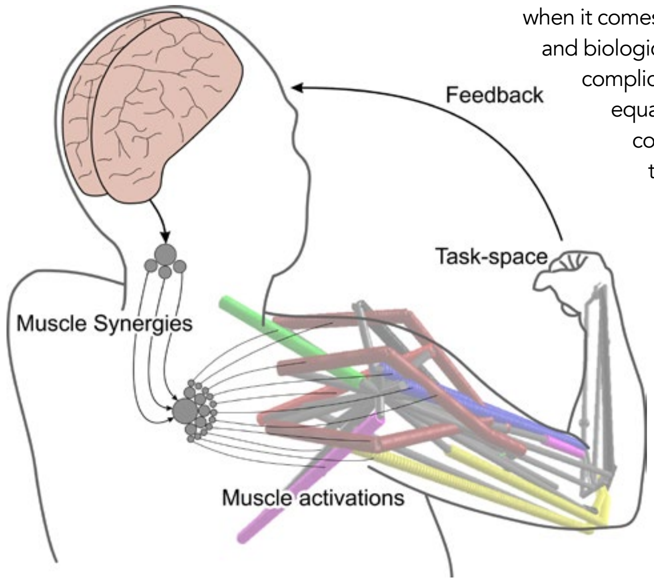
Biomechatronic modelling will change the future

From cars that predict how a human will steer to a model that tells you the perfect way to hit your golf ball, Professor John McPhee from the University of Waterloo, Canada has developed a unique way to model and control human-machine interactions. The models have a range of applications that will change the way we live in the future.

Muscle synergies (building-blocks of motion control in the human nervous system) are used in predictive simulations of human movements to understand how the nervous system controls actions.



Combining the disciplines of biology, electronics and mechanics is an extremely complex task, but one with huge possibilities. From working on autonomous vehicles to robots that can help rehabilitate patients, Professor John McPhee and his team from the University of Waterloo, Canada, have been pioneers in the field of biomechatronics in recent years.

Professor McPhee is the Canada Research Chair in System Dynamics at the University of Waterloo. The group specialises in multi-body biomechatronic systems; particularly looking into optimising their design, dynamics, and control of their motion.

ALL ABOUT EQUATIONS

Using equations to describe how an object moves is relatively simple when you have a ball rolling down a hill. But when it comes to complex machines and biological systems, it gets more complicated. "Deriving the equations of motion to explain complex systems is both tedious and error-prone," says McPhee. To tackle this, "We have automated the dynamic modelling process by combining linear graph theory from mathematics with fundamental principles from physics and biology" he says.

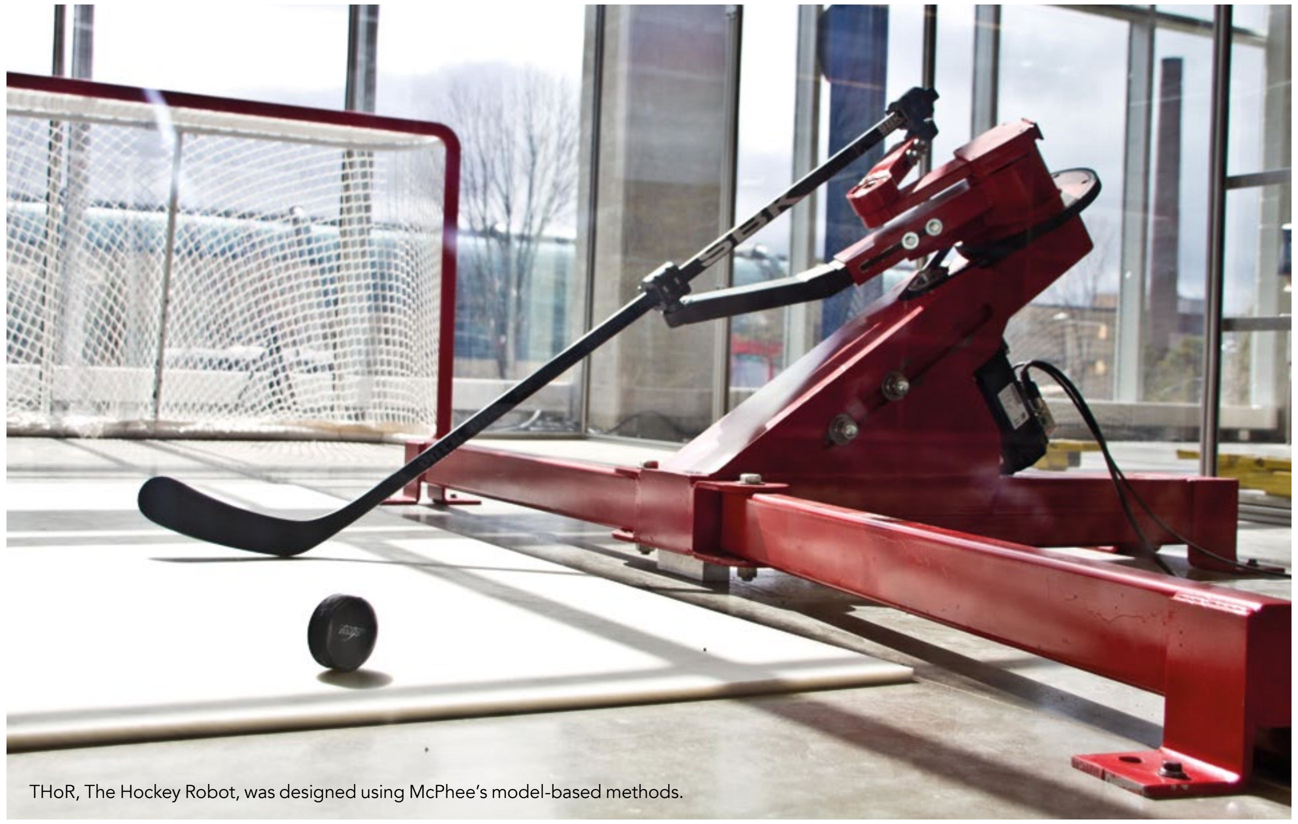
The group has used this technique to invent solutions for a variety of problems; from developing a rover for the Canadian Space Agency to a new power steering system that anticipates human reactions. Most of the projects have fascinating applications, and some even help those who have suffered medically.

