Textile Technology for Scoliosis”. \$224,977 (\$51,876 to Minnesota). Sub-Award: Tom Plocher (Lead PI, Moai Technologies). (4/05/2014 – 3/31/2015)

National Science Foundation, Computer and Network Systems: CAREER: “Toward Pervasive Wearable Technology: A Cut-and-Sewn, Textile-integrated Smart Clothing Platform”. \$399,708 (3/1/2013-2/28/2018)

NASA Minnesota Space Grant Consortium. “Wearable Technology CLUSTER”. \$10,000 (12/1/2013-8/31/2014)

National Science Foundation, Smart Health and Wellbeing. “Electronic textiles for ambulatory health monitoring”. \$498,000 (\$191,997 to Minnesota) Co-PIs: Dr. Tom Martin (lead PI), Dr. Mark Jones (Virginia Tech) (10/7/2011-8/31/2014)

Minnesota Agricultural Experiment Station. “MIN 53-042: Wearable Technology in Personal Protective Equipment for Worker Safety: Sensory Feedback Systems to Enhance Perception of Body and Environmental Conditions”. (Approx. \$80,000 for 3-yr grant) (8/30/2012 – 8/30/2015)

Other relevant accomplishments and activities

Press Release

Rolstonon. K. (2014, May). Mind the gap: Redesigning the hospital gown. *The Coloradoan*. Retrieved from <http://www.coloradoan.com/story/csu/discover/2014/05/14/mind-the-gap-redesigning-the-hospital-gown/9088495/>

Where Tech and Fashion Come Together. (2014, January). *BBC News Technology*. Retrieved from <http://www.bbc.co.uk/news/technology-25421096>

World’s Sexiest Knee Brace’ on Show. (2013, September). *BBC News Technology*. Retrieved from <http://www.bbc.co.uk/news/technology-24207133>

Smart Clothes. (2014, January). *Big Ten Network Profile*. Retrieved from <https://www.youtube.com/watch?v=TylFWDDmWm8>

Upward and Onward. (2014, July). *University of Minnesota Newsletter*. Retrieved from <http://discover.umn.edu/news/design-architecture/university-minnesota-students-take-wearable-technology-space>

Invited talk

Park, H. (2013, November). *Present and future of protective clothing research*. Presented at the special seminar for Research Center for Textiles and Fashion, Yonsei University, Seoul, Korea.