L'evolved: Autonomous and Ubiquitous Utilities as Smart Agents

Harshit Agrawal*
MIT Media Lab
75 Amherst Street
Cambridge, MA 02139 USA
harshit@media.mit.edu

Sang-won Leigh*
MIT Media Lab
75 Amherst Street
Cambridge, MA 02139 USA
sangwon@media.mit.edu

Pattie Maes
MIT Media Lab
75 Amherst Street
Cambridge, MA 02139 USA
pattie@media.mit.edu

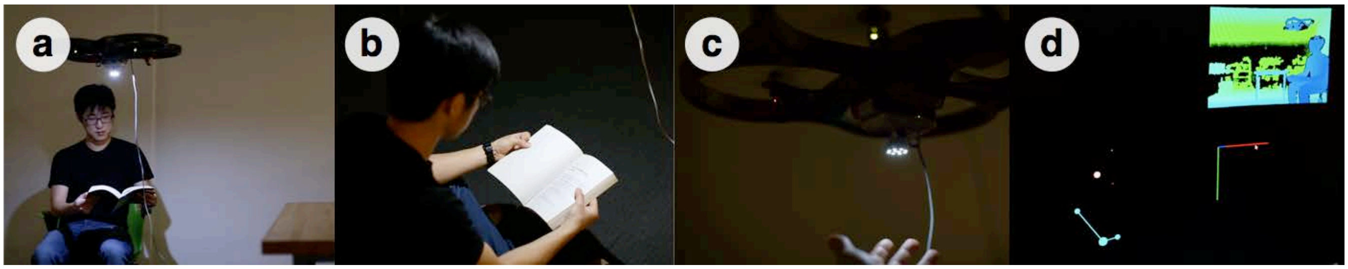

Figure 1: *L'evolved* lamp system. a, b) The lamp follows a user and lights up to help reading in the dark. c) Drone technology allows free 3D motion of the lamp. d) The user's activity in space is captured using a depth camera based tracking setup.

ABSTRACT
Ubiquitous computing has been focusing on creating smart agents that are submerged into everyday environments, however, recent development on physical computing is demanding a shift from calm computing to a physically engaging form. Computing is no more limited to increasing our comfort through passive and pervasive deployment, they can now be created as being more actively and physically intermeshed into our tasks. We present *L'evolved*, autonomous ubiquitous utilities that assist in user tasks through active physical participation. They not only dynamically adapt to individual user needs and actions, but also work in close tandem with the users. Among explorations on potential applications, we harness drone technology to realize the design and implementation of example utilities that afford free motions and computational controls. Through various use scenarios of those exemplary utilities, we show how this new form of smart agents promises new ways of interacting with our physical environments. We also discuss design implications and technical details of our implementations.

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Ubiquitous Computing; Actuated Furniture; Actuated Environments

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ACM Classification Keywords
H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen)

INTRODUCTION
Despite huge increase in computational power and machine learning technologies, UbiComp research has remained to providing contextual cues and assistances to users limitedly in digital format. To realize UbiComp's vision of providing computing power to people in real world contexts [26], we need to develop computational agents capable of engaging physically in spaces where our bodies belong.

Recent developments on physical computing hint the plausibility of moving 'engaging UbiComp' into physical spaces. Particularly, robotics technologies are migrating into everyday objects and environments, for example, moving furniture [2], shape-changing furniture [22], and as a more artistic example, self-balancing furniture [8].

To enable engaging physical UbiComp, it is required to appropriate such movements of physical computing that can allow much more direct collaboration with the users and improve their productivity and comfort. Formerly calm computing can now have a means of physical output through embedded actuation potentials within their existing physical design.

We present *L'evolved*, autonomous ubiquitous agents that transcend the notion of conventional static utilities to assist in our everyday physical tasks with higher level of physical engagement. By leveraging the capabilities of drones to freely move around in 3D space and be computationally controlled, we present a new paradigm of physical

* The first two authors contributed equally to this work.

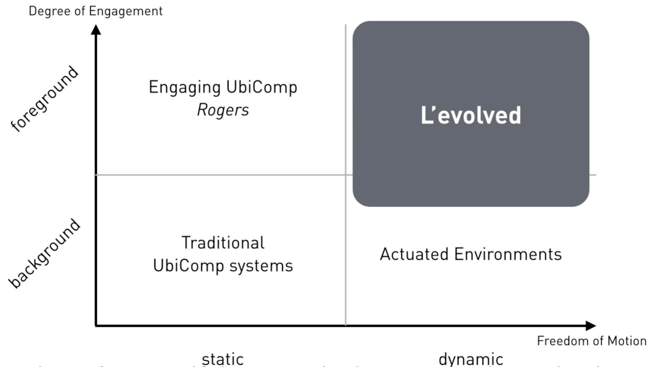

Figure 2: The shift in how ubiquitous computing assists in human task along with the trending physical computing paradigm hint an open space for *L'evolved*.

