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DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

PROPOSAL FOR THESIS RESEARCH IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

TITLE: EGGWAY: A Mobile Platform with an Intuitive Physical Interface

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BRIEF STATEMENT OF THE PROBLEM:

We predict that the emergence of humanoids will be preceded by a class of less complex *utilitarian mobile* robots. Such robots will perform specific tasks under the interactive supervision of a human master (e.g., personal assistance, delivery, surveillance, human/robot transport). Even though they will not look or function like humans, these machines should still support natural physical and social interactions if they are to integrate effectively into our lives. This research presents the design, fabrication, and control of Eggway, a robot for investigating these interactions. Eggway is a *dynamically stable*, sphere-based robot capable of omnidirectional locomotion. Because it actively balances on a single point of contact with the floor, the platform is particularly well-suited for maneuvering in environments built to accommodate the human form.

Using this research platform, we propose to investigate what meaning, or state, people associate with particular robot movements and likewise what intentions people believe correspond to their own actions. The hope is to qualify and quantify a mutual and intuitive action-based repertoire for communicating with such a general mobile platform. Such a dialogue allows the robot to be controlled through direct physical contact with a human user (e.g., pushing, patting, leaning) and, in return, to convey its state through its motions (e.g., shaking, spinning). The proposed thesis also considers the practical applications of the robot, particularly as an assistive device such as an active walker, for the elderly or physically challenged.

1 Introduction

Since World War II, man's relationship with machine has inspired the creation of entire disciplines, such as Human Factors and Human-Computer Interaction (HCI) (31). It is only within the last decade, however, that researchers have begun to identify metrics for specifically human-*robot* interaction (HRI) (50, 27, 23). The relatively recent development of HRI is due to advances in artificial intelligence (AI) and engineering that have made semi-autonomous systems achievable. The complex control and higher level behaviors that enable the systems to perceive, react to, and influence our dynamic environments give rise to a variety of human-robot interaction roles. It is these robotic characteristics of situatedness and physical embodiment as defined by Brooks (20) that are responsible for distinguishing these roles from those typically defined between a human and a computer (49).

Despite the variety of robots currently being developed, however, most of the literature on our interactions with them was initially limited to teleoperated systems and more recently to humanoids, anthropomorphically-inspired systems that exhibit some aspect of human intelligence, be it either superficially or on a deeper cognitive level. This research bias is not surprising. One of the earliest motivations for developing humanoids centers on the idea that humans provide the best templates for machines that could foreseeably cohabit human-centric environments. And, if the AI research trends of the last decade are any indication of the machines of the future, we will someday share our lives with such robots. But there are also many potential robotic applications that will not require the social or functional complexity of such a robot. In light of this, we predict that the emergence of humanoids will be preceded, if not accompanied by, a vast array of *utilitarian mobile* robots. Such robots will perform specific tasks under the interactive supervision of a human master (e.g., personal assistance, delivery, surveillance, human/robot transport). They will not boast anthropomorphic features or the range and depth of human competency because their practical applications will not require those features.

In fact, simple versions of these specialized robots are beginning to trickle into the private sector (13, 5). Though now regarded as novelty, the stuff of Sharper Image™catalogs, soon they will become fixtures in our daily lives. Our interactions with these robots are indications of why HRI is still in its infancy. Advertisements for robotic lawnmowers (4) and vacuums (8), for instance, actually celebrate how little human interaction they require; the products lack the functional and social sophistication needed to sustain a more complex human-in-the-loop dynamic. But besides the relative shortage of information that exists on interactions with utilitarian mobile robots, the state of HRI also reflects a lack of breadth on the user end. That is to say, human-robot interchange is still directed by robotics experts, not ordinary people. Yet, just as the computer was passed down from specialist to civilian, so will be the robot. As the robots become more thoroughly enmeshed in society, people will form working relationships with them. The quality these robots add to our lives will be determined by both the importance of their function and the efficacy of our interactions with them. These interactions are two-way dialogues defined by the efficient communication of state and intent by both parties.

