Research Statement

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If one word can represent the glue that binds my research concepts and intentions it would be "human". With a mechanical engineering focus, my predominant interests are concerned with how humans interact with machines and how humans can be described as machines. Although past decades of mechanical engineering advancement have made great strides in automatic control and machine design, this body of research often neglects the intimate association between humans and machines, a relationship that exists now and will for much of the foreseeable future. As machines are developed to tackle more complicated tasks they will need to be more aware of their environment, especially the human's actions and intentions. A machine that is aware of the human will result in a system in which the human's higher cerebral control abilities are complemented by massive data parsing and repetitive tasks at which computers excel. In order to design devices that optimize this symbiosis we must better understand how people interact with their surroundings and use machines to do so. Such advanced technologies have recently come to light, examples of which are self-driving cars, assistive aircraft control, haptic feedback, human-aware factory robots, and others. The more we can understand how the human behaves the better these devices can be designed to compensate for human weaknesses.

My doctoral dissertation focused on the human's unique ability to balance a mostly unstable vehicle, the bicycle. The bicycle is an interesting machine because it requires a human's constant interaction to balance and stay on course. This makes it an ideal platform for investigating many, if not all, of the facets of complex human control and complementary machine design, all in a tractable, economically viable, and socially familiar machine. On-board data acquisition has improved dramatically with the advent and rapid growth of micro- and nano-scale sensors paired with data collection abilities in small devices such as smart phones, which is helping to propel engineering into the realm of big data. These technologies allowed me to collect substantial amounts of kinematic and kinetic data from both the bicycle and the human subject in maneuvering experiments. I made use of a combination of first-principles modeling techniques and grey box system identification approaches to develop realistic models of both the bicycle and the human's control behavior. The bicycle dynamics and control research is covered in detail in my dissertation and a series of journal and conference papers listed in my resume.

My doctoral work has developed my aptitude in a broad range of theoretical and experimental sub-disciplines including:

First principles modeling

- Classical mechanics
- Multibody dynamics
- Classical and modern automatic control systems
- Vehicle dynamics and control (single track vehicles, automobiles, and aircraft)
- Human operator/manual control
- Human biomechanics
- Human power generation

Data centric modeling

- System identification (black/grey box, linear/non-linear)
- Statistical modeling (e.g. multi-level modeling)
- Signal processing

Experimentation

- Vehicle instrumentation and data acquisition
- Human instrumentation and data acquisition
- Motion capture
- Wind tunnel experimentation
- Vehicle handling qualities

Software engineering

- Algorithm design
- Open source software development
- Agile development
- Test driven development
- Web development

Miscellaneous

- Sports engineering
- Advanced machine design
- Appropriate technologies
- Human powered machines

My future research directions will leverage collaborative initiatives to fill gaps in my expertise. I want to develop a more holistic research plan centered on the human as a controller and his/her interactions with machines. In particular, collaboration and connection to the fields of machine learning, neuroscience, and cognitive psychology will be a priority because the prediction of human behavior while interacting with a machine requires greater understanding of the human mind and internal control scheme complexities.

My primary goal will be to assemble a team of scientists (students, post docs, and fellow colleagues) to tackle fundamental concepts in our understanding of the human control system and the machines with which a person interacts. The applications are wide ranging but the research will focus primarily on the basics of human motor control from simple balance to manipulator control and vehicle control. I want to push the boundaries in understanding how to utilize human physiological feedback signals in automatic control systems and, in particular, to increase the automatic controller's operator "awareness".

Questions I plan to seek answers to include: Can machines become aware of their surroundings so that they never harm a human? When does the automatic system take control of the vehicle if the human isn't up to the control task? Can automatic control constantly be aware of the human's state such that it can adapt to the human's ability or inability? Automatic control of manually controlled systems must be able to augment the human's actions both enhancing their ability and filling in when the human loses the ability to be an adequate controller. It should be aware of the environment when the human cannot be.

