Changing Face of Robotics
Welcome to “Changing Face of Robotics” - a collection of Maplesoft customer case studies and application stories.

Engineers, scientists and researchers from around the world use Maplesoft technology to solve extremely difficult problems in a diverse range of industries and technical disciplines: Kinova uses Maplesoft solutions to develop a controller for a robotic arm that enables people with limited upper-body mobility to perform routine tasks with independence; Quanser Inc. uses Maple and MapleSim to design an unmanned aerial vehicle experiment platform; Maplesoft products are helping Hockey Robotics to improve the design of hockey sticks. In this collection of customer application stories, you’ll find these and many other exciting examples of how Maplesoft technology is used in advanced engineering and research projects.

In engineering research and design, detail is vital. Design engineers and researchers must not only define their problems clearly, but they also require in-depth analytical tools to help them understand on a fundamental level, the intricacies of the problem, and ultimately solve that problem and apply its solution to develop new products and technologies. Fortunately, Maple™ and MapleSim™ are available to underpin that process.

The application stories in this collection demonstrate how technical computing software, symbolic and numeric technologies, and physical modeling and real-time simulation solutions have allowed engineers to bring their mechatronics and robotics projects in on time and on budget. They illustrate how engineers and researchers use Maplesoft solutions to rapidly accelerate their design projects, as they develop the next generation of products that shape the changing face of robotics.

Please enjoy this collection of Maplesoft customer case studies and application stories, with our thanks.

To learn more, please visit: www.maplesoft.com/robot

Sincerely,

Jim Cooper
President and CEO
Maplesoft
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Robotic technology has improved dramatically in the past decade, and applications are getting more exciting as well. Robots are cool again, and for engineers, designing the new generation of robots is one of the most exciting types of projects. While the prior generations stunned the world by sending men to the moon in the 1960s, this generation will soon make a robot dance better than Michael Jackson.

A new generation of engineering and scientific techniques are empowering and fueling the rapid pace of innovation within the modern robotics community. Advancements in mechatronics and symbolic model formulation techniques are driving robotics innovation, from humanoid robots to autonomous cars, and beyond. What was once the stuff of science fiction seems to be within reach for the engineering community.

**Emergence of mechatronics**

Arguably, one of the most important techniques that emerged from the engineering community over recent decades is mechatronics - the computerized control of complex mechanical-electronic systems. Once engineers figured out practical ways of implementing digital control using computer chips, the world had a workable framework for intelligently controlling very complex machines. Today, mechatronics techniques are heavily used in a range of industries, including automotive, aerospace, manufacturing, power, and of course, robotics.

Like every other technology-driven segment, robotic developments have advanced at an exponential rate. However, as with many technology segments, there are natural limits to the effectiveness of traditional techniques and tools. Where existing tools can no longer evolve to keep pace, new tools must be created to fill the gap. For example, in the late 1990s, engineers at the Canadian Space Agency (CSA) introduced a new technique for increasing the modeling fidelity of the robotic manipulators that were deployed in the Space Shuttle and the International Space Station (Canadarm and Dextre). They were among the first to develop software tools to automate and optimize the derivation of dynamic model equations when they developed a system called Symofros, which is based on a symbolic computation system.

**Reduction in model development time … increase in model fidelity … feasible speeds in real-time simulation.**

**Symbolic modeling**

Since then, the use of symbolic techniques has rapidly evolved, and many more streamlined products have entered mainstream engineering. One such example is MapleSim – an advanced physical modeling and simulation tool that uses symbolic techniques to enable rapid prototyping of complex systems.

For multibody systems, the symbolic formulation is done by applying linear graph theoretic techniques. Linear graph theory allows representation of core model topology via mathematical graphs, then, systematically associates graph elements with mathematical relationships describing the physics. In the end, linear graph theoretic techniques can efficiently derive a compact set of differential equations, which minimizes the total numbers of equations, variables, and model complexity. The symbolic framework ties the graph theoretic tools to the Modelica language, which takes care of the other physical domains. These advanced mathematical algorithms, which are rooted in symbolic computation, rapidly and accurately produces the desired equations in a useful mathematical form.

The engineers at the CSA used symbolic computation to perform the algebraic steps of model derivation, model simplification, and the conversion of the resulting mathematical expressions to C-code. The result was a substantial reduction in model development time, an increase in the fidelity of the model, and
feasible speeds in real-time simulation via the C-code. This modeling approach is now widely applied in the development of modern robotics.

**Autonomous vehicles**

One such area is that of autonomous vehicles, such as unmanned aerial vehicles (UAV) or ground-based vehicles (UGVs). These space-age vehicles are capable of very complex movements and are intelligently guided by on-board algorithms. Although exclusive groups like the military have had such technology for years, these devices are now available for experimentation and research by a much broader range of engineering groups.

The prohibitive cost and sometimes relative danger associated with manufacturing and testing these vehicles means that developers require an effective and affordable platform to develop and refine the technology. By turning to symbolic model derivation, they can take advantage of high-fidelity, mathematics-rich modeling to quickly prototype these advanced systems. Used in this way, symbolic technology enables developers to test for possible dynamics and design defects long before expensive prototypes are built.