It has been shown that humans are inclined to respond to sufficiently complex non-living things by applying knowledge of our own social experiences. In other words, we apply social models to our interactions with technology, often attributing mental states to machines in order to interpret their behavior (25, 34, 47, 16). Based on this underlying notion that humans prefer to interact with machines in the same way we interact with each other, there are many forms that the human-robot dialogue could take (e.g., natural language, facial expression, gesture, etc.) These points advocate designing interfaces for robots that are suited to the average person who is already well-versed in social interaction (unless, of course, a future filled with millions of unprogrammable mobile VCR's appeals to us). Ultimately, whatever the format of the communication is, it must allow for the human to interact with the robot in a *transparent, consistent,* and *intuitive* manner. These requisites for comfortable human interaction are even more important if we consider the variety of robot platforms and the extent to which they could potentially pervade our lives. A new overload of so many different interaction protocols could prove burdensome and disruptive to people unless these dialogues are somewhat spontaneous.

These issues raise a few questions about the specific nature of the dialogue. What form do the actual symbols, the functional primitives, of the communication take? How do we implement an intuitive dialogue with these utilitarian robots who do not support anthropomorphic morphologies or necessarily accommodate characteristic modes of communication? What is the common link among these robots that can leverage a consistent dialogue?

Our proposed research addresses these questions by framing them in the context of the physically embodied robot. Though utilitarian mobile robots each have different specialized functions, all these functions rely on mobility. Thus, from the range of ways in which humans could possibly communicate with these robots, we choose to focus on nonverbal physical exchange; our approach is grounded in the underlying mobile capabilities of the platforms. The human-robot interactions we are interested in center around physical expressions. Though not based on conventional verbal or body language, we propose these interactions still fall within the boundaries of natural communication. This proposal introduces a dialogue that leverages off the idea that movement is a powerful and intuitive mechanism for communicating state and intent.

In other words, a human user can effectively control a robot through direct, discreet contact, such as shaking, pushing, leaning, tapping. These social actions not only convey a user's intent, but can also be regulated to relay intensity. Furthermore, the actions (and their meanings) come naturally to us, as is evidenced by the fact that humans frequently use them to control each other as well. Common examples of this include: nudging or tapping to get someone's attention, shaking to revive or "reset," pushing to direct, or patting to give feedback, grabbing to stop. (Interestingly enough, these actions are also similar to the one we use in communicating with our dogs.) Finally, these actions can also be reflexive, as anyone who has ever ridden a Segway® could tell you. The robot can also communicate its state through movement. For instance, oscillation could convey uncertainty, rotation could convey disagreement, etc. Thus, we make the argument the physical embodiment and mobile capabilities of robots can engender a mutually effective, yet simple dynamic. Very little work has been done to explore this action-based modality as it applies to human-robot interactions.

In order to effectively test these ideas about intuitive physical interfaces, we need a physical platform. To this end, our work involves the design, fabrication, and control of Eggway, a dynamically stable, sphere-based robot capable of omnidirectional locomotion. Unlike traditional wheeled robots with large, low, statically stable bodies, Eggway actively balances on a single point of contact with the ground. This holonomic design makes the platform particularly well-suited for maneuvering in environments built to accommodate the human form. Besides self-stabilizing, the utilitarian robot is to be controlled through direct physical interaction with a human user. The remainder of this proposal outlines an implementation strategy for the robot and a plan for analyzing the robot's interaction with people. For the purpose of organization, we present the work as it unifies the following three motivational thrusts:

Form involves the design and fabrication of the mechanical, computational, and sensing hardware. The goal is to engineer a utilitarian mobile robot platform that can easily integrate into our social and physical surroundings. Dynamic stability is stressed as a functional requirement. This work is significant in understanding the physical requirements of a single point of contact system.

Function deals with the software control for the robot. First, we hope to implement controllers for robust dynamic stability and effective locomotion in unstructured human environments. We then aim to establish a safe and responsive user interface, or in other words, the low-level control of the human-robot interaction. This includes how robustly and reliably the robot reacts to environmental perturbations (e.g., changes in terrain and object collisions) as well as user handling (e.g., ”manual” steering, stopping, disabling, and accidental impacts). The control contributes to our understanding of such a dynamically stable, yet statically unstable robot.