During my tenure as a graduate student researcher I gained a great deal of experience in organization, project management, student mentoring, and successful grant writing. For example, I closely mentored six graduate students, and numerous undergraduates in a lab setting. The final years of my graduate work were funded by a National Science Foundation grant (# 0928339), which I played a large role in writing and managing under my principal investigators, Dr. Mont Hubbard and Dr. Ronald Hess. Before the NSF funding, I was also awarded a Fulbright to the Netherlands from the Department of State, which is a very competitive individual grant. Combining those with successfully obtaining many university-level grants and co-writing two successful Google Summer of Code grants has made my experience at obtaining funding very strong. Furthermore, I am a very active participant in service to academics in my field of study and to my department and university. I have organized and chaired conference sessions, been elected to the scientific committee of my sub-field's main conference, and developed broad relationships with my fellow researchers all at the graduate student level. My role as a co-founder of the Davis Open Science group has allowed me to participate in many panels and meetings on topics such as Open Access at the university level. I feel fully prepared to pursue and secure funding to manage a large lab with many simultaneous research projects all the while serving in academic leadership positions.

Research Proposals

I plan to conduct research that will fundamentally change our understanding of human/machine interaction. The following synopses describes areas where I see the most potential for impact.

Manual Control and Human Machine Interaction

I plan to explore the human as a machine controller for very fundamental problems. For example, current understandings leave much to be desired when we ask fundamental questions such as "How do we balance a broom stick on our hand?" To answer this question, we need to consider the fundamental sensory information that we take in, how we process that and produce the correct control action. Developing experiments involving such input/output relationships with simple machines can help expose the essence of human control which will have broad impacts for understanding more complex scenarios such as operating a spacecraft.

In contrast to simple systems and first-principles modeling constructs, the collection of a large amount of varying dynamic data from force, kinematic, and physiological sensors combined with machine learning and system identification will allow for the development of predictive models of human control behavior in both simple and complex tasks.

Balance

One of the most fundamental control tasks we accomplish, as human, is postural balance. Balancing is learned at a very young age; a task that initially dominates computations in areas of the frontal cortex. This later becomes a learned skill as much of the computation moves to the more reactionary portion of the brain towards the spinal cord. I plan to to study details of postural control and the way we learn the skill through carefully crafted collaborative experiments with neuroscientists and psychologists that can expose the sensory motor control the human uses in balancing.

Single Track Vehicle Dynamics

Single track vehicles such as bicycles, motorcycles, and unicycles offer a unique platform to study and understand human control. These vehicles limit the human's input sources to affect the vehicle's behavior which allow for more controlled input/output experimental relationships. Furthermore, the vehicles themselves have non-trivial open loop dynamics which provides a rich system for exposing the human's unique control abilities such as non-minimum phase, instability, disturbance recovery, and directional/tracking control. This research can have impacts on basic human operator control theory and on the design of the vehicles themselves, for improved safety and optimal characteristics for maneuvering.

Vehicle and Machine Handling Qualities

When humans interact with machines, whether it be flying an aircraft or playing a video game, the operator has a subjective opinion of the ease of control. For example, does the machine do what I want it to with minimal effort? Although machine performance during a manually controlled task and the machine's open loop dynamics can be objectively measured, there must be connections between the subjective feeling and these objective measurements. Unlocking this connection will allow for the design of machines that complement the human in a passive way by changing their open loop dynamics through machine design.Furthermore, if knowledge of handling qualities is combined with automatic control the machine adapt to the human's desires without modifying the vehicle's physical design. But developing theoretical models that describe a machine's ease of control will take an interdisciplinary approach that involves an understanding of dynamics, control, neuroscience, and psychology. Topics of this nature dominant research in human factors, but the link to vehicle design and engineering is still weak. I plan to strengthen that link with collaborative research in this area.

Bicycle and Motorcycle Tire Modeling

The rigid body dynamics of bicycles and motorcycles have advanced enough for relatively good prediction abilities, but the most glaring deficiency are models that can accurately predict the ground reaction forces between a tire and the rolling surface. I am interested in collecting large amounts of tire force data using the latest ob-board kinetic sensing techniques to acquire data in normal driving behavior (i.e. not on a tire testing machine). This data will be used to create data driven models and identify parameters in first principles models.

