The Future of Robots

Rodney Brooks

MIT Artificial Intelligence Laboratory

Academic work on behavior-based robots in the 1980's is just now being realized in applications for robots in remote and dangerous locations, and for robots for the home. The first part of this talk will outline how these applications are being developed. In the 1990's a number of research institutions turned their attention to building humanoid robots. At the MIT AI Lab we concentrated on social interactions between such robots and people. The second part of the talk will describe this research and then speculate on what sort of applications there might be in the future for such robots.

Until the mid 1980's mobile robots were very slow. They all used a sense-model-plan-act cycle. While stationary they would sense the world in some way (e.g., The Cart at Stanford took nine images for nine-eyed stereo, while Hilare at Toulouse scanned its world with a rotating laser beam). This data would then be used to build or augment a two or two and a half dimensional model of the world. Next a planner would be applied to the world model, searching for the shortest or best path to a goal. Finally, using dead-reckoning, the robot would move perhaps one meter, then stop again to sense the world - the limiting factor in its motion being the combination in the uncertainty in the world model it built and the uncertainty in the dead-reckoning control of its motion. None of the robots at the time were able to deal at all well with dynamic environments where other objects were moving in the world.

While mainframe computers were much slower than even the cheapest PC today, it still seemed that such robots were not able to operate anywhere near as well as an insect in a much more complex environment, and with possibly similar levels of computation available. In the late 1980's a number of reactive approaches were developed where robots with very little onboard computation were able to move about in office environments amongst people moving about, and at speeds comparable to a slow walk. The key idea was to stop trying to build a complete world model, but instead to use the world as its own model, but with very short computational that extracted just the necessary information from the world in order to make a simple motion.

For instance, a robot with side looking and forward looking sonars could navigate through the corridors of an office building by moving left or right, with plenty of damping, to try to equalize the distance reported by the sensors on each side, and by rotating in place whenever the front-looking sensor detected something close by in front of the robot. These simple to compute rules let a robot run down the middle of corridors, even skirting around objects stacked against the walls, and finding a new direction at the end of a corridor. This reactive strategy could then be augmented with fairly simple higher level systems which gave a purpose to the robot.

Strategies such as this were developed initially at SRI International and at MIT, but later were adopted by many research groups around the world. At Carnegie-Mellon

University neural based strategies similar in basic underpinnings were eventually used to automate driving cars on freeways. Eventually these approaches were augmented to what is now known as "behavior-based approaches" where many simple behaviors compete for control of the robots. This has been the basis for many projects in Artificial Life where robots have been used to investigate evolution and learning.

After many use of development robots based on these principles are finally starting to be developed for practical applications. Robots that have reached the market in the last three years have included:

- lawn mowing robots,
- home floor cleaning robots,
- robot dolls,
- oilwell maintenance robots,
- commercial cleaning robots,
- museum tour guides,
- military reconnaissance robots.

Each of these applications has required many innovations beyond the original behavior-based approach, but all of them rely on that at core. Some of the new innovations include mapping techniques, local navigation, emotional models, human-robot interaction capabilities, and self-diagnostics of robot health.

Over the last ten years there have been a number of new developments in building robots with human form that are able to interact with people in human-like ways. Much of this work has happened in Japan, but there has also been significant work in North America and Europe. Many of these humanoid robots use the behavior-based system at their core. Additionally there have been many innovations in a number of areas:

- new methods for bipedal walking
- models of the human visual system including
  - saccades,
  - vestibular-ocular reflex,
  - smooth pursuit,
  - stereo from vergence,
  - body centric coordinate systems,
- natural speech interaction including prosody detection,
- emotional models based on the human amygdala,
- emotional displays through robot facial expressions,
- social turn taking.

With these capabilities humanoid robots are able to interact with naïve people who have not been informed about how they should interact with the robot.

What are the applications for such robots. Some argue that they will be ideally suited to provide companionship and nursing care to elderly people. Others claim that since human houses have been built to accommodate people with human form, then robots with human form will most easily be adapted as home robots. The range of possible applications for humanoid robots is quite large, but it may turn out that we do not really need or want them in our lives. We may be happier to accept simpler robots that can carry out mundane tasks for us, rather than wish to accommodate an intelligent emotional species of robot into our lives.