Formality involves software implementation and analysis of the human-robot interaction on a more social level, i.e., how the robot interprets user commands and how it conveys its own state. We plan to investigate, through well-defined experiments and surveys, what meaning, or state, people associate with particular robot actions and likewise what intentions they believe correspond to their own actions. The significance here lies in qualifying and quantifying an intuitive action-based repertoire for mutually effective interaction with a general mobile platform. Success in the domains of *form* and *function* is prerequisite to achieving this main contribution. We interpret our findings in respect to practical applications of the robot, emphasizing its use as a rehabilitative or assistive device.

The goal of the research described herein is to combine these three areas. The thesis will present the case that an action-based dialogue is a useful and practical alternative for interacting with utilitarian mobile robots. This communication may be used as a stepping stone for other modalities. However, we propose it can form a basis for our interactions with a vast array of very different task-specific mobile robots. Eggway’s form and function, in particular, seem to make it well-suited for use as an assistive device. We aim to demonstrate that given the robot’s small footprint and dynamic stability, such an action-based user interface will make Eggway an intuitive and helpful active walker.

Clearly all three areas are highly interdependent. Yet, separately, they provide a systematic approach strategy and a metric for evaluating our milestones. Each of the following three sections revisits, one of these themes in detail, presenting background literature, current/pending accomplishments, methodologies, foreseen challenges, and possible extensions of the project. Section 5 delineates a timeline for completion of the research.

2 Form

A robot's morphology directly influences its functionality and prescribes its social interface. Thus, there are a number of criteria to consider in designing robots that must perform tasks for and with humans. The authors of (28) suggest that for people to feel comfortable using *utilitarian* robots, the machines must reflect a degree of "product-ness." Furthermore, since such robots must operate alongside and in contact with people, their physical form must support safe, compliant, and responsive control architectures and should also suggest their intended function. *Mobility* imposes even stricter design requirements on a system, especially if the robot needs to operate in environments built by and for people. This involves maneuvering in and accessing a world that is tailored to the human form and its capabilities (21).

While bipedal robots could potentially satisfy these requirements, wheeled robots pose a less complex, and therefore more imminently practical, solution. Traditionally, however, these platforms have large bases and/or short payloads in order to keep their centers of mass close to the ground. Though this small height-to-footprint ratio may provide *static* stability, it renders the systems inadequate in human-centric environments. The large bases prevent the robots from maneuvering in areas that are easily negotiated by people, such as densely populated, cluttered, or narrow spaces. Their statically stable bodies also restrict them from getting close to furniture and other objects (e.g., workstations, doorhandles, countertops, etc.) that people access regularly. Furthermore, the need for a relatively low mass distribution means that the bulk of the robot, including sensors and actuators, need be located below the height of the human torso. This makes it difficult for these robots to physically or socially interact in environments adapted to the level of our eyes, the extent of our reach, and the significance of our faces.

Dynamically stable wheeled robots, on the other hand, are better suited toward the operational impositions of human-centric environments. Conceptually akin to inverted pendulums, such platforms can balance by actively compensating (i.e., applying forces and torques) for center of mass perturbations in the horizontal plane, much the way humans do (44). This adaptive ability relieves them of the design constraints necessitated by their statically stable counterparts. A dynamically stable robot can handle having its center of mass situated much higher off the ground. It can also correct for mass redistributions on the fly and therefore accommodate the independent movement of other onboard components or robots. Because it allows for this flexibility and also enables a robot to lean, dynamically stability can increase the effective volume that a mobile robot can access, just as our arms and our torsos enable us to reach far beyond the support polygon of our feet. Furthermore, since a dynamically stable robot can balance on one or two points of ground contact, the footprint of such a system can be consistent with human dimensions. These robots are therefore capable of approximating our form, and thus our interactions with the artifacts and modern environments we have built around us.

