Personal Robots: A Personal Computer Industry Perspective

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I. Introduction

We view Domestic and Professional Service Robots, or Personal Robots, as a potential extension to the Personal Computer market. Personal Robotics could be an engine of economic growth for the computer industry, and the entire U.S. economy. Achieving this, however, will require coordinated effort among academia, government, and industry. The U.S. is a leader in software, information technology, and semiconductors, and should make use of its leadership in computing to take a leading role in Personal Robotics as well. Companies such as Intel can contribute by creating products, standards, and technologies that will help enable a Personal Robotics ecosystem.

II. Promising application areas

Intel, together with partners such as the Center for Aging Services Technologies, the State of Washington, and the Veterans Administration, is investing in R&D to create technology to support aging in place, allowing elderly people to live in their own homes longer, rather than in assisted care facilities. One of Intel's five business groups, Digital Health, is focused on this application space. Much of Intel's aging-in-place R&D investment to date has been in sensing and inference techniques that do not require substantial actuation: for applications such as remote monitoring of elders' Activities of Daily Living, and medication compliance monitoring. The natural extension of this effort is to add robotic actuation, either autonomous, tele-operated, or hybrid. Together with the CMU / University of Pittsburgh Quality of Life Technology Center Active Home Program, we are working on mobile manipulation systems that can provide physical assistance to elders at home (such as picking up dropped items from the floor, bringing medication at the required time, meal preparation and cleanup), moving far beyond the initial passive monitoring and reminding schemes.

Other promising Personal Robotics applications extend existing Personal Computing market segments, for example gaming. Recently custom input devices for gaming have emerged (such as the custom guitar in Guitar Hero, or the Wii Fit exercise board). We believe that robotic gaming, using custom actuation as well as sensing, will become an important application category and market segment (and open possibilities beyond today's gaming haptic input devices). Another example of Personal Robotics applications that extend Personal Computing applications is physical inventory management. Currently barcodes and RFID are used to synchronize electronic database records with physical objects in industrial settings. Because of the limited range and field of view of these technologies, the physical / digital link can only be established at particular choke points, such as a loading dock door, where RFID readers are commonly mounted. Mobile manipulation systems promise to generalize and extend current inventory management systems to the point that they could be applied cost effectively in natural settings such as homes. A robot could regularly monitor inventory in unstructured environments like kitchens or nurse's stations. The physical / digital link would be continually refreshed by a robot examining the inventory, with the need for RFID or barcode-reading "choke points" eliminated. Perhaps most importantly, such systems can not only monitor the inventory, but retrieve or replace items. These capabilities could produce a "tidying bot," which systematically returns items such as books and toys to pre-defined "tidy" positions, or fetches desired items. A "re-stocking" bot is another natural extension: the first step is to detect that some supply is depleted; the next is to re-order the supply (from an online supplier, perhaps) and then re-stock that supply when it arrives.

An already well-considered class of Personal Robotic applications are those in which dirty, dangerous, or dull human manual labor is replaced with computing and robotics. There are numerous applications, such as cleaning, in this class, but they are well known and need not be listed here.

In a final analogy with Personal Computing, we believe that Personal Robots will do some jobs in homes that no one does today, because they cannot be performed cost effectively. Personal Computers (in particular word processing / desktop publishing) allowed the production value of typical home and business documents to rise drastically, to level that was not economically feasible previously. Personal Robots will likely be used to perform personally expressive, non-utilitarian tasks such as peeling grapes, ornately decorating cakes and other food items, cooking with highly complex and precise recipes, cutting paper into complex shapes, making elaborate sewing or embroidery, or performing music, that might in principle be performed by humans, but rarely are because the cost would be prohibitive.

III. Critical research challenges

We believe that the critical research challenges for Domestic and Professional Service Robotics are

1) **Sensing and perception:** the laser rangefinder drastically simplified and advanced robotic navigation. We believe that this sensing technology, and other new sensing technologies (not necessarily modeled on human perception), have the potential to similarly simplify and advance manipulation. Regardless of the correct solution, the problem of extracting spatial information is crucial for both manipulation and mobility.
2) **Representation, reasoning, and planning under uncertainty:** Computing speed has risen enough that planning can now be applied to problems of realistic size, and can be executed "in the loop," fast enough that re-planning can occur in real time as new sensor data arrives. The successful DARPA Urban Challenge clearly demonstrated the feasibility of this approach.
3) **Manipulator hardware:** The scarcity of manipulator hardware options, and the relatively slow pace of innovation in manipulator hardware, is a substantial limitation for the field. The design of the leading commercially available robotic manipulator, the Barrett Hand, has not changed in about 10 years.
4) **Indoor navigation:** Indoor environments provide new challenges to mobile robots. These environments are filled with clutter, from moving objects like people to movable objects like furniture, and other impediments like staircases and doors and cabinets that require active physical interaction. While there are promising initial solutions, their practicality must be further explored.
5) **Mobile manipulator cost reduction:** The cost of a platform capable of mobile manipulation is still extremely high. Reducing the cost sufficiently will require more than ordinary market mechanisms. Innovation will be required. It may be that improved computing and sensing can allow less stringent actuator specifications.

IV. Viable solution strategies

In several cases above, the statement of the research challenge suggests a viable solution strategy: for example, increased government funding and academic research attention should be devoted to manipulation sensing, hardware, planning, and control. Certain meta-strategies in the research community will help too: standardizing on a robotics framework such as Willow Garage's ROS will improve research efficiency, and accelerate the growth of a robotics ecosystem, by reducing the need to re-implement well-researched functionality. In the near future, there will be a crucial requirement for industry to devote additional resources to maturing robotics software and hardware standards. Just as the Personal Computing ecosystem was incubated from its early days by government funded academic research, and then thrived and grew by industry imperative once a certain level of size and standardization was reached, the Personal Robotics ecosystem can expected to follow a similar trajectory.

Currently Personal Robotics is at a critical developmental stage where substantial government-funded academic research is required, but industrial opportunities are beginning to appear. The revenues of iRobot, arguably the first Personal Robotics company, were greater than $100M in 2005 for the first time. This revenue milestone corresponds to Apple Computer in 1981 and Microsoft in 1983. A difference between the Personal Robotics industry of 2008 and the Personal Computing industry of the early 1980s, however, is that fundamental research questions, in areas such as perception, still limit Personal Robotics. Furthermore, certain enabling products that Intel or other industrial partners could supply are still missing, such as robot control "system on chip" ("SoCs" combining computing, analog I/O, and fast digital communication), wirelessly powered sensors to reduce manipulator wiring burden, and low latency video codecs to support teleoperation.

In addition to enabling products, Intel can also help create and promote standards for robotics when appropriate, as the company has in the case of USB, WiFi, and numerous other successful computer industry standards. Part of the value of the workshop for the Intel participants would be to gain a better understanding of the optimal moves Intel could make to help accelerate the formation of a Personal Robotics industry. We believe that government, academic, and industrial partnership can solve the remaining problems and turn Personal Robotics into a robust engine of economic growth for the nation and the world.[1]

[1] Disclaimer: The views expressed in this document are those of the authors, and do not necessarily represent the views of Intel Corporation.