REHABILITATION ROBOTS

McPhee's group have published papers on describing how rehabilitation robots can help stroke victims. After a stroke, patients often have trouble moving their arms, and it is known that immediate therapy can be helpful for improving movement. However, this requires much one-on-one time with a therapist, which can be slow and expensive. If the therapist was assisted by robots, which use models and machine learning to study each patient and predict how they should be exercising their arms, then the therapist can treat multiple patients simultaneously, reducing bottlenecks and costs to health care systems.

GOLF SWINGS

However, stroke patients are not the only group of people that stand to benefit from McPhee's work. The same models used to study the movement of patients' arms were applied to golf players, to help improve their swing and optimise equipment. In a study presented at an international conference this year, McPhee and his team developed a model of a golf swing, by studying the interactions between the golfer, the club and the ball. The team's musculoskeletal model included wrist, shoulder, torso, and pelvis, and provided insights into dynamic swing planes and



THoR, The Hockey Robot, was designed using McPhee's model-based methods.

torso-pelvic separation (the "X-factor"); previous models neglected these important phenomena.

WHAT-IF SIMULATIONS

Other models looked at bikes and wheelchairs used in track cycling and wheelchair basketball, calculating the precise dimensions that would optimise the performance of their Olympic and Paralympic research partners.

One specific model developed by McPhee is what he calls a 'volumetric contact model'. In general, this can be applied to any situation where two surfaces come into contact. As a result, it also has a huge variety of applications;

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tyres and the road, a foot on the ground, and a golf club striking a ball.

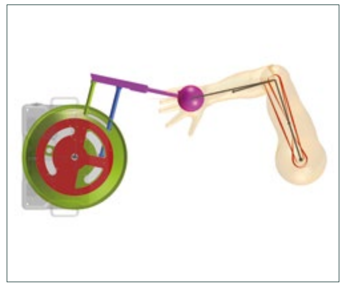
One of the reasons the team has been able to develop such a wide range of applications is that the kind of models they use do not rely on gathering data from experiments first. "All of our models are 'predictive', meaning that we can perform simulations without requiring pre-defined experimental data," says McPhee. "This paradigm allows us to perform 'what-if' simulations that are critical for design optimisation. We can test various scenarios and see the results right away, without the need to build many costly prototypes."

Predicting how humans stand up from a chair enables the design of new assistive devices.

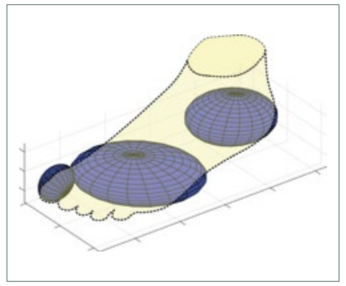
After the models are developed, they are compared to real-world examples to test the model accuracy. For example, the neuro-musculoskeletal models are based on underlying physical and physiological phenomena, such as skeletal dynamics and muscle fibre activation rates. Then, McPhee and his team test the predictions with outcomes they can measure, like EMG signals in muscles. In the golf swing example, the optimum output from the model faithfully reproduces the swing of an elite golfer.

SELF-DRIVING CARS

In a similar way, the team has created a range of models for various aspects of autonomous vehicles. "We develop powertrain, vehicle chassis and battery models following the same approach, where extensive track and dynamometer



Combined biomechatronic model of a human arm and a rehabilitation robot.



