SUMMARY
The use of information technology is already contributing significantly to the enhancement of healthcare delivery and improvement in the quality of life for Canadians. However, the deployment of information technology has only scratched the surface of possibilities that new computer technologies and information science have to offer. There are great opportunities for computer technologies to accelerate our understanding of how to sense and collect valuable health and wellness data and indicators. To analyze and use that information for evidence-based healthcare. To stabilize physiology, modify risky behaviours, design and field “snap” clinical procedures, and care for people with health challenges. The main emphasis of this Chair is on transformative changes and new directions that information technology can bring to the healthcare system from an end-to-end perspective. More specifically, the Chair is focusing on the following research objectives:

- Medicine for all: The MedROAD projects;
- From Medical Imaging to Virtual Treatment Planning and Training;
- Networked Collaborative Systems for Consultation, Surgical Planning, Postoperative Evaluation, and Education;
- Commercialization of research outcomes.

Since the start of the Chair, many of these projects have evolved, and many of them have been deployed for real clinical applications. This year, CISCO System agreed to advance the 2021-22 installment from the usual August 1, 2021, timeline to start instead on March 1, 2021. Therefore, the Chair will end on February 22, 2022. This advanced money will allow Dr. Boulanger to focus most of the Chair's resources on the MedROAD project. We aim to transform MedROAD from a proof-of-concept to a genuine commercial product. As a result of this development, in January 2020, Dr. Boulanger and two other business partners created a new start-up company called Naiad Lab Inc to market the MedROAD and MedBIKE products. Since this incorporation, Naiad Lab was able to secure a large investment from private venture capital to commercialize both products.

RESEARCH PROGRESS

Medicine for all

MedROAD: This project, started in 2014, aims to increase access to necessary medical diagnostic tests for patients in remote regions of the world. Our research group has developed a portable medical diagnostic kit that allows remote medical testing and assessment. Our devices have the capability of sending medical information wirelessly to a secure server where remote emergency and specialist physicians can access and analyze the data and provide a clinical decision. The MedROAD acquisition system consists of numerous portable medical-grade instruments, such as a fully automated blood chemistry analyzer capable of measuring up to 100 metabolites. All devices transmit geo-located data wirelessly via a smartphone, relaying the encrypted data in HL7 to a secure remote server using an internet connection through LTE wireless or satellite connections. The new data is then automatically analyzed by the server computers at the server location and compared to known pathologies and patient history using machine learning algorithms. Following data analysis, alarms are generated to warn the remote specialist physician to look at a specific patient data point, allowing for faster treatment strategies.
From 2016 to 2020, we did numerous pilot projects with aged care facilities and medical clinics to test and optimize the concept of MedROAD. Following an extra investment of $50K from CISCO Systems we were able to run a key pilot study with the Associate Clinic in Pincher Creek from November 5, 2020, to March 1, 2021. A total of 27 patients registered for continuous use, and ten patients registered as irregular users. MedROAD has two primary ways of providing care: 1) Virtual clinic hub/room in the clinic, and 2) At-home monitoring of chronic conditions. In this pilot study, MedROAD was used for home monitoring for patients suffering from chronic hypertension, diabetes, and COVID-19. The results indicate that using MedROAD can reduce by 75% clinic visits for hypertension and diabetic patients resulting in significant savings of time and money for the patient and the healthcare system. One senior patient reported a calf injury through a virtual call. MedROAD system was used to remote diagnose their ruptured of the Achilles tendon and to arrange an orthopedic follow-up. An ER visit was prevented. A patient with both diabetes and rheumatoid arthritis reported an infected toe that had progressed into osteomyelitis. The MedROAD system virtually monitored their toe through image sharing (uploaded into the platform). These images were shared with infectious disease specialists to help with managing the patient’s condition. An ER and clinic visit was also prevented, saving time and money. The pilot project demonstrated that some aspects of MedROAD need to be improved:

- MedROAD need to be more user-friendly, especially on the patient's side;
- Low physician buy-in uses of the home monitoring system was due to AHS payment options (no fee structure for healthcare providers doing asynchronous communication);
- Physicians' time constraints are a significant issue. They can be solved via a more robust and intelligent alert system designed to reduce the load on a physician until it is necessary.

