Bipedal Walking Robots: Advancing the Science through Killer Applications, Replication and Validation, Standards and Common Platforms, and Competition

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Abstract: Pioneering research in bipedal walking began in the 1960s, about 20 years after early computers started appearing. Between then and now computer science has advanced tremendously. As for bipedal walking research, progress has been slower. Today's most advanced bipedal robots fall down when pushed slightly, walk very slowly, and cannot take a corner without slowing down significantly. It is unlikely that the next 20 years will see progress in the bipedal walking robot arena that is as impressive as the last 20 years of computer science.

At the cornerstone of successful science can be found the following hallmarks: killer applications, replication and validation, standards and common platforms, and competition. In the case of computer science, all of these are plentiful. In bipedal walking research, several are lacking, suggesting that there are fundamental reasons why bipedal walking research will progress more slowly than computer science has. In this paper we will explore how these hallmarks contribute to the rapid advancement of science and compare computer science and bipedal walking research along these lines. We will draw conclusions on what can be learned to help increase the rate of progress on bipedal walking research by more fully incorporating these hallmarks.

Key words: : biped, robot, walking, research, infrastructure

1 Introduction

Thomas Edison was one of the most prolific inventors of all time. However, many think his most important contribution was the invention of the industrial research laboratory itself. By developing a method for rapid invention and rapid commercialization, Edison helped revolutionize nearly all sciences. One lesson to be learned is that it can often be helpful for a scientific community to take an occasional step back and look at the workings of the community as a whole and see what can be done to increase research productivity. To do this accurately and thoroughly is a Herculean task that should draw on expertise from Science Historians, Philosophers, and Anthropologists. This paper is in no way intended to be a thorough examination of the bipedal walking research community. It is more an invitation to those in the community to think about and start a discussion on such matters and to consider research methods that maximizes the benefit to the entire community.

This paper was motivated by and prepared for the 2002 FIRA Robot Soccer World Championship. 2002 marks the first year of the Humanoid Robot World Cup Soccer Tournament (HuroSot), a tournament dedicated to bipedal walking robots. Previous FIRA

Robot Soccer World Championships, and other robot soccer competitions, have proven to be a very valuable way to promote and advance robotics research. The improvement in play over the years of the various robot soccer teams has been an indication that progress is being made, and that the competitions are helping to drive that progress. Robot competitions like these help provide many of the cornerstones of science. They provide common problems and promote common platforms. They provide for competition through the various tournaments. The contests themselves provide an application for the robots and force the validation of algorithms in a more real setting than one's laboratory.

In this paper we will examine the bipedal walking research enterprise in terms of hallmarks of successful science including killer applications, replication and validation, standards and common platforms, and competition. We will compare advances in computer science to those (or lack there-of) in bipedal walking robotics in light of these hallmarks.

One can argue that this comparison is utterly unfair. Computer science is perhaps the most phenomenally productive science ever pursued by mankind. However, the intention is to examine computer science in terms of the hallmarks listed above and to contrast it along the same lines with bipedal walking research. In doing so, certain procedural changes that will increase progress become apparent. Some of these procedural changes will happen naturally over time and cannot be easily affected by individual researchers. Others, however, might be sped up by individual decisions. The reader is encouraged to expand this exercise him or herself, to think of ways in which he or she could contribute to the advancement of the science through process innovations in addition to technical contributions.

In the following sections we will examine some of the hallmarks of science and how it relates to bipedal walking research. We will then make recommendations, in light of these hallmarks, that can help increase the productivity of the bipedal walking research community.

2 Killer Applications

The key features of a "killer application" for a technology are that it is

- Widely used.
- Extremely economical.
- Provides an order of magnitude improvement in productivity or results.

For computers, killer applications are abundant, as computers perform many of the tasks that humans are poor at, such as mathematical calculations, or keeping track of large databases. Some of the first uses of computers were for numerical computations for research and defense. Early commercial uses were word processing, database management, and games. These applications continue today and are joined by information retrieval, communication, video production, publishing, and warfighting. It is hard to imagine an aspect of our lives that has not been affected by computers. Just about every advance in computer power has been greeted by a new application. Real time video streaming is one of the current applications driving computer technology and computer purchases. Tomorrow's applications are lined up, waiting for their turn, and driving investment.

There are many potential long term applications for bipedal walking robots. Some day such robots may clean our houses, fight our wars, and perform our menial labor. However,

while early computers performed tasks that humans are poor at, these typically cited applications for bipedal robots are those tasks that humans perform well at. While it is relatively easy to match the abilities of humans in multiplying numbers and recalling addresses, matching the dexterity of a human may prove very difficult, requiring billions of dollars and tens to hundreds of years of research before these long term applications are feasible.

Until then, it would be desirable to have a continuous stream of killer applications which can be benefited by bipedal walkers at various stages of development.

