RoboVac and the Cat Will Get Along Famously*

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Abstract

The first robot vacuums might be realized sooner if their designs sacrifice some efficiency for robustness achieved by persistence, and if they can expect reasonable co-operation from the household. In many houses, there are times when each room is unoccupied long enough to permit its being vacuumed without disrupting normal family life. Sacrificing sophistication to achieve minimal competence earlier, RoboVac version 0.0 might operate only in "vacuum-proofed" houses. Similarly, early versions of RoboVac need not sweep the room with maximum efficiency if the room is vacant for reasonable stretches of time. Over time, RoboVac should increase its efficiency by learning the house layout and the best times to clean each area.

Keywords: robustness, persistence, increasing sophistication and efficiency, physical interaction with inanimate objects, interaction with other agents (humans and animals).

Introduction

The first robot vacuums might be useful even if they use simple strategies and clean with suboptimal efficiency. In many houses, there are times when each room is unoccupied long enough to permit its being vacuumed without disrupting normal family life. Humans and house pets are likely to absent themselves from the room being vacuumed. (Have you ever seen a cat stay in the same room with a running vacuum cleaner? A dog may try to play with the machine, but such a dog is likely able to avoid injury. RoboVac can "discourage" play by being a boring playmate.) Also RoboVac can seek out unoccupied rooms to clean. RoboVac version 0.0 need not necessarily be able to operate in rooms with fine antiques and crystal. Might not people be willing to "vacuum-proof" their houses in order to avoid the chore of vacuuming? (However, RoboVac would have to cost less than a housekeeping service or otherwise be more desirable than existing alternatives.) Similarly, early versions of RoboVac need not sweep the room with maximum efficiency if the room is vacant for long stretches of time. It must merely continue vacuuming until the room is reasonably clean. If a room is vacuumed with sufficient frequency (for example, every couple of days) then a little skip is hardly of concern unless it is missed consistently. Over time, RoboVac should be able to learn a map of the house and each room to reduce its vacuuming time, but it should retain the plasticity to handle rearranged furniture.

Robustness, Robustness, Robustness

A robot vacuum must be robust. Being robust might be operationally defined as not being annoying to the people where RoboVac is used; the job gets done with minimal intervention from operators. Robustness does not require that RoboVac never get stuck in a corner, but it should get out eventually. In other words, RoboVac needn't be incredibly intelligent if it is persistent enough to succeed in a reasonable amount of time. We must be careful not to be too impatient with a system simply because we humans may see an immediate solution in a particular situation. If the system will accomplish the task when it is left alone for a reasonable period of time, then that is sufficient for a start. (One counterexample is cleaning up after a party, when the mess may be large and patience in short supply, but the solution may have to be manual touch-up cleaning.) Over time, the system should gain efficiency as it learns its environment. It is more important that the floors get vacuumed than that RoboVac behaves cleverly after pondering the situation at length.

One path to robust performance of RoboVac in the real world is persistence. Rather than having RoboVac use clever strategies that attempt to guarantee success, it may suffice for RoboVac simply to detect whether it has accomplished some small task if it persistently attempts to achieve the result. This point is nicely illustrated by the example of an African wasp that drags its prey into its burrow for processing. The wasp hauls the paralyzed prey to the opening of the nest, enters the nest to make sure the way is clear, and returns to

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check the prey. If the prey has not moved from its resting place, the wasp proceeds to haul the prey into its lair. However, if the prey has moved, the wasp stings the prey again and repeats the drag-inspect behavior. A malicious god could starve the wasp to death by moving the prey every time the wasp inspects its burrow. The wasp survives despite this feature of its behavior because its world is not excessively adversarial. Similarly, it is sufficient in the early stages for RoboVac to accomplish a job in a suboptimal fashion by persistent simple attempts. For instance, consider a millipede traversing a pile of rocks by a woodland trail. The millipede apparently travels in the direction that it wants to take. When it encounters a precipice, it searches to the sides for passage. A patient observer may find the millipede attempting the same impassible route several times in several minutes. Nevertheless, the millipede's persistence and nondeterministic behavior eventually lead it to a navigable route. A similar approach may be needed to make early progress in achieving robust behavior in RoboVac's complicated and unpredictable world.