**Humanoids - the new space race**

In parallel with autonomous vehicles, another area of great fascination for today’s engineer is research into humanoid robots. While government and university officials point to future personal service robots as a strong motivator for humanoid research, there is another goal that fuels this activity. In countries such as Japan and Korea, humanoid research and development is a highly competitive and prestigious endeavor. It is a highly visible articulation of technological capacity and creativity that constitutes a modern ‘space race’ among those nations.

> “Humanoid research and development constitutes a modern space race.”

Of course, achievements in humanoid robotics are also tied to progress in modeling techniques. Humanoid research shares the same dependence on multi-body dynamics theory and HIL testing as its counterparts in other robotic domains. Indeed, symbolic derivation and code optimization have already begun influencing the techniques and the thinking behind humanoid robotics.

It has been a remarkable couple of decades for robotics. Just as computing technology blew open the doors to new possibilities in so many fields, roboticists are now enjoying prominence with new initiatives that are amazing. Smarter modeling technology continues to be a key part of this revolution, as the benefits of decreased model development time, increased model fidelity, and faster HIL performance are so important to the robotics field.
Kinova Robotics designs and manufactures innovative robotics products for personal assistance and service functions. Their flagship robotic arm JACO, now in its second generation, enriches the lives of people with limited upper-body mobility by enabling them to perform routine daily tasks safely and independently. Maple™, Maplesoft’s flagship product for technical computing and documentation, was used by engineers at Kinova to derive and manage the complex matrix equations that underlie the advanced algorithms which control the JACO robotic arm, leading to improved functionality.

JACO features six interlinked segments – the last of which is a three-fingered hand – and operates with 6 degrees of freedom. With a reach of 90cm, it can be mounted onto a motorized wheelchair or a fixed base. Using a joystick controller, the user can move the robot’s hand in three-dimensional space to grasp and release objects as required, to perform routine tasks.

Kinova’s Robotic Algorithms and Control Team faced a key challenge in the design of the arm’s controller. In order to safely operate the robotic arm, they needed to design advanced algorithms involving large matrix equations to calculate the kinematics and applied forces through the arm.

An added complexity is that these computations, which are run on a microcontroller, must be performed repeatedly, at very short time intervals. Therefore, the algorithms must be continuously refreshed at a rapid rate, which creates a very large matrix of simultaneous trigonometric equations.

This kind of mathematical challenge is where Maple excels. Maple’s high-performance symbolic computation engine enables you to describe, visualize and solve complex mathematical problems. Maple features efficient algorithms and tools for high performance computing and large-scale problem solving, enabling it to solve even those problems that are beyond the reach of other software systems.

“We needed software that is known for robustness and very intuitive to use. Maple was the perfect software to meet these requirements,” says Dr. Alexandre Lecours, project manager in the Robotic Algorithms and Control Team.

Using Maple, the team set about defining the problem and creating a program to solve it. The first step was to define the inputs to the program – which included the number of links, their lengths, and the joint angles. After defining the relationships between these variables, they were able to create a system of trigonometric equations that represented the problem to be solved.
Then, they used Maple’s symbolic computation engine to analyze and simplify these equations to generate the output function, which calculates the position of the hand.

This optimized output function – still in its symbolic form - was then converted into C++ code for use in simulation, and in the arm’s embedded controller. Dr. Lecours explained the reasons for this approach. “We could have done the computation directly in C++,” he says. “However, there are a number of calculations within the matrices that would have resulted in a multiplication by zero. Maple enabled us to evaluate these ahead of time and factor them out, to arrive at a reduced set of equations with fewer computations.”

“There wasn’t any other software that could help us solve this problem symbolically.”

Given that these computations are being continuously performed with every change in any one of the motors as the robotic arm moves around, having the code in its most optimized form enables the controller to run more efficiently. By eliminating all the null branches of calculations, the controller is able to determine the hand position faster, providing more refined control and ultimately a better user experience.

Dr. Lecours and his colleagues continue to use Maple to develop embedded controllers for their other robotic products. He concludes, “There wasn’t any other software that could help us solve this problem symbolically. Not only was Maple intuitive to use, the Maple code was much easier to understand than the C++ code. This enabled us to quickly develop and debug our product, significantly reducing our development time.”
Nao is a small humanoid robot created by Aldebaran Robotics. Standing 58 cm tall, Nao is used to teach students around the world programming, and to give engineers and software developers a platform for experimentation and robotic applications. Nao was even adopted recently by a financial institution in Japan to use as bank tellers!

Engineers at Maplesoft decided to see if they could create a model of Nao in MapleSim, the advanced system-level modeling and simulation tool that applies modern techniques to dramatically reduce model development time, provide greater insight into system behavior, and produce fast, high-fidelity simulations.

Building the Model

Nao is a highly complex multibody mechanism with 25 degrees of freedom. Using MapleSim’s multibody library, Maplesoft engineers created a model using Denavit-Hartenberg (DH) convention to define the robot’s joints coordinate frames. CAD models were then imported to define body mass, rotational inertia and center of mass. Because MapleSim is a physical modeling system, the model diagram corresponds closely to the physical system itself, as can be seen in Figure 1.

Servo motors appear at each joint to drive the movement. Signals from the controller trigger the motor to reposition each joint. In combination, these individual servo motors determine how Nao moves.

The engineers were also able to model the contact between Nao’s foot and the floor. This was done by creating custom components in MapleSim, and supplying the mathematical equations that govern friction and normal force. These components were included in the model at each point of contact on the base of each foot.

