Projects: Real-Time Control Code

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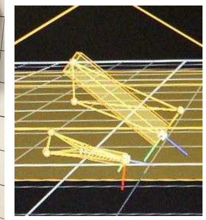
Robot software is made particularly challenging by strict timing constraints and multiple control threads. It is not easy to ensure safe and stable control of complex, dynamically-balancing robots in which small glitches can send the robot tumbling.

The lower-body strength-augmenting exoskeleton "XO"

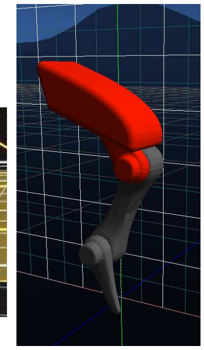
Multithreaded Controller for the XO Hybrid Electro-Pneumatic Exoskeleton Prototype (2010)
Prof. Sang-Ho Hyon, Dept. of Brain-Machine Interface, Advanced Telecommunications Research Institute, Japan

This lower-body exoskeleton project aimed to provide adjustable, 0-100% support of strength and/or balance for elderly and paraplegic patients. Most of the engineering work involved integrating the various pieces built by Japanese contractors together with Prof. Hyon's algorithms to form the first fully functioning control and diagnostic system of the exoskeleton's myriad sensors, valves, and motors. I designed the system's multithreaded, soft real-time priority-based scheduler, GUI, and control loops. Software-level and electrical-level joint-travel protection and fail-safe behavior were of paramount importance for a powerful machine that is literally strapped to a human body.

Monopod with reflective markers



Camera's noisy reconstruction of marker positions



Inferred robot state viewed with OpenGL

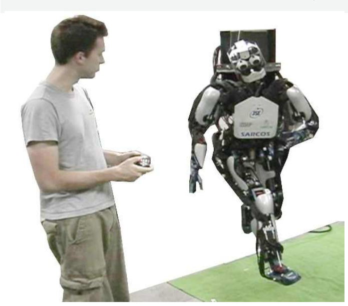
Real-Time Inference of Monopod Hopping Robot Orientation using Cameras (2012)
Prof. Nikos Tsagarakis, Prof. Darwin Caldwell, Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

Before a robot can be controlled, its present state must be precisely measured. But when a monopod hopping robot is flying through the air, no simple sensor can tell you the full state of the robot in relation to the environment...or even which direction is down. To solve this problem, I configured a Vicon 5-camera system to measure the position of reflective markers attached to a hopping robot, so that the position its the three rigid bodies could be reconstructed and error-corrected in real time. The inferred joint angles were then fused with data from joint sensors, fed to the control system of the robot and displayed in real-time in a simple OpenGL viewport and matched against a physically accurate rigid body dynamics simulation that I wrote.

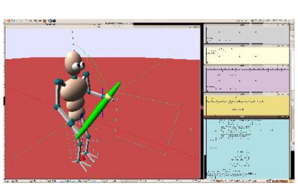
HOAP-3 Humanoid Robot RTLinux Real-time Control Software, Build Scripts, and Kernel (2007)
Prof. Yoji Uno, Prof. Kouichi Taji, Biomechanical Control Group, Dept. of Mechatronics, Nagoya University, Japan

This project involved a 27DOF humanoid robot named HOAP-3 that had been donated to the lab because nobody knew how to make it work. I reverse-engineered the legacy control software, documented findings in Japanese and English, re-configured the RTLinux kernel, and developed a custom C/C++ kernel module build system so that researchers could easily compile and execute their hard-realtime control programs in kernelspace. The system is still in use to study human gait, stroke rehabilitation, fall damage avoidance, and dynamic programming.

The HOAP-3 Robot



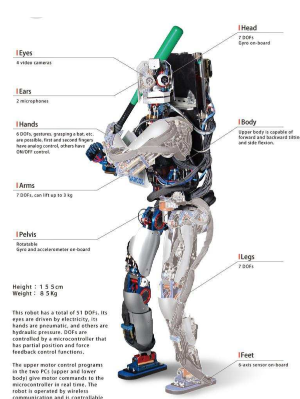
Controlling CBi with a joystick



Baseball batting simulation

Keyframe-based Postural Control using Monotone Cubic Splines for Rapid Creation of Motions for a 51 DOF Hydraulic Humanoid Robot (2010)
Prof. Sang-Ho Hyon, Dept. of Brain-Machine Interface, Advanced Telecommunications Research Institute, Japan

This powerful 200lb, 51DOF hydraulic humanoid made by Sarcos, Inc. was a real beast. The joint control, kinematics, and vision processing required three hard real time computers to communicating to meet a 1000Hz deadline; control failure could result in the powerful hydraulic cylinders damaging the $1M robot...or nearby people! I debugged and documented the legacy software system and assisted with the transition to the realtime kinematics/dynamics control libraries developed by Prof. Schaal (Stanford). I also wrote a joystick driver, a monotone cubic spline interpolation system, and used it to develop joint trajectories for realistic baseball batting motions. Getting the robot to hit a baseball reliably proved too difficult and remains an unsolved problem in humanoid robotics, as well as in some human leagues.



