



## Robots in the kitchen: Exploiting ubiquitous sensing and actuation

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### abstract

Our goal is to develop intelligent service robots that operate in standard human environments, automating common tasks. In pursuit of this goal, we follow the ubiquitous robotics paradigm, in which intelligent perception and control, are combined with ubiquitous computing. By exploiting sensors and effectors in its environment, a robot can perform more complex tasks without becoming overly complex itself. Following this insight, we have developed a service robot that operates autonomously in a sensor-equipped kitchen. The robot learns from demonstration, and performs sophisticated tasks, in concert with the network of devices in its environment. We report on the design, implementation, and usage of this system, which is freely available for use, and improvement by others, in the research community.

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### 1. Introduction

We aim to develop intelligent service robots that operate in standard human environments, automating common tasks. To date, the research community has focused primarily on self-contained, stand-alone robots that would act autonomously in unmodified environments. The goal is to enable a robot to do, like humans and other animals do, all sensing, deliberation, and action selection on board. We advocate an alternative path to competent robotic agency, known as ubiquitous robotics, that combines intelligent perception and control with ubiquitous computing [29,23].

Computing is ubiquitous when computing devices are distributed and embedded invisibly into the objects of everyday life. These devices sense their environment, connect automatically to each other to form sensor networks, exchange information, and act to modify their environment. They range in complexity from simple, embedded sensors, to traditional autonomous mobile robots. For example, in a sensor-equipped kitchen, cupboards “know” what is inside them because objects are tagged with RFID (Radio Frequency Identification) tags, and cupboards are equipped with RFID tag readers. A robot whose task is to deliver coffee mugs could benefit greatly from access to information about the cupboards’ contents.

If we consider the future of service robotics, it seems likely that service robots will be competent, and versatile agents in

sensor- and effector-equipped operating environments, rather than autonomous and insular entities. This is the basic idea of ubiquitous robotics. Following this paradigm, a robot can connect to the sensing and actuation network of its operating environment, and use the sensors and actuators, as if they were its own.

Ubiquitous robotics is a promising route to achieving autonomous service robots, because sensor and computer networks can substantially enhance the robots’ perceptual and actuation capabilities in important ways.

- Special purpose sensors Rather than relying on general purpose sensors such as cameras and laser scanners, sensor networks allow for the definition of task-specific sensors. Using RFID tags and readers and acceleration sensors for objects and hands, sensor networks can detect force-dynamic events such as an object being picked up or put down. Or, using long range RFID tag readers in cupboards and under tables, the network can sense that objects that appear and disappear in the sensor range of particular RFID tag readers.
- Perception of high-level events with low volume data. The special-purpose sensors generate very low sensor data volume, and generate sensor events highly correlated with robot tasks, such as activity recognition. For example, the ubiquitous robotics system can recognize that people have breakfast by cups and plates disappearing from the cupboard, appearing shortly after on the table, and finally moving into the dishwasher [18].
- Understanding everyday activity. The sensors in the network enable ubiquitous robots to observe activities very reliably, and comprehensively, over extended periods of time. Activity observation can be at different levels of abstraction. The robot can recognize activities, by interpreting the appearance

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