Based on the lessons learned during the pilot studies, we are in the process of re-engineering MedROAD toward a commercial product. To do so, we are now focusing on improving usability and refactor the software core to commercial grade. As with most extensive software development, this is quite an endeavour and requires a large team of programmers, interface designers, and software engineers. Starting March 1, 2021, we hired three more programmers and one user interface designer to improve MedROAD capabilities. This team is in direct contact with clinicians to help us improve usability and add new functionalities that fits their needs.

**From Medical Imaging to Virtual Treatment Planning and Training**

**Multiview Ultrasound:** In 2016, we were able to secure a three-year NSERC/CIHR Collaborative Health Research Project to explore using a newly patented ultrasound multi-view fusion technology (see Figure 1a). In the current system, we use optical tracking to align multiple ultrasound scans. A set of markers attached to the ultrasound probe is used to track the device in 3D space using a commercial multi-camera Optitrack system. Chest and abdominal respiratory motion and cycle are also measured using other markers placed on the patient. The 3D transformations measured by the tracking system are then used to align and register the multiple ultrasound scans. In addition to field-of-view improvement, the fusion of multiple ultrasound images also improves image quality and contrast. As planned, the 2019 activities consisted mainly of performing clinical testing of the Multiview system with patients from the Mazankowski Heart Institute. These clinical tests were successful at demonstrating the advantages of the Multiview approach for imaging. Still, it became clear that the optical tracking approach suffers from occlusion problems, which interfere with the free movement of the sonographer. We concluded that solving this occlusion problem would require that the ultrasound probe tracking be measured mechanically using a robotic arm (see Figure 1b). There would be no optical occlusion problems with the robotic arm. In addition, the programmable aspect of the robotic arm could be used to automate some of the digitizing functions. The robotic version of the system could allow the sonographer to place the ultrasound probe at a location that needs to be scanned without the constraint of gravity. The sonographer could then remotely control the robot arm using a haptic device and apply the desired pressure on the probe to perform semi-automated measurements. Due to COVID-19, the delivery of the robot arm was delayed by six months and was finally delivered in March 2021. In addition, a wireless ultrasound probe was also purchased in March 2021 to be added to the end-effector of the robot.
Once operational, this system could relieve the sonographer's physical burden, reducing fatigue and repetitive stress injuries. With this system, the sonographer could perform remote imaging of COVID-19 patients without danger of contamination. We now have all the required equipment (haptic interface, robot, and ultrasound probe) to deploy the system. Unfortunately, due to COVID-19 restrictions at the Mazankowski Heart Institute, we will only be able to start work in the lab by September 2021.

**Networked Collaborative Systems for Consultation, Surgical Planning, Postoperative Evaluation, and Education**

**MedBIKE:** Exercise-based cardiac rehabilitation (CR) is the physical activity component of a multi-disciplinary cardiac rehabilitation program and is an integral step in caring for patients with acute or chronic cardiac disease. However, most patients do not participate in exercise-based CR despite evidence for improved outcomes and event reduction. Between 2016 and 2018, we developed a virtual reality-based remote exercise-based CR system called MedBIKE. MedBIKE allows patients to perform a controlled exercise program in the comfort of their own home using virtual reality gaming to improve adherence to the exercise program while being monitored by a remote CR clinician. Using MedBIKE, the clinician can make sure the patient follows the level of exercise prescribed by his/her cardiologist to improve his/her heart condition. In 2020, a new version of MedBIKE for pediatric cardiac rehabilitation was developed and delivered to Dr. Michael Khoury at the University of Alberta's Department of Cardiac Rehabilitation. It was planned that MedBIKE would undergo a two-year clinical trial in autumn 2020, but because of COVID-19, this activity is now rescheduled to start in January 2022. A grant proposal to the Heart and Stroke Foundation was approved in June 2021, and we were awarded the total amount of $300K for two years. This new grant money will allow us to hire a programmer and a game designer to upgrade the MedBIKE software and design the latest specifications of the medical team.

**ADDITIONAL ACCOMPLISHMENTS AND ACHIEVEMENTS**

Dr. Boulanger's research work is recognized around the world. He has published more than 450 scientific papers. He has patented (12) new concepts like the Multiview ultrasound probe, which may revolutionize medical imaging by replacing expensive imaging sensors like CT and MRI during cardiac procedures. For 2020-21, he and his team published ten papers in peer-reviewed journals and conferences with his team. In 2020-21, he was awarded an extra $50K from CISCO Systems to deploy MedROAD at the Pincher Creek clinic, $300K from the Heart and Stroke Foundation for the MedBIKE project and $600K from Alberta Innovates AICE for three years to develop various aspects of the Multiview ultrasound project using a robot arm.