Simple Strategies

Some simple strategies may suffice to get RoboVac operating initially, since there are some simple constraints that can be exploited. For instance, it is more important for RoboVac to adequately clean open areas that are easily negotiated than to reach into every corner. Most traffic occurs in open areas, so most of the dirt and matted carpet that vacuuming is intended to treat is in areas that are easy to reach. Even if RoboVac could handle only open areas on a daily basis, that would be helpful since only the corners would have to be cleaned manually. Corners could be cleaned less frequently, since they essentially only collect falling dust. High traffic areas present a problem for an inefficient vacuum since they are probably traffic bottlenecks, and yet ideally they would be cleaned daily. The problem with cleaning high traffic areas at night is that most vacuums are so noisy that they would disturb sleep and other quiet activities. The problem with cleaning these areas during the day is that by their nature these areas are seldom unoccupied for long periods. There are a few obvious strategies. One approach would be for humans to signal RoboVac when it would be a good time to clean high traffic areas. This is similar to starting the dishwasher when its noise will not be disruptive. This allows the occupants to tell RoboVac to vacuum these areas when they leave the house to run errands or work outdoors. Nevertheless, RoboVac will undoubtedly find itself in the path of people passing through a traffic area it is cleaning. A simple strategy for RoboVac to minimize interference with human activities is for it to freeze whenever someone approaches. RoboVac must be small enough that people can get around it. If RoboVac notices frequent passage of humans it could at least hug the wall until the activity subsides. A simpler approach would be to add another signal to RoboVac to tell it to keep clear of traffic areas for a while. This would need to be used only when RoboVac happened to be in a busy traffic area, so it could be a simple "suspend" button.

Stairs are among the areas that are most heavily trafficked and probably least often vacuumed. Stairs present an interesting problem for vacuuming. Ideally they would be vacuumed daily, like other high traffic areas, and they are difficult to vacuum. On the other hand, stairs are traffic bottlenecks. Further, it is a significant challenge to design a machine that will climb and descend the stairs and vacuum them even without interference from human and animal traffic. The problem of traffic in the stairway bottleneck is similar to the problem in other high traffic areas, but it is arguably more severe since space is limited and people are more likely to be poorly balanced on stairs than on flat floors. Again, RoboVac would have to freeze when it encounters people moving nearby. The machine might be made small enough to permit people to step around it, but another approach would be to design the machine such that people could step *on* it to pass. In either case, it is critical that RoboVac should be stationary in such situations to avoid tripping or unbalancing passersby. Thus, early versions of RoboVac might be forced to omit handling stairs entirely or at least in traffic, but it should be a high priority to tackle stairs since the gain would be substantial.

Progressive Sophistication

We should expect there to be a progression of solutions of increasing sophistication, from working only in "vacuum-proofed" houses to "delicate" environments that include antiques and crystal on display. The first RoboVac will probably not cope with toys and clothing cluttering the floor. If people want an early version of RoboVac, they may have to keep their houses especially tidy. The problem of floor clutter is a bit tricky. The handling of moderate sized rigid objects may yield to simple "cow-catcher" solutions. However, small objects (*e.g.*, snap-together building blocks, toy soldiers) will probably be very difficult to detect and clear away before vacuuming. Small articles of clothing should be easy grasp and pick up, but they may be difficult to spot. Blankets and other large cloths may be very difficult to handle with a gripper, but perhaps a "spatula" manipulator would enable RoboVac to move them. Large heavy toys (*e.g.*, tricycles) will be difficult to handle; they may have to be treated like furniture.

Furniture itself presents a dilemma. Ideally RoboVac would understand how to move furniture in order to vacuum under it and to replace the furniture near its initial location but offset a little to move the feet to new spots in the carpet. However, the necessary capabilities would probably make RoboVac large and cumbersome. An alternative is to use human power to move the furniture either in cooperation with RoboVac or independently. RoboVac would have to be very sophisticated to make effective use of a human helper who is moving furniture while RoboVac cleans. It seems better to have the humans nudge the furniture around occasionally. However, this presents no way for RoboVac to reach the floor space beneath a piece of furniture. A good example of this problem is the dining table. If children eat at the table, there are likely to be crumbs on the floor underneath it. (Crumbs may not remain there long if there is a dog in the house, but this suggests an alternative solution.) Therefore it is important to clean under the table regularly, but the chairs present obstacles. The solutions involve either moving the chairs as a human would, or following the dog's example, managing to reach around the chairs without moving them. For this purpose, RoboVac might be equipped with a remote vacuum head, flexible like an elephant's trunk, or rigid like an anteater's snout, with a simple brush spinning in the end to beat particles loose. This device should also handle cleaning along walls and corners, and it might suffice to clean near and even under large furniture like sofas and beds. In the absence of such a snout, the cleaning could be accomplished if the chairs where pulled away from the table after the meal so RoboVac could move under the table. It seems clear that early RoboVac versions will require furniture to be moved by humans to allow more complete cleaning.