The Hydraulic Robot CBi

Projects: Statistics & Inference

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How could we even begin to make quantitative sense of the world without statistics? The broad applicability of statistical methods have proven utility in science, medicine, politics, and business.

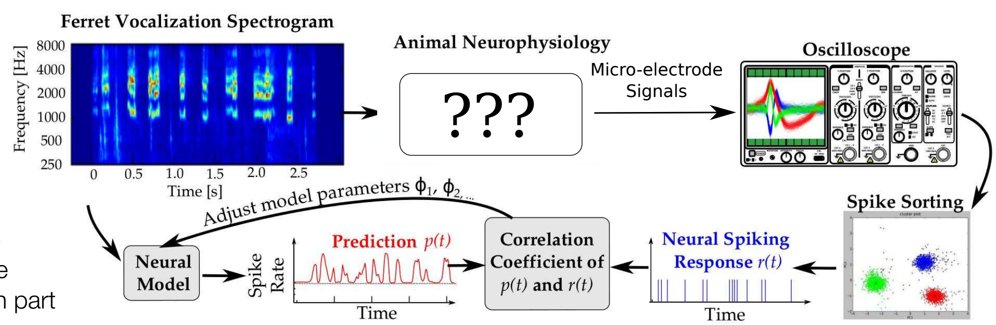
Statistical Fraud- and Risk-Scoring Algorithms (2016-2017)
Legitscript, Inc. https://www.legitscript.com. Personal reference: John Horton, CEO.

A brief background: In 2016, the startup company I was working at, Whibse Inc., was merged back into its parent company, LegitScript, so that the volume of data and large-scale harvesting software that we had developed could be could be owned and managed by the larger organization. At this point, my role shifted to being the Senior Research Developer, meaning that I was given first crack at much of the green-field software to be written. In this capacity, I wrote several prototype-level pieces of software, such as "single page app" user interfaces for analysts that used websockets to minimize response latency, on-demand full-site HTML harvest and indexing systems using Nutch and ElasticSearch backends, and a few other experiments that did not end up being turned over to production developers -- but if every experiment worked perfectly, it would not be exploratory research I guess!

Relevant to statistics and inference, I helped solve a longstanding problem at LegitScript: given a few million websites that need constant monitoring and review by the ~40 person analyst team, how can we automatically prioritize websites by their attributes to maximize the number of fraudulent, transaction-laundering, and other "risky" websites that are found per hour of analyst effort? Equivalently, how do we find which attributes of the whois records, DNS information, HTML content, or merchant transaction information are most indicative of risk?

After developing suitable mathematical assumptions and a formalism for risk scoring problems of this type, I wrote a reference document documenting the mathematics, proposed a microservices architecture and an algorithm that could accomplish this task. I then wrote the first implementation of a statistical risk analysis system that finds substrings that identify which merchant accounts and websites are most likely associated with fraudulent activity, and give presentations to other devs and stakeholders to pass the project off to a larger team. Given the opportunity for more months of research, it would have been interesting to explore deep learning techniques on this corpus of data and compare it to the "old school" bayesian statistical methods I used, but the legal requirements of the system and its use in criminal activity detection essentially ruled out non-auditable, black-box machine learning systems.

Model-Based Inference of Neural Functional Properties (2012-2014)
Prof. Stephen David, Oregon Hearing Research Center, Oregon Health & Science University http://www.hearingbrain.org



Cochlear implants give hearing to the deaf via direct electrical stimulation of auditory nerves, but people with such implants have difficulty in discriminating one voice from the background of a noisy room. This may be in part because natural auditory neural encodings are imperfectly understood, and the synthetic signals generated by a cochlear implant may be more difficult for the brain to interpret. While many publications in the field computational neuroscience present models of neural encoding, few models have been directly compared on the same data set despite this being the only fair way to experimentally evaluate their validity. We embraced this challenge and fit 780,000 parameterized mathematical models to populations of cortical neurons, testing each model prediction against data that the model had never seen before, and were able to isolate which parameters best described cortical neural function. As we learned about the core complexity of auditory neural signals, we found parameterized wavelets could create models that predicted better than state-of-the-art models, despite having 90% fewer parameters. Moreover, these models worked better with limited data sets and were more easily extended to include nonlinear temporal filters and time-varying dynamics.