He is currently supervising 5 Ph.D. students and 3 Master students to work on the various projects related to this Chair.
Dr. Boulanger is also the CTO and founding member of Naiad Lab. Inc., a company dedicated to using advanced technology solutions to enhance the health and quality of life of our clientele worldwide and to commercialize the CISCO Chair IP.

OVERVIEW OF RESEARCH PLANS FOR 2021-22

Deployment of MedROAD Virtual Clinic: Following the successful deployment of MedROAD at the Pincher Creek clinic, we now have many offers to deploy the same system at various aged care facilities and clinics. We are planning to deploy MedROAD to Covenant senior care facility and the St. Michaels Health Group. Both have expressed genuine interest in the capabilities of MedROAD, and deployment is planned for the end of 2021.

Continuous Monitoring of Acute Cardiac Patients: The recent COVID-19 pandemic has shown a strong demand for self-health monitoring systems based on wearable biosensors that are capable of automatically analyzing patient conditions using advanced machine learning (ML) algorithms. Continuous vital signs monitoring is considered an essential and critical element of safe ICU or acute care units for hospitalized patients. However, there are no continuous vital signs monitoring systems available when dealing with low-risk patients inside or outside the hospital setting. While there are vital signs spot checks every 3-4 hours in most hospitals, one can imagine that a severe change of a patient's health status can happen at any time during that period. This is even more true when the patient is not at the hospital. Any acute changes to a patient's vital signs are critical and should be dealt with, hence the need for early detection of those events to schedule timely intervention and improve patient outcomes. This new project aims to create a continuous ambulatory cardiac monitoring system that is integrated into the MedROAD VC system (see Figure 2). To do so, we plan to automatically detect cardiac anomalies over long periods using the fusion of accelerometers and ECG sensors as patients perform their daily activities. The fused data produced by these sensors is then locally analyzed by edge processors, and anomalies are then securely transmitted in a compressed and encrypted form to the MedROAD cloud, where it is stored in a secure database. A clinician can then visualize the incoming dataset using an augmented display to examine critical ECG sections that depart from normality. Dr. Boulanger's team has dedicated significant research efforts to develop advanced algorithms to perform these tasks for the last three years. A novel algorithm was designed to reduce ECG motion artifacts by combining accelerometer data synchronized with ECG data. Following motion compensation, a neural network algorithm was also developed to recognize 17 different cardiac abnormalities with an accuracy of 99%. The proposed project offers an excellent opportunity to expand our recent development into a commercial system that clinicians can use in Canada and worldwide.

Figure 2a: Vital signs measurement using Astroskin vest

Figure 2b: Monitoring Acute Patients using Residual Neural Network
From Medical Imaging to Virtual Treatment Planning and Training

**Robotic Multiview Ultrasound Imaging:** By using the robot and the haptic interfaces financed by NSERC RTI, in 2021-22, we will focus our research on the following objectives: (1) development of new semi-autonomous multi-view fusion algorithms, (2) new techniques to reduce sonographer fatigue using human-robot cooperation, (3) new configuration to protect sonographer from COVID-19 infection. This project was scheduled to start in March 2020, but due to the COVID-19 epidemic, the new start date is now September 2021.

**Networked Collaborative Systems for Consultation, Surgical Planning, Postoperative Evaluation, and Education**

**Heart and Stroke Foundation MedBIKE:** This new pediatric MedBIKE project will start in September 2021. This project, financed by the Heart and Stroke Foundation, is a collaboration between Dr. Boulanger's team, Dr. Michael Khoury team at the Department of Cardiac Rehabilitation, and Naiad Lab. The new project objectives are:

- Upgrade current software version to commercial level;
- Improve documentation;
- Implement an industry-standard software engineering scheme to maintain software versions;
- Modify MedBIKE to generate automatic reports compatible with EPIC EMR and MedROAD;
- Develop a new Unity game that fits with the new project requirements;
- Upgrade sensors and other hardware to reduce the fabrication cost;
- Develop a commercialization plan for the product.

**STATEMENT TO THE CHAIR DONOR/FUNDING ORGANIZATION**

Dr. Boulanger and his team would like to thank CISCO Systems for their generous financial and in-kind donations since the start of the Chair in 2013. Without CISCO Systems' investment, none of the research programs supported by the Chair would have been possible.