The MapleSim model also includes a Li-ion battery pack model from the MapleSim Battery Library that powers the motor, so that the behavior of the battery and its interactions with the rest of the system can be modeled as well.

Sensor readings of each joint were exported from Aldebaran Robotics Choregraphe™ to MapleSim via a time lookup table. These were then used as the command signal for each joint. The model responded in the same way the physical robot did. For instance, the MapleSim model can perform Tai Chi as adeptly as its physical counterpart.

Teaching Nao New Tricks

Now that they had a model that simulates the movements of the Nao robot, the Maplesoft engineers then wanted to see if they could not just simulate its behaviour accurately, but also teach it do to something new.

Using MapleSim’s ability to extract and analysis the mathematical equations of motion of a model, as well as its multibody analysis tools, they determined the symbolic solution to the inverse kinematic problem for the motion of the robot’s arm. With this solution, they could calculate the joint motions necessary to place the arm in an arbitrary location in space. They used this information to add a new custom component to the model that takes the desired end position and calculates the movements needed to achieve it. Then, they taught the virtual Nao to draw.

They created an application that allows a human to sketch a shape, image, or word using a mouse. The sketch is analyzed to determine the coordinates of the lines, and then the information is fed into the simulation model. The result? Nao moves his arm and draws the same thing!

Further leveraging MapleSim’s ability to solve inverse kinematics problems, Maplesoft engineers have also taught Nao other new tricks, including various dances, playing volleyball, and tracking a quadrocopter.
Why This Is Interesting

If you are working on a robotics research or design project where understanding multidomain interactions are important, then using a multidomain modeling platform like MapleSim, as this example demonstrates, will allow you to bring together all aspects of your project into one place.

- **3D Multibody Modeling**: Take advantage of 3D Multibody modeling, simulation, and visualization capabilities

- **Parameterized Models**: Conveniently access system parameters to quickly apply design changes and consider a family of designs or products

- **Multidomain Support**: Augment the dynamic mechanical system with accurate models of electric motors, controllers and batteries

- **Virtual Testing and Analysis**: Investigate system-level behavior and interaction of multidomain subsystems, without the need to build expensive and unpredictable physical prototypes

- **Component Sizing**: Easily run batch simulation and parallel processing, and collect data that can be used to assist in component sizing

- **Full Access**: Leverage direct access to equations and a full programming language to expand the same simulation model to be part of model design and trajectory optimization tasks

- **Optimized Code Generation**: Generate highly optimized C-code from the model for an essential part of model-based control design

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**Figure 2**: Servo motors for each joint drive the movement of the robot’s arm

**Figure 3**: Equation-based custom components were used to model the contact points between the foot and the ground

**Figure 4**: Inverse kinematics were used to teach the Nao model to draw
In the space industry, the design, building, and testing of rover prototypes is extremely expensive. System testing typically does not occur until late in the design/testing process, when it is more difficult and time consuming to make changes. In response to this situation, Dr. Amir Khajepour, Canada Research Chair in Mechatronic Vehicle Systems and Professor of Engineering in the Mechanical and Mechatronics Engineering department at the University of Waterloo (UW), and his team worked with the Canadian Space Agency (CSA) and Maplesoft to develop a hardware-in-the-loop (HIL) test platform for solar powered planetary rovers.

Their approach allows component testing within a simulation loop before a full rover prototype is available. It essentially creates a virtual testing environment for the component under test, “tricking” it into thinking it is operating within a full prototype. Using MapleSim, the modeling and simulation tool from Maplesoft, high-fidelity and computationally efficient models were created for this real-time application.

Using this test platform, scenarios that are hard to replicate in a lab setup, such as the Martian environment or components that are not yet available, can be modeled in software. Hardware components can then communicate with these software models for real-time simulations. The goal is to progressively add hardware components to the simulation loop as they become available. In this way, system testing takes place even without all the hardware components, bridging the gap between the design and testing phases.

The main advantage of this approach is that it significantly reduces the overall development time in the project. It also allows for component testing under dangerous scenarios without the risk of damaging a full rover prototype.

**Rover Kinematics**

In addition to simulating the rover dynamics, the MapleSim modeling environment was used to automatically generate the kinematic equations of the rover. These equations then formed the basis for other tasks in the project such as HIL simulations, path planning, and power optimization. The modular system setup enables users to quickly change the rover configuration and explore different approaches in a short time.

**Hardware-in-the-Loop Framework**

Figure 2 shows an overview of the test platform. Information regarding the rover’s position, orientation, tilt, speed, and
power consumption (obtained from dynamic models of the rover) is used as input to the software models. A library of rover components was developed within MapleSim and imported within LabVIEW™ Real-Time where the HIL program and interface were developed. The program was then uploaded to the embedded computer within National Instruments PXI where communication between the hardware components and the software models was established and the real-time simulation was run.

“Due to the multidomain nature of the system (mechanical, electrical, and thermal), it was desirable to model all the components within one modeling environment such that critical relationships can be easily discovered. In addition, computational efficiency is crucial in real-time simulations,” said Dr. Khajepour. “MapleSim was found to be the ideal environment for this application due to its multidomain abilities, use of symbolic simplification for higher computational efficiency, and ease of connectivity to LabVIEW.”

In addition to making use of MapleSim’s built-in component library, custom components were also easily developed.