computing to make products that dynamically adapt to users' need without constraints in physical motion. More interestingly, they can play a more active role enhancing and extending our capabilities to perform activities otherwise not possible. These autonomous agents open up a new space of foreground physical interaction

In the rest of the paper, we discuss novel scenarios of both assistance and active engagement afforded by capabilities of *L'evolved.* We do this by highlighting various cases of deployment this new form of physical computing opens up. We discuss in detail the design implications of an engaging physical UbiComp, along with the design considerations, limitations, and potential improvements of the proposed implementation.

RELATED WORK

Our work draws upon UbiComp research and the work done in the field of actuated environments. As we touch upon the works in these fields, we talk about the previously unexplored space that is being addressed through *L'evolved*.

UbiComp: from Background to Foreground

A central aspiration running through the efforts of UbiComp research has been to make our environments and our possessions aware, adapt and respond to our varying comfort needs, individual moods and information requirements [20]. As a consequence, the main focus of the field was to create tools to make our environment smart by embedding sensing and computational capabilities in them [9] as is seen through examples [10][14][16][24] like *Smart-Its* [29] and *HomeBlox* [25]. Solutions like the *Nest* thermostat [7] and other commercial solutions [28] offer capabilities like auto scheduling and occupancy sensing to reduce physical and mental effort of users. All these solutions stemmed from Weiser's vision of calm computing [26], such that they tend to remain in the background with limited or no output capacity. Therefore, these cannot actively get engaged into the users' physical tasks and assist them in more direct and collaborative ways.

Technologies that come to the foreground and engage users in action also have been explored. Context-aware tools like *comMotion* [17] collect data to remind users to take an action like buying food when passing a grocery, which show how technologies can come to the foreground and move users into action. Part of what Rogers argues in moving towards a more engaged form of UbiComp [20] also has to do with technologies coming to the foreground and engaging with users actively. However, these engagements still remain confined in sending a text-reminder, resulting in a severe disconnect from our physical environments, even if it is to trigger a physical action.

Actuated Environments: Getting Physical

Past research shows an effort in actuating our environments to increase the possibility of adapting spaces to user needs. Larson et al used architectural robotics to enable a dynamically reconfigurable co-working space based on different contexts [2]. Srikanth et al used drones to actuate the working environment of a photo-studio and discussed how the drones help overcome traditional challenges that require expensive mechanical intervention and often a skilled assistant [23]. Sprowitz et al created *RoomBots* [4], which are reconfigurable robots for adaptive furniture. Their recent work [19] shows the use of natural gestures to command these robots, highlighting their attempt at making the agents more engaging. While these works proposed physical assistance by actuated environments or objects, they only assist in a passive manner, not coming to the foreground of interaction, therefore limiting their assistance to affording ease or comfort than active cooperation.

Foreground Physical Assistance

It is notable that little work has been done in the area of creating physically engaging smart utilities (Figure 2). Therefore, we explore this field of autonomous and ubiquitous smart agents by creating the *L'evolved* utilities. This is in line with the work done by Hoffman et al [15] where they talk about human-robot interaction as teamwork. We push that notion to a more physically capable and utility-based paradigm.

CASE1: LIGHTING

Lighting is one of the most ubiquitous and commonly used utilities. In this section we discuss how a lamp based on our physical computing paradigm can create lighting solutions that can adapt to changes in the user's physical actions. In addition, it can come to the foreground and actively guide the user's attention to points of importance based on computer-powered decision.

Context and Spatially-aware Lighting

Using the smart lamp utility we built, one is essentially disengaged from the issue of controlling light to match one's need. Through a simple smartphone application, a user can activate 'follow and light up' mode. Once the mode is enabled, given the freedom of quick motion, the lamp flies to the position of the user and turns on its light. From there on, it follows the movements of the user, allowing for free movements or posture changes while reading in the dark. This offloads the physical efforts of the user to configure the lamp each time he changes posture. (Figure 1)

