AN OVERVIEW OF WEAPONS TECHNOLOGIES USED TO IMPROVE U.S. HEALTHCARE

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ABSTRACT

At Sandia National Laboratories the Biomedical Engineering Program uses existing weapons-related technology in medical applications in order to reduce health care costs, improve diagnoses, and promote efficient health care delivery. This paper will present several projects which use Sandia technologies to solve biomedical problems. Specific technical capabilities that are important to this program include sensor data interpretation, robotics, lasers and optics, microelectronics, image processing and materials.

Introduction

The Biomedical Engineering Program (BMEP) at Sandia National Laboratories was created to address critical issues regarding national healthcare; the overreaching mission of the BMEP is to directly address the urgent problem of rapidly increasing healthcare costs while improving healthcare quality through the application of weapons-related technology.

Sandia National Laboratories has a wealth of knowledge and technical capabilities to support its primary mission. Many of the technical advances from defense-related research programs are available for application in areas of need in the health care industry. Technological advances in the areas of microelectronics, microsensors, high-performance computing, simulation and computational modeling, advanced materials, lasers and optics, image processing, and intelligent systems and robotics could revolutionize health care delivery while reducing up-front and long-term costs. Sandia maintains a unique breadth and depth of integrated capabilities that can enhance emerging biomedical technology at every stage of development -- from concept and research through prototyping, testing and production.

Since the inception of the BMEP, Sandia technologies have been employed in biomedical applications and development projects. This paper highlights several projects in which Sandia has worked with a medical institution(s) to develop specific technologies that contribute to early diagnoses, reduced fatality, and fewer complications. These partnerships result in advances that reduce costs and/or deliver more effective treatment.

Burn debridement (Michael Partridge -- Sandians involved in the technical work on each project will be noted at the beginning of each section) -- Sandia and Massachusetts General Hospital's Wellman Laboratories are partners in a biomedical project to develop and commercialize a burn diagnostic and laser debridement device that will provide bloodless
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surgery of burned tissue by minimizing the loss of bordering healthy tissue. The system uses a laser beam to remove burned skin while automated diagnostics reduce the loss of live skin and blood beneath the burned area. Current surgical methods require cutting and abrading tissue from the burned areas to prepare for skin grafting. The improved treatment reduces medical complications, hospital stays and accompanying healthcare costs since it results in greater grafting success and fewer transfusions due to excess blood loss. The project uses technologies from many areas of Sandia including robotics, optical systems, imaging systems, sensors, reliability and safety analysis, computer modeling, and systems integration.

A robotic platform has been designed to accurately position the diagnostic and treatment sub-systems. Reference points attached to the patient are monitored by the control system to maintain precise alignment between the patient and the robotic system to account for patient movement. A structured lighting system generates a geometrical model of the burn area. Then, the robotically manipulated diagnostic system collects the data required to determine which areas are in need of treatment. The surgeon previews the procedure and the process is simulated on the patient with a low power HeNe red light laser. After adjustments are made, the process is performed with a CO₂ laser.

The diagnostic system being developed will direct the laser to remove as little live skin as possible. It is based on a procedure developed at Wellman where indocyanine, a green dye that fluoresces when illuminated at a specific wavelength, is injected into the patient's blood. This allows the diagnostic system to detect blood in the live tissue below the damaged skin. Thus, the laser can remove the dead skin without excess tissue damage. In addition to the dead skin, a layer of live tissue approximately 150 microns thick (about the thickness of a human hair) is removed to promote renewal of the capillaries and optimize the transport of

Figure 1: Burn Debridement
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nutrients to the graft. This increases the chances for successful grafting without causing substantial blood loss as compared to the present treatment in which burned skin and an uneven layer of underlying tissue are removed by hand.

Three-dimensional ultrasound imaging for improved prosthetic fabrication and fitting (Alan Morimoto) -- Each year, approximately 60,000 people in the United States have a leg amputated because of diabetes, peripheral vascular disease, gangrene, bone cancer, or an accident. The costs for each prosthesis ranges from $3,000 to $15,000, due to the lengthy hand-crafting process that requires several fittings and adjustments. Muscle atrophy or limb growth (in children) cause ongoing changes in the leg geometry which can affect the fit. Generally, patients require two or three prosthetic devices in the first year and a new one approximately every 4 years thereafter. The estimated cost of all these devices is about $1 billion a year.

In the ultrasound imaging process, a patient lowers the residual limb into a circular tub filled with water. A transducer records several hundred two-dimensional (2-D) images. The 2-D images are processed using image integration software, originally developed at Sandia for weapons components, that creates a 3-D model of the skin and underlying bone surfaces of the residual limb. The software is able to filter noise and remove motion to produce a much clearer image of the limb.

Researchers at the University of Texas, Sandia's partner in this project, perform biomechanical adjustments to the ultrasound scan data in a computer-aided design system. Design specifications based on the data are sent to a computer-controlled machine that fabricates the prosthesis. In time, this technique may become part of an advanced manufacturing process. It is hoped that it will eliminate the need for hand-crafted prosthetic devices by increasing the degree of fit, comfort, and lifetime while reducing cost.

Telerobotics and medical applications (Alan Morimoto) -- In a cooperative effort with MicroDexterity Systems (MDS), Sandia is applying its expertise in robotics, developed through
With the robotic surgery device, the surgeon's hand movements are transmitted from joystick-like controls to a surgical instrument held by a micropositioner. The computer interface allows the movements to be scaled so that a one centimeter movement in the surgeon's hand might correspond to a 900 micron movement of the tool inside the patient's eye. The system is also capable of filtering or blocking motions such as involuntary hand tremors or accidental hand movements that might damage near-by arteries or nerves. In addition, this device will aid in teaching by recording all of the motions in a successful operation and allowing other doctors to re-enact the operation by playing back the visual and tactile information.