I helped Prof. David by writing NARF, a neural data regression and fitting system with modular components that could be combinatorially combined to find better neural models, and assisted other researchers and students in writing their own modules for NARF. I focused my mathematical energy on decreasing parameter counts and exploring low-dimensional wavelet models, which resulted in our publication "The Essential Complexity of Auditory Receptive Fields" in 2016. Many other practical problems required solving, such as creating reliable fitting algorithms for the myraid models and variable-quality neural data, or even just running such a large number of simulations on a low budget. The latter required us to build a modest 10-node computing cluster of diskless linux nodes and keep it continuously busy for nearly 18 months. Even just viewing the huge number of models and visualizing the data meant building custom GUIs to browse our database, so that our decisions about how to improve models could be justified by the data.

Projects: Mechatronic Design

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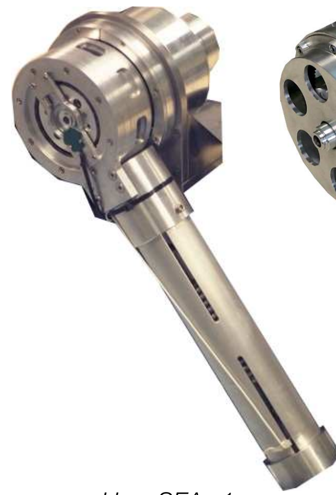
The word "mechatronic" is the amalgamation of "mechanical" and "electronic", and refers to the iterated, simultaneous design of both aspects of a dynamic system. It requires expertise in both disciplines -- or at least that MEs, EEs, and CSEs are willing to feel each others pain -- but makes resulting designs simpler, robust, and cost effective.

Hypocycloid-based Series Elastic Actuators for Legged Robots (2009-2012)

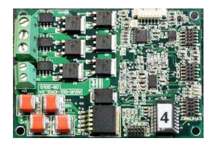
Prof. Darwin Caldwell, Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

During my time at IIT, I invented, designed, assembled, and patented two variants of a series elastic actuator (SEA) called the HypoSEA. The actuator was designed such that the passive mechanical dynamics of the monopod robot would harmoniously match the dynamics of the actuators as driven by the intended controller. Actuation systems for legged robots have peak power-to-weight requirements only slightly less demanding than light aircraft. It is thus helpful to design leg springs that reduce actuator peak power requirements by providing limited energy storage. Unfortunately, elasticity negatively affects control and dynamics of the robot unless carefully matched to the intended motion. These lightweight actuators are capable of torques equivalent to lifting 15lbs at arms length (65Nm) of torque, yet can sense the light touch of a finger. I used Solidworks and ProE to develop the 3D and 2D schematics, collaborating with an Italian mechanical engineer and machinist during construction. The unusual sensing requirements required us to also modify the firmware of a custom motor controller.

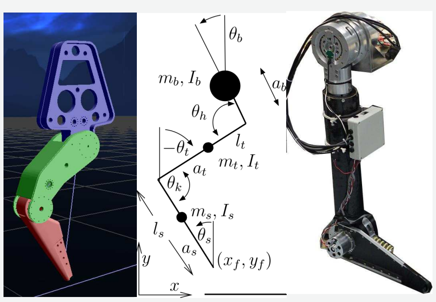


HypoSEA v1

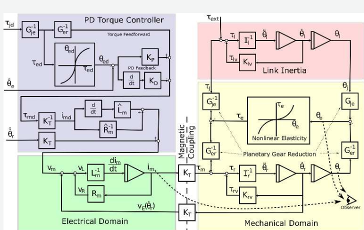
HypoSEA v2



Custom motor control circuit



Early dynamical simulation, control system, and prototype



Integrated model of control, electronics, and mechanisms

Simultaneous Design of a Monopod Robot's Actuators, Mechanical Dynamics, and Balance Controller (2009-2012)