This case for dynamic stability has been made before. A growing body of evidence in support of its feasibility and efficacy has accumulated over the last two decades through its application to robots with different morphologies and modes of locomotion. There have been many versions of dynamically stable legged robots since Raibert's seminal work on hoppers (46) up to the latest generation of small bipeds (32, 14, 33). Other research has focused on single-wheeled robots such as those built like unicycles (51, 38) and self-contained gyroscopes (42, 26). Recently, the introduction of the Segway® Human Transporter (HT)(11) brought the concept of dynamic stabilization to the public's attention. A modified, autonomous version of these vehicles called a Segway Robot Mobility Platform (RMP) has since shown to be a viable base for humanoid torsos and dexterous manipulators (21, 29) intended for human-centric environments. There are also many other examples of autonomous two-wheeled robots that maintain static stability around the roll axis but dynamic stability around the pitch axis (30, 36, 15, 57, 2, 45, 6).

Finally, a few designs have been implemented in which all control and drive components are encased by a spherical shell (39, 17, 40, 18). These wheeled and spherical systems were inspiration for Eggway, the dynamically stable robot conceived for this research. Initial interest in similar sphere-based systems has also been expressed by (37).

2.1 Physical and Computational Hardware

Eggway's morphology is guided by its intended ability to engage with humans and effectively maneuver in our human-centric environments. Thus, throughout the mechanical design process we kept in mind the following key functional considerations:

Dynamic stability about *all* axes is important because the features of an even *partially* statically stable system can actually undermine its mobility. Let's take a Segway®, for example. The base configuration of the two wheels determines a rigid polygon of support which can act as a moment arm for generating torques about the roll axis. Thus, a dynamic perturbation at one of these wheels, such as a bump or a lateral collision, could effectively cause the platform to topple. To avoid this, we chose a ball as the mechanism for locomotion. Eggway's dynamic stability allows for greater speed and efficiency even though it requires more complex control.

A large height-to-footprint ratio means Eggway can sustain human-like proportions. As previously mentioned, this characteristic is a consequence of dynamically stable systems which offer the potential for accommodating taller structures without increases in overall footprint.

Holonomic omni-directionality means the number of controlled DOF of a vehicle equals its number of total DOF. Unlike traditional nonholonomic systems, such a robot is highly maneuverable and can continuously move in any 2D direction from an arbitrary configuration without changing the direction of its wheels. Eggway can move simultaneously and independently in translation and rotation.

User compatibility is an important feature for a robot whose operational efficacy relies on human interaction or supervision. The system must be a safe, robust platform which can make use of rich, prolonged sensorimotor feedback in real-time.

The morphology of our research platform reflects these motivations. Eggway is a novel sphere-based mobile robot (see Figure 1). In other words, the chassis, or body, of the robot, is built on top of a ball such that the ball is captured, yet free to roll in any direction beneath it. This is accomplished through configurations of rollers that reduce the frictional interface between those two main components. The aim is to eliminate all such friction contributions except for that between the ball and the actuator mechanisms. This latter element determines the efficiency of the motors in propelling the robot's motion.

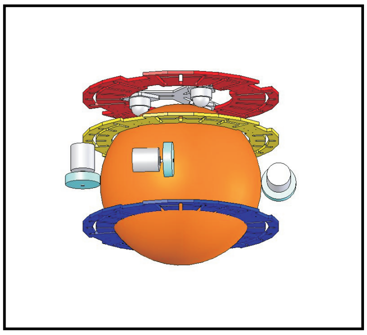

Figure 1: An oversimplified, conceptual depiction of the basic Eggway configuration including the ball, chassis, and motor-wheel assemblies.