Two potential applications for bipedal robots seem to be currently emerging. These are home entertainment and advertising. The success of Sony's Aibo showed that people are willing to pay thousands of dollars for purely entertainment appliances. Now several companies are releasing bipedal toys for similar markets. It will need to be seen whether such markets grow or stagnate and whether or not they drive bipedal walking technology.

In the advertising arena, Honda's Asimo robot is now available for rental, with several reported customers. Techno-marketing has been around for some time and has shown to be successful in some areas. If Asimo becomes "salesman of the year", then perhaps that will be a driving force to develop more advanced bipedal walkers.

3 Replication and Validation

In many scientific endeavors, replication and validation of work is seen as a necessary step before results are meaningful. In fact, in many areas, publishing before replication and validation is seen as unethical. Pons' and Fleischmann's seemingly incredible results in cold fusion are a case in point.

Computers are nearly a perfect platform for replication and validation. If a program works on one computer, it should work on the millions of "compatible" computers. Programming languages are now being developed for "write once run anywhere" development. Due to the deterministic nature of computers, it is almost silly to suggest that an algorithm needs to be tested on several models before its validity is assured. For random algorithms it should be sufficient to run the program on the same computer using a large number of different random number generators.

In the realm of bipedal walking robots, it is rare to ever see replication and validation of results. Worse yet, the information required in order to perform such replication and validation is typically completely missing. It is often simply too difficult to communicate the entire design of a robot, and the entire algorithm it uses in the traditional medium of the published paper. Few researchers have posted and maintained this information on publicly available web sites. The lack of this information limits replication and validation to only the simplest and best described algorithms and ideas. If bipedal walking research publication was held to the same standards as physics, for example, many of us would be in jeopardy of losing our careers. While it may be unlikely that any bipedal walking researchers "doctor" their results, at least Pons' and Fleischmann's experiments were quickly shown to be flawed. We will never know the validity of many published works on bipedal walking robots since many of these works do not contain enough information for replication.

4 Standards and Common Platforms

Standards and common platforms help focus a young field by allowing many people to attack the same problems with the same tools and the same evaluation criterion. They

help prevent "reinventing the wheel" so that researchers can focus on the hard issues. They also allow for the rapid commercialization of developed technologies.

In the area of computer science, there are thousands of standards from the ASCII representation of characters to internet protocols. As each new research area is conquered, standards are created which then turn that area from a problem into a tool. For example, the question of how to reliably and efficiently transmit data across a network was once a hot research topic in computer science. While there are still many researchers studying this topic, the developments of error correcting codes, network hardware, packet protocols, etc., have resulted in UDP, TCP, and other standards. Now researchers can use those standards to open up new, more advanced, areas of research such as distributed computing over a world-wide network.

The first computers were each "home grown" and only used by a handful of researchers. Quickly, however, the commercial viability of computers drove businesses to manufacture standard models and by the early 1960s a handful of common computer platforms were available.

The current state of bipedal walking robots resembles the early days of computers from a standards and common platforms perspective with different labs each having their own "home brewed" robot that can only run that labs' algorithms. Today we are seeing companies like Honda, Sony, and Fujitsu producing bipedal robots for sale. These robots, or their descendants, may become common platforms for bipedal robot researchers. Only time will tell whether a robust market exists for the robots and they become feasible common platforms for researchers.

5 Competition

Competition helps drive any scientific endeavor. While every scientist has some innate desire to be the first in the world to discover something, well-known problems can often help to focus and drive researchers. For example, in computer science, there is the outstanding problem to prove whether or not "P=NP", i.e. whether there exists algorithms that can solve a certain set of problems thought to be hard to solve efficiently on standard computers. There will be much glory to the person who firsts solves this problem. Competition in the market place also drives technology. It is hard to imagine Moore's Law, which speaks of the doubling of computer power every couple of years, without also having the corresponding capital infusion required for microprocessor fabrication. This process is only economically feasible due to the vast demand. Since the markets are only interested in the latest designs and features, market competition drives advances in many areas of computer science.

In the area of bipedal walking robots, there has not been much discussion or consensus on what the relevant problems are. Just about every researcher has taken a different approach to the problem, some focusing on stability, some on efficiency, some on speed, some on biological similarity, and some on mathematical provability of performance. Different criteria are applicable for different reasons. Since there is not an agreed upon set of problems, there does not seem to be a common drive by researchers to be the "first to do X", where "X" is a common task. As far as market competition for bipedal walking robots, it seems that there is a bit of a race between Sony, Honda, Fujitsu, and others to produce bipeds for both entertainment and research venues. Only time will tell if either of these markets exist and if they are large enough to drive progress.

6 Recommendations

We see that there are some major differences between computer science and bipedal walking research that can be cast in terms of some of the hallmarks of science presented above. We now look at each of these hallmarks and examine what can be done in each case to help speed progress in the field. In some cases, the individual researcher can change his or her own work methods to help drive the progress of the field. In other cases, concerted efforts among a number of researchers are needed. And finally, in some cases, world economical factors, hard to influence by any given individual, are important.