A model to estimate the solar radiation that a tilted surface would receive on Mars was implemented using MapleSim’s Custom Component Block. This model took into account the sun’s position and the rover’s latitudinal and longitudinal position, orientation, and tilt as it traveled from point A to point B. This was used together with a solar array model to estimate the power generation of a rover throughout the day.

“The intuitive nature of MapleSim allowed my team to create high fidelity models in a short period of time,” said Dr. Khajepour. “This played a key role in the success of this modular HIL test platform, which allowed for component testing, power level estimation, as well as the validation of power management and path planning algorithms.”

The team also used MapleSim as a key tool in an earlier part of the project to develop a full solution for the power management system of autonomous rovers. They used MapleSim to rapidly develop high fidelity, multidomain models of the rover subsystems. The goal was to develop a path planning algorithm that took rover power demands and generation into account. Using the models, the path planner found the optimum path between point A and point B such that the rover maintained the highest level of internal energy storage while avoiding obstacles and high risk sections of the terrain.

Dr. Khajepour and his team were able to create the mathematical model of the 6-wheeled rover without writing down a single equation. “MapleSim was able to generate an optimum set of equations for the rover system automatically, which was essential in the optimization phase,” he said. Dr. Khajepour was also impressed with MapleSim’s graphical interface. “In MapleSim, you can simply re-create the system diagram on your screen using components that represent the physical model. The ability to see the model, to see the moving parts, is very important to a model developer,” he concluded.
Hydraulic Stewart Platform
A 6DOF Stewart platform with hydraulic actuators, and PID controller with inverse kinematic path planning.

Nao Robot
Multibody model of Aldebaran Robotics’s NAO that simulates the robot’s movements.

Deltabot
The AEMK Deltabot™ cable-based high-speed pick-and-place robot is modeled in MapleSim.

Segway
An LQR controller is used to control the longitudinal motion of a segway.

Hydraulic Stewart Platform
A 6DOF Stewart platform with hydraulic actuators, and PID controller with inverse kinematic path planning.
Grizzly RUV Model
Clearpath Robotic’s™ Grizzly RUV Model features a 200Ah lead-acid battery pack with a nominal voltage of 48V, and a 3D tire model.

Hexapod
A walking hexapod robot whose leg actuation is provided by trapezoidal signals. Normal forces, friction, and deflections are calculated for each “foot”.

Three Finger Gripper
Multibody components and Custom components are used to model the multiple contacts between a three-finger gripper and a ball.

Helicopter
A 3DOF helicopter with PID controller is simulated.
Byrun, the walking, jumping, hopping robot, built using MapleSim models

MapleSim provides the advanced solvers that can tackle the difficult equations used to develop Byrun’s motion algorithms.

In movies, robots can walk, talk, and even pretend to be human. Their real-life counterparts are considerably more limited. But this gap is closing, and Engineered Arts, a UK robotics company, is seeking to bring reality closer to fiction.

Engineered Arts’ current flagship product is RoboThespian, the robotic actor. A full-sized humanoid with a biologically inspired design, RoboThespian is used by research and education centres the world over, to inform, to entertain, and to investigate new developments in robotics. Institutions in over 20 countries, including NASA Kennedy Space Centre (USA), Gazientep Planetarium (Turkey), Questacon Science Centre (Australia), and numerous universities world-wide are using RoboThespian every day. Maplesoft technology was used in the design and modeling of balancing and talking RoboThespian robots. MapleSim, the system-level modeling and simulation platform from Maplesoft was used to design the biologically analogous humanoid robot leg integrating a novel actuator, studying its static and dynamic stability, and building the designed leg to determine strategies for its control. However, RoboThespian, for all his conversational appeal, is largely static. His legs are powered, but he can merely squat and stand in place, never moving from a fixed location.

Enter Byrun, the latest Engineered Arts endeavour. Using MapleSim, Byrun’s designers and engineers have developed a biologically analogous leg design which will give Byrun the ability to walk, run, jump and hop. Byrun will be a new kind of full-scale dynamic humanoid that will take social robotics to the next level. With a faster, stronger, more dexterous upper body, a virtually infinite array of facial features (courtesy of his projective head display), and the same speaking and singing abilities as his predecessor, RoboThespian, Byrun has the potential to revolutionize human-robot interaction.

According to Guillaume Hirohide SASAGAWA, an engineer at Engineered Arts, “In Byrun, we want to integrate more human-like dynamics into the mechanical design. Using a human-inspired approach at a hardware level makes walking, running and jumping possible without rigid, robotic-looking motion.” MapleSim assisted in Byrun’s design by allowing engineers to simulate complex, nonlinear, compliant components such as his pneumatic muscles and parallel springs. These are used for safety compliance, shock absorption, energy efficiency, and human-like smooth motion curves.

Engineered Arts specializes in unconventional actuation solutions, chosen to best suit the application. Motors are fast and precise, but inefficient and rigid. Pneumatic actuators, on the other hand, are powerful and energy efficient, but difficult to control. The conventional approach in robotics is to use a single actuator for a single joint – Byrun will use a parallel electro-pneumatic design, where multiple actuators control single joint actions. This approach utilizes the best facets of both types of

“The software saves us significant time and cost, and allows us to explore more radical options.”
actuation, while compensating for their drawbacks. Conversely, some actuators will generate coupled motion across several axes, to imitate (for example) the organic design of the human shoulder. This makes for more natural looking motion, but can be potentially difficult to control. Here, once more, Maplesoft comes to the rescue, providing advanced solvers that can tackle the difficult multi-variant control equations used to develop Byrun’s motion algorithms.