The volumetric contact model to predict foot-ground interaction forces.

High-speed track testing of the Autonomoose (or "The Moose", Canada's first autonomous vehicle) with Waterloo's vehicle measurement system.

testing yields high-fidelity models that facilitate optimal design and control of cars," says McPhee. "We have one of most advanced automotive test labs in the world, the $10 million GAIA facility, for testing of powertrains, smart vehicle, battery components, and vehicle dynamics."

For example, McPhee and his collaborators used this technique to develop a power management scheme for a hybrid electric vehicle. The model was used to minimise the emissions and fuel consumption of the test vehicle,

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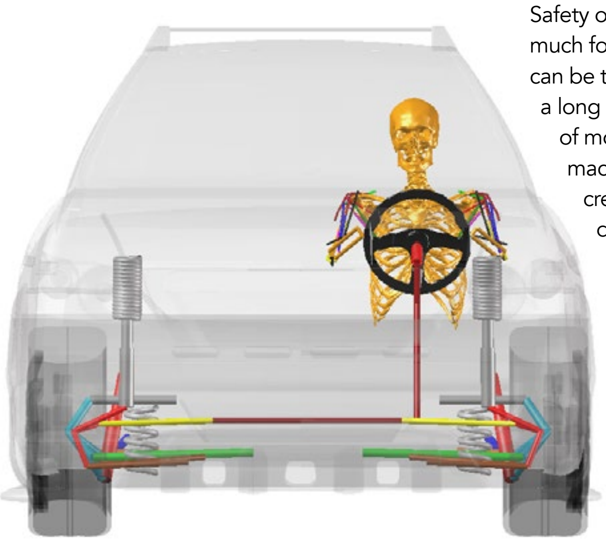
a Toyota Prius. Other work on electric vehicles by McPhee's group includes a power steering system that takes into account neuro-muscular capabilities of the driver, models for an electric Rav4 complete with optimal anti-jerk adaptive cruise controllers and a model-based controller that ensures safe driving of autonomous vehicles.

Safety of driverless cars is a topic with much focus at the moment, and testing can be tricky. "Autonomous vehicles have a long way to go, and the integration of model-based approaches with machine learning is the best way to create safer and more comfortable driverless cars," says McPhee. "Longitudinal and lateral vehicle dynamics are crucial to ensure stability during manoeuvres."

McPhee is not only interested in safety but also in improving the efficiency of electric vehicles too. "To better conserve energy during a trip," he says, "Optimal model-based controllers under development at Waterloo take into account the interplay between various components of the vehicle and the future road conditions."

Biomechatronics is an area that is only going to become more important in our future, McPhee says. One way this could happen is through patient-specific rehabilitation therapy. "Our integrated patient/robot models can help get to this goal faster," he says. "Predictive simulations before an orthopaedic surgery such as tendon-transfer is now becoming more prevalent in clinical trials. So is the use of models to design better assistive devices for elderly, amputee, and other mobility-challenged individuals."

Another area that could benefit from this kind of model-based approach is the development of powered prostheses and exoskeletons. Making exoskeletons that are optimised for each individual, for example, is an important feature that could one day be developed, but only with a thorough understanding of the human and machine interaction, which can be achieved using the modelling methods of McPhee and his team.



Electric power steering control using biomechatronic model of driver and vehicle.

Behind the Research

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Research Objectives

Professor McPhee has developed automated algorithms to model and control the motion of complex systems, mimicking biological movements. The algorithms are then used to create biomechatronic machines that improve our quality of life.

Detail

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Bio

John McPhee is the Canada Research Chair in System Dynamics at the University of Waterloo. He has pioneered the use of linear graph theory and symbolic computing to create dynamic system models and model-based controllers, with applications ranging from autonomous vehicles to rehabilitation robots. His group has won five best paper awards and his research algorithms are a core component of the MapleSim modelling software.

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- Cycling Canada
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Personal Response

Your work covers a range of applications, from driverless cars to golf swings. In your opinion, which of these is the most satisfying to work on and why?

" As much as I enjoy automobiles and sports, the most satisfying application of our work is rehabilitation and assistive devices. It is great fun to optimise the performance of Olympic athletes and autonomous cars, but greater contentment comes from helping an individual to regain lost mobility and enjoy a higher quality of life. "

Where do you see the focus of your research within the next five years?

" I see a great opportunity to combine the best features of artificial intelligence with model-based design and control. We are already doing this in our research on autonomous cars and human movements, and our future applications will include smart biomechatronic systems and assistive devices. As an example, imagine a robot that actively learns and provides rehabilitation training that is optimised for an individual patient. There are many other potential applications that come to mind, including subject-specific surgical planning and sports equipment that is tailored for each athlete. "