Five independent parameters are needed to specify the position of the robot: two coordinates of translation (i.e., x and y) and three coordinates of rotation (i.e., roll, pitch, yaw). The mechanism that governs these degrees of freedom (DOF) consists of three separate DC motors. The *pitch (x)* and *roll (y)* motors control the steering and impart dynamic stability to the robot by modulating the velocity and acceleration of the ball. They are orthogonally oriented and effectively move the robot in any direction by transmitting power either separately or coincidentally. The designation of 'pitch' and 'roll' (or x and y) is arbitrary for an omnidirectional, radially symmetric robot like Eggway, so these assignments correspond to defaults sensors. *A yaw motor*[1] enables the ball to spin in place around the vertical axis. The ball used in the most recent prototype is a heavyweight water polo ball that has an 8.5 inch diameter. The ball was chosen because it is light, yet virtually non-deformable. Also, because it is designed for use in the water, the ball has a textured top-grade rubber surface which provides a high friction interface for the actuators. The motors are each powered by two high discharge Li-Poly 2000 mAh battery packs (1) connected in series.

Each of these motors is fixed to the chassis and contacts the ball at its equator via special shaft-mounted wheels. These wheel assemblies are thus responsible for transmitting the motion of the actuators to the ball. Furthermore, each wheel has a series of free turning barrel-shaped rollers, mounted around its periphery (see Figure 2). These rollers spin passively around axes that are tangent to the main wheel. The combination of the roller elements with the rotation of the main wheel allows for multidirectional movement at the interface with Eggway's ball. Because they must be used together to provide support over 360° of rotation, each motor has a pair of coordinated wheels attached to its shaft. This use of these wheels illustrates one of the biggest mechanical challenges involved in a single point of contact robot: friction. In order for Eggway to balance, the pitch and roll motors must be constantly controlling the motion of the robot, i.e., they must never lose adequate contact with the ball. So, for the ball to be able to spin in

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[1] This motor is in the final version of the robot which is currently being designed, but is not implemented on the most recent prototype.

place by way of the yaw motor, the interface must accommodate that motion and reduce the effects of static friction at those contact points.

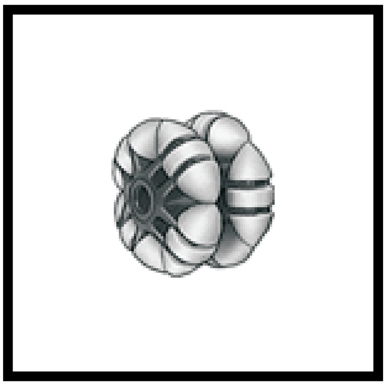

Figure 2: Dual wheels have small rollers around the outside that combine with the rotation of the wheel body to allow multidirectional movement.

The robot makes only a single point of contact with the ground and is thus statically unstable. Because it can balance like an inverted pendulum to achieve dynamic stability, however, Eggway's center of mass can be situated high above its relatively smaller base. The morphology of the robot therefore achieves maximal maneuverability, height, and stability with minimal volume.

Eggway's computational hardware architecture centers around an off-the-shelf controller board called a ServoPod™(12) based on a 56F807 Motorola DSP chip (10). The ServoPod™is a single board computer that also features many common peripherals (e.g., GPIO lines, A/D's, timesrs, quadrature decoders, SPI and SCI ports, PWM channels, etc.). The board allows high system flexibility, enables rich sensor integration, and offers clean, fast multi-axis communication.

The motors described above are each controlled through a high power Hbridge (9) that receives direction and pulse width modulation (PWM) signals from the DSP. A miniature solid-state inertial measurement unit from

Figure 3: This is a picture of the most recent prototype, which is now being redesigned into a final robot.

Intersense (7) located on top of the robot currently provides the yaw, pitch, and roll of the platform. The orientation information is sent from the gyro to the DSP via RS-232C interface and used to close the feedback loop with the actuation. Eggway's stability is dynamically achieved through this closed-loop control. Furthermore, controller gains are set by potentiometers connected to the analog-to-digital (A/D) converters on the DSP. Digital motor encoders will eventually provide feedback about the robot's translational accelerations and displacements. A simple diagram of this architecture is shown in Figure 4.