In addition to expecting successive versions of RoboVac to display increasing sophistication, RoboVac should exhibit greater efficiency as it gains familiarity with its environment. The earliest version of RoboVac might merely randomly traverse each room, inefficiently covering the space over time. However, RoboVac could increase its efficiency over time by learning the floor plan of the house and the layout of each room. RoboVac might collect data while it goes about its inefficient vacuuming in each room, slowly and incrementally building a map. Perhaps the map will grow only slowly, expanding the edge of each map that seems to be solid. Time consuming data aggregation, fusion, and reorganization can take place during natural quiescent periods such as while RoboVac recharges its batteries. In the early days, RoboVac will not know the layout of each room, and it will have to resort to brute force or random methods of covering the space. As RoboVac's map improves, it can plan its attack on each room. Understanding doorways will allow it to hypothesize traffic patterns to identify areas that should be vacuumed frequently. Similarly, the house layout can be learned over time, connecting the rooms and understanding traffic paths. With a clock, RoboVac could learn what times of day particular rooms, halls, and stairs tend to be vacant, and it could learn good and bad times to work in particular areas by remembering when it has been encouraged to vacuum (by command) or discouraged from vacuuming (by traffic or command) each part of the house. A sophisticated RoboVac might actively control its learning, interleaving exploration and "thinking" (*e.g.*, planning new explorations, analyzing results, synthesizing new maps). Learning should continue perpetually, resulting in automatic recalibration over time. This will cope with furniture being moved, additions to the house, and changing patterns of room usage.

Human RoboVac Interaction

Human operator intervention should be minimal and reasonable. For example, the operator would empty the vacuum's dust bag. RoboVac should have a docking station where it can recharge its batteries autonomously, but the operator could be expected to lead RoboVac to the docking station occasionally when RoboVac gets confused and loses its way. Over time, RoboVac should get confused less often. RoboVac should expect a reasonable level of cooperation from the occupants of the house, but it should be prepared for some playfulness as well. If RoboVac's response to moving objects is freezing, it can expect people to "tease" it, standing still when it stands still and then moving when it resumes work. RoboVac should also be prepared to endure some curious probing. A dog that would play with RoboVac could probably be expected to keep itself from injury. Infants present a situation that requires more care: the best policy is probably to shut down whenever someone is near. This would require everyone to leave RoboVac in privacy to resume its work, but that seems a reasonable price for additional safety.

Early versions of RoboVac might include some explicitly programmed policies or strategies, such as working in rooms when they are unoccupied. As a corollary, we might expect it to clean living areas at night and sleeping quarters during the day. In the absence of learning capabilities, or as a bootstrap for such learning, a human might give the robot a tour of the house, naming each room whenever it is visited, and identifying times that might be preferable or undesirable for its cleaning. This could allow RoboVac to build a simple map of the house. Later, if RoboVac gets too confused to find its dock, it could display a house layout map and ask a passing human to point out its current location and orientation. Of course, this feature could offer fun for mischievous children of all ages. An early (and possibly expensive) installation option could be to measure the house layout and explicitly present it to RoboVac, but this could be tedious except in tract housing developments.

Conclusion

In summary, the first robot vacuums might be realized sooner if their designs sacrifice some efficiency for robustness achieved by persistence, and if they can expect reasonable cooperation from the household. Conflicting goals must be balanced, and early versions of RoboVac might achieve minimal levels of competence earlier by postponing tackling some hard problems such as operating in fragile surroundings. This brief analysis suggests that constraints exist that can be exploited to bring a simple RoboVac into operation in the near future.