By creating virtual prototypes of each design phase in MapleSim, Byrun’s engineers can investigate the feasibility of mechanical solutions without needing to create a laborious series of prototypes. “The software helps us to create the design parameters in a very fast virtual environment,” explained Guillaume. “We are no longer required to rebuild the robot for every design iteration, which saves us significant time and cost, and allows us to explore more radical options. As well, complex kinematics can be easily simplified with the use of Maple – this is a powerful tool as the resources required for the project are considerably reduced.” Byrun’s hardware requires modeling mechanical, electrical, thermal and pneumatic elements – with the help of the simulation tool MapleSim, the component requirements can be largely anticipated in advance.

The team at Engineered Arts Ltd. has also found MapleSim useful for its ability to simplify complex calculations. “MapleSim’s ability to automatically generate complex mathematical models, such as the leg dynamics, is outstanding. Different parameters can be altered at different stages to reduce the complexity of calculations,” Guillaume said. “In the case of Byrun, we were able to dramatically simplify the leg dynamics, making the computations much faster. This is extremely powerful and has real impact on our project timelines and deliverables.”

In addition to designing Byrun’s electro-pneumatic hybrid legs and upper body for fully mobile walking and running, the engineers at Engineered Arts Ltd are also developing a robotic hand with the same principles, creating a compact, highly efficient compliant manipulator. They have designed an elbow joint with unconventional kinematic characteristic in humanoid robotics with electro-pneumatic parallel actuation, and are currently making a full torso-shoulder-arm model in MapleSim. This model will be used for solving forward kinematics, inverse kinematics, end-effector dynamics and compliance.

Robots like Byrun are setting a new standard for both humanoid and more general robotic design. “To be worth its cost, this robot must perform something never seen before. If it can do just 10% of John Travolta’s walk, Margot Fonteyn’s dance and Julia Roberts’ smile, we have a winner,” William Jackson, Director of Engineered Arts, told the media. “Achieving these goals is a daunting task. We are creating not just an exciting piece of hardware, but one that will make a great development platform for others to build on. When Byrun takes his next step, so shall we.” Maplesoft Engineering Solutions will continue to be part of every step taken by this revolutionary team of robotic engineers.
The Automation, Robotics and Mechatronics (ARM) Lab is a research laboratory in the Department of Mechanical & Aerospace Engineering at the School of Engineering & Applied Sciences in The State University of New York (SUNY) at Buffalo. The lab combines an in-depth understanding of mathematical theory with experimental validation to develop a new generation of smart mechanical and mechatronic systems. Their work includes projects in haptic devices for surgical simulations, musculoskeletal simulation to refine human-machine interactions, cooperative payload transport by robot collectives, and omnidirectional wheeled robots. Several of their research projects have directly resulted in the creation of commercially available devices that are then used by labs around the world for education and further research.

Since most of their projects start with an in-depth analysis of the underlying mathematics of the system, the ARM Lab requires tools for developing and analyzing mathematical equations. They have chosen Maple and MapleSim as key tools to complete these tasks. Dr. Venkat Krovi, director of the ARM Lab, finds using a symbolic approach invaluable to their work. “Performing these calculations symbolically allows for the development of exact, closed form expressions. We don’t need to worry about accumulating errors from numerical calculations. Perhaps even more importantly, with the exact mathematical equations, we can identify singularities, perform parametric design refinements, and improve the real-time model-based control strategies.”

One of the ARM Lab’s research projects involved the study of kinematic and dynamic simulations of 6 degree of freedom 6-Prismatic-Universal-Spherical (6-P-U-S) type manipulators. This type of manipulator combines a platform that moves and a fixed base, interconnected by several legs. In his research, Dr. Krovi and his research team analyzed a general 6 DOF 6-P-U-S manipulator. They used Maple and MapleSim to automatically generate the governing equations, and conducted a kinematic analysis of those equations with Maple. Starting with these general equations, specialized equations were extracted from the general system that correspond to a specific architecture with desirable properties – superior structural design with minimal interior singularities within its workspace. They were then able to analyze the workspace of such parallel-architecture manipulators, with the primary goal of optimizing the link geometries and parameters to enhance overall workspace and other selected geometric workspace-based performance-measures.

Dr. Krovi and his team then worked with Quanser Consulting Inc., a world leader in the design and manufacture of advanced systems for real-time control design and implementation, to create a physical prototype of the parallel arm manipulator corresponding to the design developed from the specialized kinematic and dynamic equations. Quanser also used MapleSim’s modeling and simulation capabilities during the final design and development process. The 6 DOF motion platform, termed the Hexapod, is now part of Quanser’s mechatronic controls collection and can be used in various applications, including vibration studies, earthquake simulations, and flight simulations. Dr. Krovi continues to use the Hexapod in his research and teaching and MapleSim and Maple in ongoing research projects at the ARM Lab.
Using MapleSim in Unmanned Aerial Vehicle Models Provides Insights Not Possible with Traditional Tools

Unmanned aerial vehicles (UAV) are an increasingly important tool in situations where it is dangerous or extremely difficult for humans to enter. In addition to military applications, UAVs are used in environmental surveys, agriculture, and disaster relief efforts, and are one of the most active areas of contemporary engineering research. In order to help researchers develop new algorithms for controlling UAVs under a variety of different conditions, Quanser Inc. developed the QBall-X4, a UAV experiment platform for research in UAV control and design.