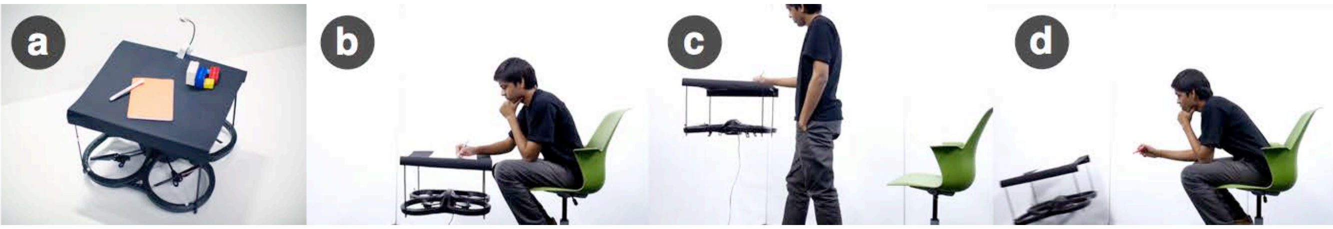

Figure 3: *L'evlovled* desk system. a) The desk is implemented using a drone attached to a desk surface. b, c) The desk adapts to a user's postures or walking direction. d) Auto-eject capability adds alarming or preventive function to the table.

Guide and Navigation

Our lamp also has the capability to move around and direct a user's attention to a certain spatial position and thereby assists in navigation or a search. For example, the lamp remembers the last location where the user stopped reading a book and switched off the lamp. Later on, the lamp can light up above the book to remind the user where it was left. (Figure 4) This is not only possible in static mode as in *Search-Light* [11], but could also be useful for guiding as a user walks around an indoor space. Therefore, based on certain information associated with coordinates in space, the lamp can guide the user to a certain location in a building, or notify the user when a place of interest is nearby.

CASE 2: FURNITURE

We look at a basic furniture element, the desk, which is another essential utility that enables a lot of tasks that we carry out everyday. However, the static and unresponsive nature of desks causes a lot of adaptation on a user's side. We show how such user's adaptation endeavor can be reduced through *L'evolved* desk, made as a cubic wireframe structure with Balsa wood covering over the drone. (Figure 3 (a))

Dynamic Pose Adaptation

The desk dynamically adjusts its position according to the user's movements. Therefore, the user can now easily shift between sitting and standing at work, thanks to the desk automatically changing its height. Along with its capability to conform to the user's posture, it can be programmed to keep changing height after a certain interval of time, thereby acting as a reminder mechanism to the user for healthier working habit. Also, the desk is able to move around with the user, enabling the user to walk and write simultaneously, thereby letting the user break free from the limitation of being static when working on a desk. (Figure 3 (b, c))

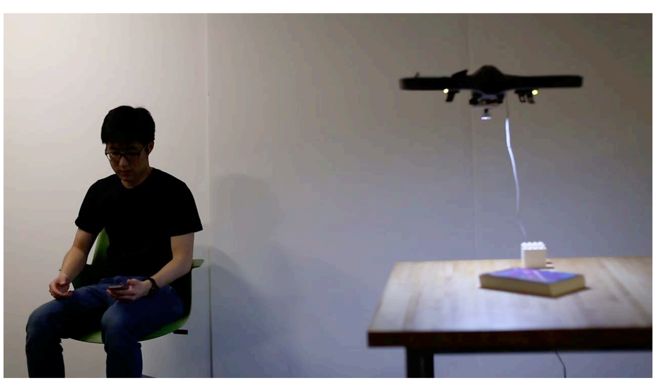

Figure 4: A lamp can direct a user's attention to a location or an object of interest. It can memorize the last location of a book the user was reading, and shed light on it

Auto-Eject

The responsive nature of *L'evolved* utilities to act in real-time enable design features like auto-eject. This mode is one where the desk moves away automatically after a person finishes a task or if the person is about to make incorrect moves. By tracking and identifying markers on pens, it is possible to exploit the user's context around a task with the pens on the desk. If the user puts away a pen, the desk automatically goes away based on the inference that the task is finished. If the user takes out the pen again, it comes back and adapts its position according to the user. If the user picks out a wrong pen, the desk flies away, auto-ejecting. Therefore, the desk can work in a very close tandem with the user, realizing a seamless and tightly coupled interplay between users and utilities. (Figure 3 (d))

Auto-Completion

Computational motion control of the desk can open up further design possibilities like auto-completing by the desk moving on a computed path when a person holds a pen over it.

CASE 3: DIGITAL APPLIANCES

Assistant Appliance

Digital appliance objects like an alarm clock or a hair-dryer can be redesigned with added physical capabilities. An alarm clock can be made not only to run or fly away to wake someone up [3], it can also make a person stretch their body to reach and switch the clock while kick-starting oneself. A hair dryer can move around with a user allowing to get disengaged from hair drying process, thereby offloading physical effort and focus while searching for clothes.

Autonomous Tool

Physically capable actuated appliances or tools can actively perform self-assigned tasks. Users don't need to pay attention or specify actions, but the appliances become proactive and carry out operations such as house keeping (robot vacuums), monitoring (autonomous surveillance drones), and so on. Such tasks can be designed to disengage from the users' context for short-terms, however, remotely integrated into everyday lives as a result of continuing active task completions.