Figure 4: Eye Surgery System

Improving feedback to surgeons during minimally invasive surgery (David Foral) -- Minimally invasive surgery (MIS) involves the insertion of surgical instruments through small openings in the patient as opposed to the normal, "large" incisions required for standard procedures. Because surgery is less traumatic, patient recovery times can be reduced from weeks to days. Although the benefits to the patients are enormous, surgeons must consider the increased risks associated with MIS due to limited tactile feedback. Development of sensor and feedback systems within the tools would give doctors better "feel" and more control over the operation. Sandia's systems integration and sensing expertise are being used to develop a tactile sensory feedback system for MIS. Important sensory information such as the tip tool force, grasping or cutting force, and the force applied to retractors is targeted in this project. Identification of biological structures such as blood vessels will also be addressed. The sensing and feedback systems will complement existing video camera displays giving the surgeon a full complement of sensory information. As the project progresses, one goal is to deliver essential tactile and visual information to the surgeon in a rapid, reliable manner without causing information overload.

Blood glucose sensing (David Haaland) -- A technology developed by Sandia and the University of New Mexico (UNM) School of Medicine uses non-invasive infrared absorption spectroscopy to determine the diabetic's blood glucose level. Presently, glucose levels can be measured only by drawing blood. In the new technique, near-infrared light is transmitted through the patient's finger and spectral data is collected. Because glucose absorbs infrared energy at specific wavelengths, the data provide quantitative information on the concentration of glucose. The spectral data analysis uses chemometrics, a combination of mathematical and statistical tools, which were originally developed to monitor the concentrations of gases that
evolve during the aging of explosive materials. Adaptations of the same technology are being developed to monitor blood alcohol and cholesterol levels.

Noninvasive Cervical Cancer Diagnostic Device (David Sandison) — At present, diagnosis of cervical cancer requires many tests spread over several visits to the doctor. The M.D. Anderson Cancer Research Center and the University of Texas/Austin have developed a fluorescence spectroscopy device which can identify normal and specific pre-cancerous cervical tissues with the same accuracy as trained technicians in much less time. However, the prototype diagnostic equipment for this cervical cancer detection is too large, about the size of a washing machine, and too expensive, $40,000, to be commercially feasible. Sandia is working with a small business to develop a product based on the prototype device, which is smaller and more affordable. Sandia engineers are using instrument development and miniaturization expertise originally gained in weapons research to replace components in the prototype with parts that are smaller and less expensive. The goal of this project is to produce an instrument that can detect precancerous or cancerous cervical cells earlier, faster, and less-invasively than current techniques.

Ion-induced nuclear radiotherapy (Barney Doyle) — A concept for a new radiotherapy system, ion-induced nuclear radiotherapy (INRT), has been developed and tested at Sandia for delivering large doses of radiation during cancer treatments with little or no damage to surrounding healthy tissue. Currently patients requiring traditional proton radiotherapy must visit a facility which can generate protons with 50 to 200 MeV. Such facilities generally use linac or cyclotron equipment which costs in the range of $100 Million. The INRT method confines radiation in a conduit needle and uses sub-MeV ion beams. These low energy levels may be met by table-top size equipment which would cost in the range of $200,000. The smaller equipment may also allow bringing the equipment to the patient, rather than the other way around, during surgical treatment procedures.

The INRT process directs an ion beam down a conduit needle like those used to collect tissue during a biopsy. The beam strikes a piece of isotope material mounted at the tip of the conduit needle, nuclear reactions occur at the needle's tip, and reaction-specific radiation products are emitted. Such products, like energetic protons, are then at the correct site for localized treatment of cancerous tumors. Systems using the INRT method are expected to be able to treat millimeter-sized tumors with minimal risk to healthy surrounding tissue, while current methods of proton radiotherapy treat areas on the centimeter scale. Researchers have used computer-based simulations based on weapons-related radiation dose studies to calculate the delivered radiation dose and the relationship between delivered dose, distance from the needle tip, and exposure time.
Implantable devices (Jerry Love) — A core technology that fulfills physicians' needs for a system to use implantable devices has been developed. The technology is based on electromechanical devices developed by Sandia for use as safety devices in weapons systems. The original application of an implantable insulin pump was developed with the UNM School of Medicine. Three pumps were produced in this project; one was put in a person in 1981 and two in two other patients in 1982. One of these pumps stayed in the patient for 10 years. When removed from the patient, the electronic housing was still hermetic, there was little indication of mechanical fatigue, and the pump itself showed modest corrosion. When supplied with new batteries, the unit functioned normally.

This project increased Sandia's implantable technology knowledge base in the areas of electronics, biocompatibility, hermeticity, sterilization, acceptance, human factors, and compressive forces caused by scar tissue shrinkage.

Measurement of ionizing radiation (Robert Hughes) — A small radiation sensing field effect transistor (RADFET) microsensor has been developed with the UNM Cancer Center for improved dosimetry. The RADFET is roughly the size of the "o" in the "In God We Trust" inscription on a dime and thus could be inserted in a medical catheter for in vitro measurement of cancer therapy radiation doses. The RADFET is an electronic device which can be produced with standard semiconductor fabrication techniques.

Conclusion

The projects highlighted in this paper illustrate the use of Sandia-developed weapons-related technology in various biomedical applications. These cooperative ventures combine existing technology with emerging medical processes to enhance treatment while reducing costs. Sandia invites contact from medical institutions for future cooperative ventures that use weapons technologies in medical applications.

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