6.1 Killer Applications

It is difficult to force killer applications. While we can try to push applications, their final acceptance or rejection must come from the end user, i.e. the customer. Having some "Market Pull" instead of a pure "Technology Push" is often a very important factor in determining the rate of progress of a technology. This is perhaps an aspect that individual researchers have very little control over. However, there are a few things an individual researcher can do:

- Try to envision new short term uses of bipedal robots. While bold "blue sky" applications such as fighting wars or caring for the elderly are important for long term research funding, short term markets demand applications that can happen today.
- Try to envision uses of technologies that are related to humanoid robots or contain technical aspects that need to be developed for humanoid robots. These side uses may have enough value that funding humanoid research itself can be justified by the side applications.
- Think of how basic research in bipedal walking robots can benefit other partially related fields. For example, walking algorithms may be important in powered orthotic braces, human biomechanics studies, and functional electrical stimulation walking.

6.2 Replication and Validation

With the current means of reporting work on bipedal walking robots, it is very difficult to reproduce and validate other researchers work. The major recommendations in this area are therefore related to better information dispersal including the following:

- Make source code for algorithms and tools that are not part of a commercially available package available online.
- Make algorithms that are used on a custom robot also work in simulation when possible so that others without access to the robot can reproduce and modify the simulations.
- Put design specifications and drawings for custom robots online.
- Use common robot and simulation platforms whenever possible. Use commercially available platforms when they are sufficient for the algorithms to be performed.
- Strive to make an algorithm work on a number of different robot platforms (especially in simulation) to demonstrate the fundamental aspects which are applicable to a number of different platforms.

6.3 Standards and Common Platforms

Standards and common platforms will make replication and validation easier and will also allow for more people to engage in the field due to mass manufacturing cost reductions. Standards and common platforms can be developed by corporations, by groups of researchers in the field, or by collaborations between the two. Some common platforms are already being developed. The following are recommendations for researchers in the field for promoting standards and common platforms, and for making sure these platforms are suitable for their needs:

- Communicate with companies that are developing research platforms to make sure that the features you desire for your research are available in the platform.
- Determine where it is difficult to reproduce other's work due to the lack of standards, and then engage the community to develop the necessary standards.
- When standards and common platforms are available, try to use those standards and common platforms if they suit your needs.

6.4 Competition

Market competition is up to the corporations and the markets. This paper has the humanoid robot researcher in mind and therefore this section focuses on what the individual researcher or the research community can do to promote competition in the field. Of course, for some, the competitive pressures of publishing are enough. However, the following are some recommendations for encouraging competition:

- Compete in robotic competitions such as the FIRA Humanoid Robot Soccer Tournament.
- Develop common problems and success criterion for various bipedal walking tasks and sub-problems. In communicating your work, clearly state what the task or subproblem is and what a measure of success is so that others can try to extend your work and make improvements that can be measured with that measure of success.
- Suggest other problems with clearly stated measures of success that other researchers could attack.

7 HuroSot/FIRA

We see that there are several areas in the bipedal walking research community that can be improved by focusing on some of the hallmarks of science. Robot competitions such as the FIRA games help promote the incorporation of these hallmarks into a research community.

One aim of the FIRA games, as stated in the FIRA bylaws, is to "promote the developments in autonomous soccer robots and intelligent systems." In terms of the cornerstones of successful scientific endeavors, we can examine how the FIRA games, and other competitions like it, can help advance the field of humanoid robots.

Killer Applications Competitions such as the FIRA games help promote the entertainment markets of robots. We are now seeing heavily viewed television shows, such as Robot Wars and Battlebots emerge. Perhaps advanced robot competitions such as the FIRA games will encourage the development of television programs and entertainment venues that are geared towards more advanced robots.

Replication and Validation Competitions such as the FIRA games encourage replication of algorithms that have proven successful for other competitors. By having many

teams try those algorithms, validation occurs and perhaps even collaboration by researchers who discuss improvements on the algorithms.

Standards and Common Platforms Competitions such as the FIRA games encourage, and even sometimes require, the use of common platforms. This is partially to make sure that the competitions are fair and also to simplify the rules and administration of the games. The games provide common problems, while the success of a team is a form of evaluation criterion.

Competition Obviously, competitions such as the FIRA games promote competition in the field. They also may promote competition in the marketplace, as corporations that provide the platforms for the competitions will benefit from free development work on their platforms. The corporations therefore have a competitive pressure to produce platforms that can compete successfully in the games.

8 Summary

It can be useful for scientists engaged in a scientific field to occasionally take a step back and examine the process in which they, and their research community, engage in the scientific method. Now is a good time to make this examination as this year marks the introduction of the humanoid soccer league (HuroSot) to the FIRA games. These games should help increase the productivity of this scientific community as they encourage refinement of some of the cornerstones of successful scientific endeavors.