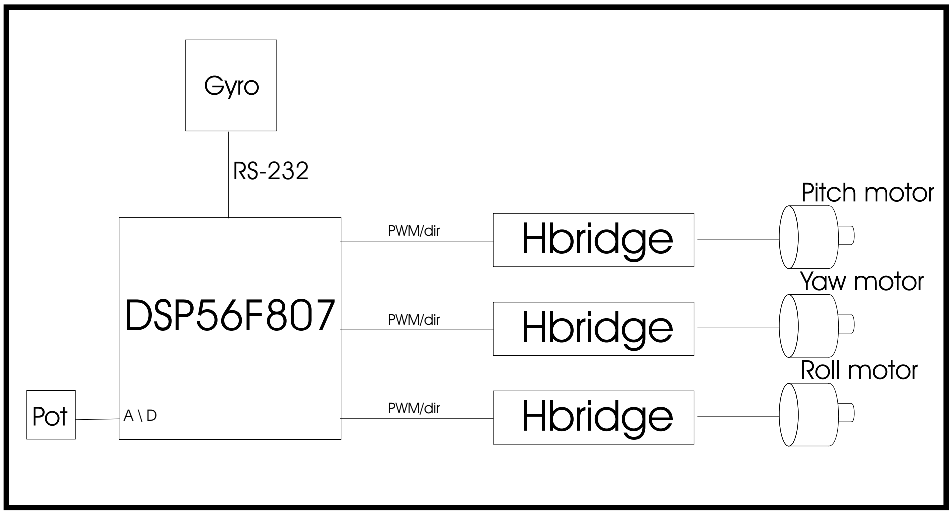

Figure 4: Simple computational hardware architecture of recent prototype.

2.1.1 Progress

The proposed work has so far focused mostly on the mechanical design and fabrication of a platform that can achieve single-point-of-contact dynamic stability. Three increasingly complex prototypes of the robot have been built to test varying drive mechanisms, ball types, and friction parameters.

From these experiments, we have garnered important information about how certain hardware choices affect the robot's ability to balance. For instance, we have found that the ball must be non-deformable and light to, respectively, avoid shape deformations and inertial elements that compromise dynamic stability. We have also seen the importance of minimizing contacts between the ball and the robot chassis because of side effects of friction.

Thus most recent incarnation of the robot has only a pitch and a roll motor, as it was designed to evaluate the configuration's ability to balance with simple inverted pendulum control. However, the next and final version of the robot is well underway. The redesign accommodates a hollow 8 inch diameter aluminum ball and has a much smoother and simpler ball/chassis interface than the prior prototypes. The design also includes the third yaw motor, a more user compatible morphology, and larger achievable tilt angles. We will be designing and casting our own actuation wheels out of rubber along the lines of the skate wheels mentioned above. Finally, we are considering using different gyros for balancing as well as other sensors for the robot including: sonars, laser range finders, strain gauges, and force sensitive resistors (FSRs).

3 Function

The authors of (56) use the term *application specific mobile robot (ASMR)* to describe an autonomous vacuum cleaner that integrated morphology, sensors, and "intelligent" software. What we refer to as a *utilitarian mobile robot* expands on this general definition. In the context of this work, such a robot is defined basically as "a system whose primary function is dependent on the system's mobility and on some level of human interaction." But there are some subtle implications of this definition that deserve further explanation.

- The morphology and competencies of the robot are specialized for a specific mobility task or group of tasks. Examples range from a vacuum cleaning robot (or less specific floor cleaning robot) to a general mobility platform that could be easily adapted for transporting objects, assisting the disabled, or surveying landscapes.

- The robot does not have significantly anthropomorphic features or human-like behaviors because its practical application does not require that level of complexity. Furthermore, because the application is embedded in mobility, the robot will most likely embody characteristics that enable it to move quickly and reliably in our living spaces. In this case, it makes sense to us that its interactions with people will be more attuned to its physical actions then to conventional speech or emotional content. Unnecessary or overly human-like behaviors may even prove confusing or uncomfortable to a user and distract from the robot's utility.

- The robot must engage a user beyond just powering it on or off; the robot supports and its function requires more of a human-in-the-loop dynamic. The robot must be technically 'autonomous' in that it perform tasks in unstructured environments without continuous human supervision. However, because the tasks rely on human interaction and are, in fact, meaningless without it, the robot's autonomy is *conditional*. For instance: a delivery robot relies on people to be the recipients and sources; an active walker relies on a human's need for assistance.