PROTOTYPE IMPLEMENTATION

The system consists of two main parts - a ground control tower for tracking and fixing the position of drones in 3D

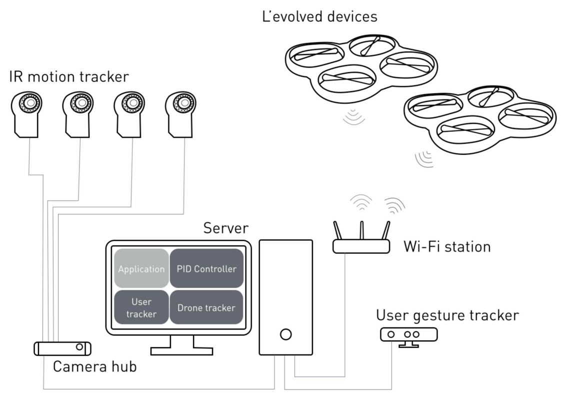

Figure 5: System configuration.

space and a human skeleton tracking system. The communications between the drones and the computer is done through Wi-Fi. (Figure 5)

IR Motion Tracking

We tracked the drones in 3D space by attaching retro-reflective markers, and capturing them with an Optitrack motion-capture system [6]. In the desk implementation, we use the presences and positions of different pens with different marker IDs to activate different desk modes as described previously.

PID Control

The coordinates of the drone in space are sent to a computer, the central processing hub running different applications and sending control commands to the drone accordingly. We used the Parrot Drone 2.0 [1] SDK through which we send (roll, pitch, yaw, propeller speed) input to move the drones towards a goal position in space. Current positions of the drones from the motion tracker are fed into a PID loop, and the control parameters for roll, pitch, and propeller speed are computed using final goal position and PID gain parameters. The gains for the PID were optimized for the desk and lamp scenario separately, as different attachments to the drone result in different weights and balances, requiring optimization accordingly. The software runs at 30 frames per second, with minimal latency.

This PID control system also benefits direct physical interaction with the table, as it provides additional stability once it is pressed away from its lock-in position. As a user writes, he automatically pushes the desk down, resulting in the drone trying to recoil back up due to PID control. This makes the desk stay more stationary, allowing high dexterity tasks like writing to be comfortable.

Tracking Users

Human position is tracked using a Microsoft Kinect Xbox 360. The Kinect tracks the skeleton of a user. From this, we extract the coordinates of the head and the arms of the user. This data is used to estimate the rough posture of a user and is fed to the PID control loop.

Physical Design Consideration

The design decisions were driven by the constraints defined by payload capacity (200g) and the aero-dynamics of the AR Parrot 2.0 drone. The most critical limitations of drones are their limited payload and battery capacity. However, we already witness existing products such as Cyphy [4] and Endless Flyer [13] for battery solutions and high-payload (up to 6kg) drones [5]. The drone need not be powered all the time; it could be designed to anchor while at rest. Also, our system allows controls of multiple drones in a simultaneous manner; therefore drones can share the payload to offer higher capacity in synergy.

DESIGN IMPLICATIONS

Physical Action Capability

L'evolveds are capable of physical action based on context sensing in real-time. The need of more direct task engagements of utilities makes the design of physically capable utilities plausible and necessary. This is shown in the desk prototype and scenarios presented in this paper as well as prior arts presenting actuated smart tools [18] [21] [27].

Shared Role – Co-Act, Act-First or Independent Agents

The leveling across foreground/background allows different styles of engagement. Utilities can co-act with users to complete a task, like lighting up required areas to help a user read a book on the go. They can also act-first and lead the interaction, guiding the users to initiate a new task. These utilities can also be totally disconnected with the users' context, working as independent agents performing tasks out of the users' immediate attention or presence.

Dynamical Role Change

L'evolveds can be reconfigured for and/or assigned a task role that a person needs. For example, as blocks of furniture element, different pieces can come together to form a table of needed size by sensing number of people in a physical space. The same desk could act as module for writing on, and could double-up as a self-writing desk at one point, moving below a pen held by a user. This is similar in spirit to the work of emergent Physical Displays [12] where self-organizing elements come together to form a display based on the environment they are in.

CONCLUSION

In this paper, we explored a potential research area and discuss its implications in UbiComp, through designing and implementing utilities that have the ability to move around in free 3D space, and to dynamically adapt to and collaborate with users. These utilities can physically participate in the users' tasks in various level of engagement between background and foreground of the users' consciousness. As a result, the utilities around in our physical spaces are no more passive tools that only we as users choose to utilize, but they become living entities that off-load our physical and mental effort in accomplishing tasks as well as being actively and collaboratively engaged within the tasks.

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