Open Vehicle Model and Simulation Database

The creators and developers of the world wide web have caught on to the big data movement and it is beginning to drive prediction and analyses on a grand scale. For example, Google and Facebook, rely on the ability to parse massive amounts of data and make predictions of their users' behavior. But much of the engineering world is still behind the times when it comes to big data. It is obvious that the more data we collect about systems in the world, the more realistic and predictive our models can become. We now have the capability for data driven models and predictions of physical phenomena by making use of vast database stores and cloud powered computing resources. It is critical that the field of engineering as a whole embrace this movement, make data sources widely accessible, and enable these disruptive technologies for the benefit of society. All of my future work will have a data component that supports these ideas, but in particular I plan to start an initiative of sharing data in the vehicle dynamics field.

Scientists and engineers create a variety and large quantity of dynamic models of vehicles. In the field of research that I have dedicated my graduate work to, there are well known models like the "bicycle" model for cars, the Pacjeka automobile tire model, the Whipple bicycle model, the Sharp motorcycle model, etc. As it stands, these models are relatively inaccessible because either the model is not detailed enough in an accessible manuscript or, maybe more importantly, the software to produce the model is not open source and/or requires special permission for use. This current unavailability of free and unhindered use of these models detracts from the scientific community's ability to trust and reproduce results. This issue can be mitigated by embracing open data methodologies. A large database that allows models to be developed, submitted, and validated for easy reuse will allow models to be validated against data on a much larger scale. I plan to start with vehicle models, but this concept can extend to any system described by differential-algebraic equations. I plant to build on other open modeling languages and standards, such as Modelica, to provide some of the framework needed to make this a reality.

Furthermore, dynamic data is constantly collected on different vehicles but is generally only stored locally on scientists' computers. If there were an easy way to store time series measurements with accompanying meta data, a large online database of simulations could be built up. This would allow modelers to validate their models against thousands and thousands of simulations. In the fields I work in, most models are accepted after being validated on only a tiny set of data. Imagine if you could validate your model on huge datasets of simulations.

I intend to develop an open (i.e. liberally licensed) database with both vehicle models and simulation data which will provide easy and open access to both submit and query the desired data. This system may very well be able to be expanded to any research field that works with similar data types.

Open Source Software

The academic needs powerful cutting-edge computation tools at his or her disposal. Especially in academia, I believe these tools are best provided through open source software collaboratively developed among leading scientists and primary users in the field. The nature of open source software parallels the idea of reproducible, reusable science. I have spent a great deal of time working on open source software and it is tightly knit into my research. I would like all my research to have open source software as an integral component. Some specific examples of projects I have worked on and have in mind are given below:

- Dynamics (problem development, simulation, and visualization)
- Symbolic equation of motion generation for dynamic systems

- Control Systems
- System Identification

I am interested in developing reusable, highly tested open source software suites that leverage cloud computing resources to solve computationally large problems in my field, but that is general enough so that researchers from many other fields can make use of it and contribute to it.

Human Inertia

I would like to develop more realistic mathematical models for estimating human inertia. Current rigid body models do not accurately model the human inertia around the joints when in arbitrary configurations. The need for more complex volumetric equations defining the flexible regions around the primary joints can increase the accuracy of human inertia estimation in arbitrary configurations. These models which have low computational and measurement latency should be validated against more precise and resource intensive measurement techniques like MRI and vibration mode analyses.

Human power

Humans are power generators and there are many ways to efficiently make use of the human's mechanical capabilities to do work. Humans have long used tools of various efficiencies for agriculture and food processing. Making these processes most efficient is still important for much of the developing world. Improvements in efficiency of tasks such as transporting people and goods, moving water, grinding raw foods, washing clothes, etc. are all possible. But also with the advent of extremely low power electronics (less than 5w) the human's excess power can potentially keep devices like cell phones, pace makers, and small computers powered. I intend to study these aspects of human power generation and develop dedicated summer enrichment programs for students to develop appropriate human powered technologies for both the developing and developed world.

Energetics of Transportation

Transportation research and modeling techniques do not always take full advantage of the predictive ability of the laws of motion. Utilizing simulations of dynamically constrained systems can add great insight in understanding transportation systems and giving results that are useful to engineers, planners, and policy makers. The following lists some of the topics that I have worked on and plan to in my future research:

- Speed limits per vehicle kinetic energy
- GPS controlled speed limits
- Self driving cars
- Efficient route choices based on the energetics of travel
- Fuel economy feedback reformulated with energy economy in mind