MapleSim, Maplesoft’s modeling and simulation product, is a key tool for Quanser design engineers in developing the QBall. The QBall-X4 is a quadrotor helicopter design with four motors and speed controllers fitted with 10-inch propellers. The entire mechanism is enclosed within a protective carbon fiber cage. The first step in its development was to create high-fidelity 3-D dynamics models of the system and its flying characteristics. The results and insights gained through using MapleSim were then transferred to the remaining toolchain to complete the development.

MapleSim gave Quanser engineers two significant advantages over traditional tools. The most important benefit to using MapleSim was its ability to fully capture the dynamics of the gyroscopic effects, the stabilizing effects of the spinning parts of the QBall. With traditional tools, gyroscopic effects are extremely difficult or impossible to treat, as developing sufficiently high fidelity models by hand is simply too difficult and too time consuming. Typically, design engineers resort to making various model simplifications or compromises for the model; ultimately, this reduces the accuracy and effectiveness of the simulation process. Since MapleSim automatically derives the system equations directly from the model diagram, the Quanser engineers developed a very high fidelity model with gyroscopic effects in very little time and with little effort.

"I was very impressed with how little time it took us to configure a high-fidelity model using MapleSim.

— Derry Crymble, Quanser Inc.

Secondly, because it was so easy to make design changes in the MapleSim physical modeling environment, Quanser was able to test different designs for the rotors and choose the one that worked the best for them. MapleSim let them efficiently consider and dismiss alternate UAV configurations, such as single rotor, or coaxial counter rotating propeller configuration, before settling on the quadricopter design.

Quanser was surprised by the speed with which the models were developed. Derry Crymble, lead engineer for the QBall-X4 project commented, "I was very impressed with how little time it took us to configure a high-fidelity model using MapleSim."

Dr. Jacob Apkarian, Founder and CTO of Quanser added, "MapleSim was an eye-opener for us. It gave us insights that we otherwise would not have had. We discovered behaviors in the system we hadn’t taken into account until we ran MapleSim simulations. We learned a lot about the system using MapleSim."

Today, the Qball-X4 is one of Quanser’s premier products and is used by researchers in both academic research and industry. MapleSim continues to be a valuable tool in Quanser’s development initiatives.
Researchers use MapleSim to develop musculoskeletal arm and robot models for rehabilitation

Movement disorders in the upper extremities, which are common among post-stroke patients, demand effective rehabilitation procedures. Rehabilitation robots are now being used clinically, but because of emerging proposals of motor learning there is still much that can be done to improve the designs and control algorithms of these robots. For example, one of the neglected aspects in the design and development of rehabilitation devices is the modeling of human interaction with the robot.

An emerging area of research is the use of musculoskeletal models to study human movement, making them an appropriate tool to interact with rehabilitation devices in simulations. In this project, researchers at the University of Waterloo, Borna Ghannadi and Dr. John McPhee, used MapleSim from Maplesoft to develop a musculoskeletal model of the human arm that provides the human action for an upper limb rehabilitation robot, in order to develop new model-based controllers for it. The controlled robot is tested in partnership with the Toronto Rehabilitation Institute (TRI) and Quanser Inc.

The TRI/Quanser robot is an end-effector based planar robot, which performs reaching movements in the horizontal plane for therapy of the shoulder and elbow. The team decided that a fitting starting point was to develop a simplified planar 2D musculoskeletal arm model which consists of two hinged links and six muscles, and assumes no tendon compliance.

After evaluating tools from multiple vendors, the team selected MapleSim for their model development work. Describing their choice, Dr. McPhee says “Taking into account simulation times and quality of results, MapleSim, because of its symbolic computation technology together with optimized code generation, performed better than the other software platforms. Therefore, we selected MapleSim for use throughout this project.”

The team then developed an impedance controller which can automatically adjust itself in a variable admittance environment, representing the variable levels of movement disorders affecting rehab patients. The controller was simulated running on the 2D model, in 4 different modes. The first two modes, simulating a healthy arm, were used to calibrate and tune the controller, while the second two modes which simulated a post-stroke patient’s arm, were used to evaluate its performance.

Hand position error and muscle activation levels were measured and compared during simulation runs in the different operating modes. The results were positive, and in line with expectations, demonstrating that it is possible to use musculoskeletal arm models to evaluate the planar robot.

During the next phase of the project, the team will develop an advanced 3D musculoskeletal arm model with integrated muscle wrapping. As musculoskeletal models become more detailed and life-like, engineers are able to enhance the design of control algorithms for upper limb rehabilitation robots, which ultimately improves the rehabilitation process for post-stroke patients.
Maplesoft announced a major adoption of its products by NASA’s Jet Propulsion Laboratory (JPL). JPL is implementing Maple, MapleSim, and MapleNet in its various projects. Whether creating America’s first satellite, Explorer 1, sending the first robotic craft to the moon, or exploring the edges of the solar system, JPL has been at the forefront of pushing the limits of exploration.

Curiosity, JPL’s latest space rover, which launched in 2012, aims to explore Mars to investigate whether the planet could have ever supported microbial life. Other JPL projects include spacecraft missions to comets, asteroids, and the edge of the solar system, as well as satellites that monitor the land, oceans, and atmosphere of our own planet.