- Because it is active and mobile, the robot must exhibit safe, reliable behavior in dealing with the people and artifacts surrounding it.

Eggway's competencies are motivated by this definition and its implications. This requires formulation of low-level controllers to preside over the robot's stability, locomotion, and interactions based on its perceptions.

3.1 Low-level Motion Control

We differentiate between the robot's low-level and higher-level mobile functions. The former refer to the abilities that prescribe the robot's core mobile competencies; they designate *how* the system moves. The latter functions (discussed in Section 4), on the other hand, correspond to *why* the robot moves. (55) distinguishes between high and low-level user control though we can apply the abstractions to inherent robot functions. Low-level functions are evident when there is a tightly-coupled user interaction. The extreme of this is tele-operation (41) in which a user is completely controlling a robot's actions. Thus, these functions refer to ones at a purely action/perception level, i.e., how the motors move in response to sensor input. Given these lower-level functions, higher-level ones correspond to ostensibly more autonomous, socially grounded behavior, i.e., the robots interpretation and consequent reaction to user commands and the environment. These functions are apparent to a user in more loosely-coupled social interactions. Thus the socially grounded higher-level functions are dependent on the lower-level performance.

For Eggway, there are three major components of low-level functionality:

dynamic stabilization involves how robustly the robot balances,

locomotion refers to how well the robot rotates and translates in space,

user compliancy refers to how the robot performs the prior two components when a human is in contact with it.

Because Eggway makes only a single point of contact with the ground, it cannot function unless it is actively balancing. Therefore, dynamic stability control is of foremost importance. Once this is accomplished, the robot should also be able move around in the world. This means applying the concept of balancing in place to locomotion, i.e., translation and rotation. This is easier to understand if we think about human movement. People are not statically stable, but are constantly controlling their balance in order to stand up straight. It is easy to take this for granted because we rarely think about having to balance. Yet, we all had to actually learn how to do this when we were young. When we walk or run, we also maintain this dynamic stability.

In the same way, Eggway must be able to sense what direction it is falling and drive (by actuating the ball) to catch itself. This should happen when it is trying to stand or rotate in place as well as when it is moving around. A consequence (and control challenge) of this mobility is that for the robot to initiate a translation, it must disturb its own balance by leaning. Eggway should also be able to balance and move when a human user is holding on to it, either for stability or to steer the robot. Ultimately, the low-level control of the robot should elicit stable reactions to environmental (including human) stimuli such as changes in terrain, collisions, accidental impacts, 'manual' steering, etc.

The most recent prototype of the robot is capable of balancing in place within a 15°from vertical stability cone. The goal is to achieve a 45°cone. This dynamic stability is achieved through a fairly simple proportional (P) controller that calculates PWM values for the motors based on feedback from a gyro. The PWM signals switch H-bridges to control the voltages going to the motors, and thus their velocities. The gyro is connected to the DSP via a serial port at 9600 baud.Right now the code is written in a language called IsoMax which is based on FORTH. We are currently porting all code into C.

The current balance algorithm leaves much to be desired and the gyro information is not as reliable as it could be. We plan to do Matlab analysis of the system to get a better grasp of balancing and motion control requirements. We will start by focusing on the problem of stabilizing an inverted pendulum. This is a widely used example for studying feedback control of unstable systems (52, 54, 3). We will test various closed-loop control strategies on the robot in order to achieve extremely robust dynamic stability, effective travel at moderate speeds, and safe, reliable user interaction. If conventional control schemes do not prove acceptable, we may add adaptive control elements that learn how to move the motors to stabilize the robot (30, 22, 53). We also plan to equip the robot with more sensors such as laser range finders or sonars. Besides being used to detect obstacles and people, these could potentially be used for boundary mapping as well. At this early point, we do not plan to implement navigation or path planning on the robot beyond direct contact responses. Though built to accommodate cluttered human-centric environments, we will run the robot in open spaces, focusing on its interactions with users.