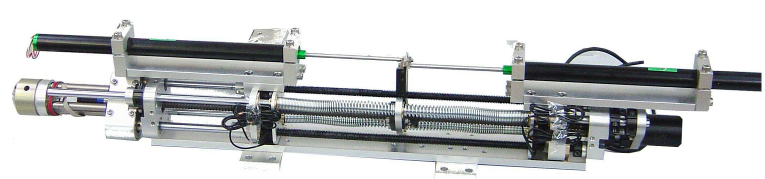
Prof. Nikos Tsagarakis, Prof. Darwin Caldwell, Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

The control algorithms that describe legged locomotion are often somewhat independent of the number of legs. A quadruped is mathematically similar to two connected bipeds, or to four properly synchronized monopedal hoppers. Thus, as part of my Ph.D. thesis project, I constructed a monopod hopper as the mechanically simple but hard-to-balance legged robot. I began by creating a virtual model centroidal momentum balance controller, wrote a rigid body dynamics engine, designed the under-actuated hopping robot mechanical system, and tested the proposed control system in simulation. This enabled me to accurately estimate control torques, and customize the actuation system perfectly for legged locomotion. As the design progressed, the simulation, control system, mechanical structure, and actuator requirements were prototyped and iterated until the final jumping robot was completed. The technical details of this robot are documented more fully in my thesis.

My "Kangaroo" Robot

Design and Control of a Novel Variable-Stiffness Series Elastic Actuator (2008)

Prof. Hosoe, Control Systems Theory Laboratory, RIKEN Biomimetic Controls Research Center, Nagoya, Japan



While at RIKEN, I conceived and designed a variable stiffness series elastic actuator for a minimally-actuated passive dynamic robot. Passive dynamic robots are mechanical systems with dynamics that walk stably without any motors at all, but have limited robustness to disturbances. Our goal was to examine whether an actuator with reconfigurable mechanical dynamics could. The design is described in detail in my masters thesis, and was precision-fabricated by Japanese engineers at Ono Denki (www.ono-denki.com).

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Startup Companies

I am very fond of research laboratories and startup companies, which are often filled with smart people, passion, innovation, and the opportunity to learn to do things in new ways.

Developer at Whibse, Inc. (2014-2016)
Whibse, Inc. Reference: John Horton, CEO

As an inventor and entrepreneuer wanting to participate in small teams doing cool things, I was attracted to Whibse's stable, yet still very much "startup" atmosphere and its clearly positive social benefit. Whibse was a startup funded by a stable larger parent company, LegitScript, which works to stop illegal online drug sales, and more broadly, to stop fraudulent activity, illegal products, and transaction laundering. Stopping illegal activity online was something I could get behind morally, and our technical tasks were interesting challenges: web-scale data collection, focusing at first on whois parsing and then later expanding into DNS records and limited HTML analysis as well. This data was then used by analysts at LegitScripts in various ways. For example, by maintaining indexes of "every domain that linked to another domain" we could quickly discover the domains used merely to drive traffic to specific illegal online activity.

Whibse was very much a back-end tech company. Working with 2-3 other developers, I wrote a highly scalable, fault-tolerant distributed harvester for HTML, DNS, and Whois, to maintain fresh, forward and reversed-indexed copies of the world's top-page HTML, DNS records, and Whois records for more than 300 million websites. We worked with Clojure, Java, Javascript, Cassandra, AWS S3, and relied heavily on AWS auction systems to minimize the cost of thousands of continually harvesting instances. It was really fun to see billions of entries in our databases and terabytes of network traffic managed by such a small team.

Entrepreneurship

In 2013, I founded a startup company to produce next-generation mobile robotic actuation systems for academic researchers, industrial research, and OEMs. Our aim is to build the best high-torque motor module in the world.

Founder, President, Janitor of Octopus Robotics, Inc. (2013-present)

To be an entrepreneur is to wear many hats.

Depending on the day, you may find yourself soldering, doing taxes, deciding what features to drop or add, trying to attract good people to your cause, talking with customers, drafting schematics, machining metal, working with graphic designers on marketing materials, or just writing code as fast as you can. Mostly, you learn about the value of persistence ... and how easy it is to underestimate the number of janitorial tasks that often fall to the owner of a small bootstrapped business!

Octopus Robotics' first product is the Mussel Motor, a self-contained high torque actuator with built-in torque control systems that is designed to simplify making high-fidelity haptic and force-sensitive systems. Why is this important? People use telephones to speak and hear over a distance, they use video to see and be seen over a distance, but for the ability to touch and feel over a distance something that can be widely adopted, more economical and accurate torque control actuators need to be developed. Our primary customers at the moment are researchers and roboticists, but we also see applications in telemanipulation fields like hazardous material handling, remote surgery, and VR gaming.