Maplesoft products are expected to help JPL save time and reduce cost by providing more efficient and smarter methods for mathematical analysis, modeling, and simulation. Maplesoft solutions are built within a natively symbolic framework, avoiding some of the worst sources of error and computational inefficiencies generated by traditional, numeric-based tools, thus providing great tools for precision-rich projects such as those of JPL.

In addition to using Maple for advanced mathematical analysis, JPL will use MapleSim, Maplesoft’s high-performance physical modeling and simulation platform, as a key tool in its engineering workflow. MapleSim works in combination with Maple. It accesses Maple’s symbolic computation technology to efficiently handle all of the complex mathematics involved in the development of engineering models, including multi-domain systems, multibody systems, plant modeling, and control design.

“Maplesoft products will allow JPL to unify their approach to mathematics, modeling, and simulation,” says Paul Goossens, Vice President, Applications Engineering, Maplesoft. “MapleSim’s intimate connection to the underlying physics of the system models, combined with the knowledge capture and analysis capabilities inherent in Maple, will make project design and development faster and more accountable. JPL scientists will arrive at optimal solutions much faster, and their models will be much more reusable.”
Following the completion of the DeltaBot, a robot based on an innovative cable-actuated delta-style design, Dr. Amir Khajepour received a surprising number of requests from industry for its use. Based on this commercial demand, Dr. Khajepour established AEMK Systems, a company specializing in the design and distribution of high-speed, cable and vision-based robotics systems for use in a variety of industrial applications. The DeltaBot is capable of over 120 pick-and-place cycles per minute and handling up to 20 kg.

The AEMK DeltaBot robots use cables instead of rigid arms to reduce moving inertia and mechanical equipment costs. The simple design and scalability of the DeltaBot means that it can easily integrate into existing automation environments. The DeltaBot is capable of over 120 pick-and-place cycles per minute. One of the distinctive features of the DeltaBot over other delta robots is its high payload capacity. While other delta robots are limited to payloads under 3 kg, the DeltaBot is capable of handling up to 20 kg. Its high speed, low maintenance costs, and high payload capacity make it a very attractive industry alternative in many automation applications.

Early in the initial research phase, Dr. Khajepour chose Maple, Maplesoft’s advanced technical computing software, as a key tool in the robot research project. All subsequent design improvements and enhancements to the Deltabot system were developed using Maple and MapleSim, Maplesoft’s high-performance physical modeling and simulation solution. Maple and MapleSim are built on a foundation of advanced symbolic computation technology, which lets users obtain highly accurate results about the system behavior.

"Maplesoft technology was an integral part of the design process of the DeltaBot system, and is now an integral part of the robot’s ongoing development," says Dr. Khajepour, President and Founder of AEMK Systems, and University of Waterloo Professor of Mechanical Engineering. "With the use of Maplesoft technology, the initial development time for the robot was significantly reduced, and we continue to benefit from shorter development cycles as we make enhancements to our products."

AEMK Systems is currently using MapleSim to model and simulate the DeltaBot system for use in real-time hardware-in-the-loop (HIL) testing, as part of its ongoing research and development program. When converting the concise model equations to real-time source code, the code generation tools in MapleSim apply additional optimization steps, further improving simulation speed so the results can be used in real-time systems.

"By using MapleSim and Maple, we will be able to design and test enhancements to the DeltaBot much more quickly than with other design tools," says Dr. Khajepour. "These products make it possible for us to be very responsive to the needs of our customers and the changing demands of industry."

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— Dr. Amir Khajepour, AEMK Systems
Learning to Walk Faster with High Performance Modeling

The ability for robots to mimic humans is one of science’s most talked about issues. The rewards for reproducing human movement and actions go far beyond engineering, having applications and ramifications for medical treatment, computer technology, defence, exploration, and much more.

A project using MapleSim physical modeling software at the University of Manchester is helping to perfect the process of humanoid walking in robots. The new centre at Manchester, the Centre for Interdisciplinary Computational and Dynamic Analysis (CICADA), has been working with Professor Darwin Caldwell at the Italian Institute of Technology, Genova, who has been developing a novel compliant humanoid robot (CCub) based on the previously developed humanoid robot iCub at IIT.

Part of CICADA’s work looks at walking characteristics and other locomotive actions using a hybrid model. The model uses spring/dampers to simulate ground reaction force, actuator dynamics, and compliant elements to capture the robot’s full dynamic response.

One of the challenges facing the Manchester team, lead by Dr. Martin Brown and Dr. Gustavo Medrano-Cerda, is visualising experiments quickly and effectively, to avoid slowing down the process and to ensure that experimentation is valid and relevant. “The ability to visualise in MapleSim, without having to write our own programs, has been invaluable,” says PhD student Houman Dallali. “What’s more, we can directly generate C++ code to interface with the hardware and speed up the controller implementation/debugging process.”

With a comprehensive and advanced library of models online – in one place – Mr. Dallali has been able to construct complex simulations easily using the ‘drag and drop’ modeling environment and then edit existing models with little effort due to MapleSim’s intuitive interface. The inclusion of linearization techniques in the MapleSim offering is also important for robotic modeling. “We are building models faster and completing experiments with better data thanks to MapleSim’s accuracy and kinematics capabilities,” Mr. Dallali continues.