4 Formality

There is much literature based on the social relationships that arise between humans and more human-like robots (19, 43, 35). These researches do a service of defining the term ”social” in its application to the machines (19), the interactions (24), and models of human social development (48). We find these works very helpful in identifying how and if the term applies to the class of utilitarian mobile robots whose levels of control and autonomy correspond to their specialized functions specific environments.

In Section 3 we define these robots as having functions that require some level of a human-in-the-loop dynamic. On the spectrum of human-robot interaction, our relationships with them fall somewhere in between ones we would have with fully humanoid systems and the ones we have with today’s robot vacuums. Thus it is a bit unclear as to what form of dialogue we should use to communicate with these machines. Whatever the format of the communication is, it must allow for the human to interact with the robot in a *transparent, consistent,* and *intuitive* manner.

- The *transparency* of the interface is an aspect of user friendliness which refers to how much the technical details of the platform are hidden from the human. A transparent dialogue thus allows a user to concentrate on a robot’s intended utility rather than it’s internal functionality. Utilitarian robots should not require (though they may be able to accommodate) any more levels of communication than are necessary to accomplish the tasks we give them. Furthermore, the control protocol should exploit the robotic assets that are most appropriate for each specific goal.

- A *consistent* dialogue is one that is platform independent. This is an important feature for a class of robots to adhere to. Though each member of the class may have a specialized ability or intended function, they would all share a set of base competencies. The argument for consistency takes advantage of the underlying capabilities commonly availed to a group of robots in order to define a uniform dialogue.

- Finally, the human-robot interaction should be *intuitive*. It should be quick and easy for the human to learn, if not natural or reflexive. This applies to the symbols we use to control the robot as well as those used by the robot to convey its state to us. So, even though we may not have common morphologies or competencies, an untrained operator should easily be able to communicate her intent, as well as interpret, predict, and elicit desired robot behavior. This is a key issue for autonomous mobile robots that are actively functioning in dynamic unstructured environments, and more even importantly, doing so alongside humans. In order to engage people on a safe and effective level, robots must operate at human interaction rates and respond to changes in real-time. But this holds for us as well. A dialogue that is nonintuitive, requiring us to think before we act, so to speak, can be potentially very dangerous, especially if the interaction is grounded in direct physical contact.

Our proposed research attempts to define a such a dialogue with these robots that is based on physical expression and which exploits their mobile capabilities. In other words, the functional primitives of the communication involve direct contact and observable motion.

Clearly this framework can only be investigated once the groundwork for the robot is fully established. We plan to analyze human interactions with the robot through carefully designed observational and written surveys. These experiments will have two aims:

1. to identify what discreet actions people reflexively or naturally use to command such a robot, e.g., shaking, tapping, leaning, hitting, and
2. to delineate what motions such a robot can exhibit in order to relay its state, e.g., spinning, rocking, tracing out patterns, etc.

We will develop software around the first of these results in the hopes of implementing a transparent, consistent, intuitive interface for a user to convey intent and intensity. The results of the second point could be used to establish standards of nonverbal communication for mobile robots. Perhaps someday, these primitives, which would be platform and language independent could for the basis for interaction with the robots that will come to intimately share and change our lives.

Based on this work, will make the argument that physical embodiment and mobile capabilities of robots can engender a mutually effective, yet simple dynamic. Very little work has been done to explore this action-based modality as it applies to human-robot interactions. In particular we would like to focus the on use of Eggway as an assistive device for physically challenged and elderly people. The robot could serve as an active walker to that actively helps to stabilize a user. Sensory capabilities could be added which could also assist the person in navigation and evaluate their condition.

5 Timeline

Date	Milestone
Nov 2004	Final robot version built and balancing robustly)
Jan 2005	Low-level user control done
Feb 2005	Some high-level user control implemented
May 2005	High-level control done; (possible) student run experimentation on human-robot interaction, surveys out
July 2005	Survey analysis; thesis writing
August 2005	graduation

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