The speed and success of the MapleSim-aided research means that the CICADA team will quickly move on to projects for dynamic walking with full body control and extended range of gaits. Dr. Martin Brown and his PhD student Onder Tutosoy are working on ‘reinforcement learning’ for humanoid robots as well as ‘iterative learning’ techniques. “In the future, we will be adding logic and learning approaches to our code and looking to develop applications from the research, such as better prosthetics and walking aids,” says Mr. Dallali.

“...Visualise, without having to write our own programs, has been invaluable.”
— Houman Dallali, University of Manchester
With the widespread adoption of composite ice hockey sticks over the past decade, the frequent breakage of these sticks is all too common. Not only do these breaks drastically change the game at the professional level, they also lead to exorbitant costs for players. Reliable and durable hockey sticks can have a large impact on the game itself, on professional and recreational players, and of course on the wallets of parents whose children aim to be hockey stars one day!

Hockey Robotics is a company that has pioneered the concept of robotic testing for the hockey industry. It specializes in hockey stick design, performance, and durability testing using an advanced hockey stick testing robot. Hockey sticks most often break during a slap shot; therefore the company’s goal was to produce a robot capable of properly mimicking the professional hockey slap shot. The Hockey Robotics team, with support from industry partnerships, manufactured the SlapShot XT, a dynamic hockey stick robot capable of delivering a slap shot at speeds up to 110 mph. Hockey stick manufacturers are now using the robot to test their designs in a highly repeatable and controlled manner, providing evaluation data never before available.

The SlapShot XT is the first ever robot capable of executing a slap shot like a professional hockey player. The robot’s integrated advanced electronics and software allows the gathering of data never seen before, enabling even more detailed analysis of the results to support further refinements in hockey stick design. The SlapShot XT is bringing about revolutionary changes in the way hockey sticks are developed.

In hockey sticks, breaking may occur when the stick is subject to very large three-point bending loads during a slap shot. The first step in creating the robot was to fully understand the motion of the hockey stick during a slapshot using advanced motion tracking techniques, and then create a virtual model of the robot to reproduce that motion. During slap shots by highly proficient hockey players, the trajectory of the stick was tracked at important locations using high-speed cameras. By analyzing this data, the SlapShot XT robot was designed and developed to accurately re-create the loading to which a stick is subjected during a slapshot. The SlapShot XT is capable of shooting a puck at over 100 mph with either a left- or right-handed stick.

MapleSim played a critical role in the design and development of the SlapShot XT. MapleSim is a physical modeling and simulation tool from Maplesoft built on a foundation of symbolic computation technology. It efficiently handles all of the complex mathematics involved in the development of engineering models, including multi-domain systems, plant modeling, and control design. MapleSim allowed Hockey Robotics to efficiently and accurately simulate the coupled dynamic electrical and mechanical behavior of the equipment. MapleSim enabled the concurrent study of the flexible body deformation and rigid body motion of the machines, which is a very difficult, time-consuming, and error-prone task when done by hand. It also allowed them to quickly prototype the designs and investigate the coupled motion of the mechanisms very easily.

A four-bar mechanism was synthesized to match the hockey player’s motion, and subsequent dynamic and stress analyses were used to develop and confirm the performance of the resulting robot design. A flywheel maintained the stick’s momentum during contact with the ice, and the robotic hands allowed the stick to bend about two axes, storing and releasing strain energy throughout the shot. The final design was evaluated using NX 6 from Siemens PLM Software and finite element models of the components.

“MapleSim is the engine driving our development.”

— Dr. John McPhee, Hockey Robotics
The result was definitive: The robot provides repeatable, unbiased test data on the performance and durability of hockey sticks, a first in the industry.

“MapleSim is the engine driving our development,” said Dr. John McPhee, Chief Scientist at Hockey Robotics. “It has been crucial in our development and testing, resulting in tremendous savings in design and prototyping. In addition, MapleSim allows us to perform engineering analysis that was previously too challenging and computationally intensive for our industry to undertake.”

Future projects at Hockey Robotics involve using MapleSim to develop a rapid prototyping tool that they believe has the potential to permanently change the way that hockey sticks are designed and evaluated. They expect that their new solution will provide much shorter development cycles and substantial reductions in development costs for hockey equipment manufacturers.
About Maplesoft

Maplesoft, a subsidiary of Cybernet Systems Co. Ltd. in Japan, is a global provider of high-performance software tools for engineering, science, and mathematics. Its product suite reflects the philosophy that given great tools, people can do great things.

Maplesoft’s products help to reduce errors, shorten design times, lower costs, and improve results. Maplesoft’s core technologies include the world’s most advanced symbolic computation engine and revolutionary physical modeling techniques. Combined together, these technologies enable the creation of cutting-edge tools for design, modeling, and high-performance simulation.

Engineers, scientists, and mathematicians use Maplesoft products to enable them to work better, faster, and smarter. Maplesoft’s customers include Ford, BMW, Bosch, Boeing, NASA, Canadian Space Agency, MDA, Microsoft Research, Ulysse Nardin, Liebherr, Mitsubishi Securities, Cleveland Golf, Stanford University, the University of Waterloo, TU Wien, Cornell University, the State University of New York, and the University of Notre Dame, covering sectors such as automotive, aerospace, robotics, electronics, defense, energy, financial services, entertainment, and academia. With Toyota, Maplesoft founded the Plant Modeling Consortium to promote the development of new design techniques for automotive and related industries.

About Cybernet Systems Co., Ltd.

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