Towards Managing Consumer Energy Demand with the Aid of the Internet of Things

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Abstract: We present a system that may be used to control demand-side electricity consumption. The user interface, designed in consultation with the target group, is simple and well suited for developing regions. The underlying technology is sophisticated and designed to be incorporated into the Internet of Things. We describe the technology used and dedicate a section on the potential benefits of making consumer energy demand information available at regional and national levels.

Keywords: Internet of Things, energy demand management, fiducial.

1.   Introduction

Worldwide, the consumption of energy is fast reaching the point where resources cannot meet the demand. In addition, energy consumption is skewed to the developed regions. The United States of America hosts 4.5% of the world's population [1], but is responsible for 19% of the global energy consumption [2]. However, regions of low development such as Africa and India hold potential to surpass the developed regions as far as their combined energy consumption is concerned. This unfortunate potential is due to the increasing population growth rate in these regions.

Although technology is available to the user to control energy consumption, this technology is not necessarily appropriate to societies in developing regions. The appropriateness, or rather inappropriateness, of the application of some modern technology in developing regions, is discussed next.

Computer-based technology has a good penetration in the developed regions [4]. In these regions the general public is familiar with the operational design of computer-based technology, such as the requirement to navigate multiple layers of the visual menu to make a single change to the device's configuration. In contrast, the general population in developing regions interact mostly with technological devices that have a one-to-one representation between the operation of an interface and the outcome of that operation.

If compared with the technology available in developed regions, the interface structure that the general population in developing regions is used to can well be described as a 'flat' menu structure with only a single layer of options to choose from. An example of such a flat menu structure is that of a plough drawn by oxen in a plantation field. For each operation required to plough the field, the human-machine interaction model dictates that there exists a single corresponding interface that is dedicated to that single operation. An example of such an operation is the adjustment of the plough height regulator. When

comparing this interaction model to that used in the design of modern technology that is so prevalent in developed regions, one finds that a single interface is shared amongst multiple purposes. As an application example of the interaction model so often used in developed regions, consider how a modern home entertainment centre is configured in order to watch a movie from a specific video source: Configuring a modern home entertainment centre is usually done with the aid of a 'menu' and four 'selection' buttons that are used to navigate an on-screen menu. Only after having navigated multiple menu levels does the user get to the sought-after option. At this point the user indicates her preference by pressing another key usually named 'OK' to indicate the final decision to the underlying electronic system.

A user interface such as the one described for selecting a movie from a specific video source adds an unnecessary cognitive burden to the user. This cognitive burden is due to the mental image the user has to construct of the menu structure being navigated.

Children quickly acquire the skill of forming a mental image of the modern device being configured, but adults are in general not as fortunate. Children are very skilful at navigating the various menu structures once they have been mastered, even doing so without any feedback, visual or otherwise. An example if such accomplishment is a child operating a mobile phone under the desk in a classroom, clandestinely sending a message to a friend without ever looking at the phone.

These two examples illustrate the complexity people are exposed to when a designer has to craft a user interface for some new technology that will ultimately be deployed in both developed and developing regions.

Considering again the opening statement of this introduction, that is, that societies in developing regions have the potential to collectively consume more energy than developed regions currently do, then it becomes evident that making an effort to reduce this consumption is prudent. But, when considering the differences in the interfaces societies in the developing and developed regions are largely accustomed to, it is also evident that the same interface design approach will not be usable in both societies when adults have to be accommodated. We therefore propose an alternative interface for a user in developing regions, applied to the domain of end-user controlled electrical energy consumption.

Our aim with the preceding introduction is to illustrate the need for an appropriate energy control interface that is designed for adult users in developing regions. In addition to describing our user interface, we also motivate why the user interface has been integrated with the Internet of Things.

This paper is structured as follows. First we provide the objectives of this research project and the methodology followed. Next we describe the Internet of Things and its relevance to the project. This is followed by a description of the technology used. The next section provides information on how to use the system. We then give our research results, followed by the potential business benefits that could result if this system is implemented. We then conclude.

2.   Objectives

We had three objectives in conducting this research:

The primary objective was to empower an end-user in a developing region to control the on/off times of domestic electrical appliances.

A second objective was to empower a person, who is not familiar with multiple modern appliance menu levels and the accompanying mental load required to navigate these menus, to control electrical appliances. The aim was for a system that is simple to use; once the system has been installed, the user plugs an appliance into an electrical receptacle that has previously been mapped to a particular fiducial. The user is also free to create her own physical representation of the appliance and attach the fiducial to the bottom of this

creation. In our concept demonstrator we have simply glued pictures of appliances to the top of wooden blocks, and the corresponding unique fiducial to the bottom of the block.

A third objective was to integrate such a control mechanism with the Internet of Things so that data on electrical energy consumption could be made available to authorities to aid in regional and national electrical energy management.

3.   Methodology

The system consists of hardware and software components. Different methodologies were used in developing these components:

The spiral development methodology [4] was used for the software components of the research project.

Development of the human-computer interface required the identification of potential users, and group interviews with these potential users. Based on the outcomes of the workshops, we developed the final user interface.

4. The Internet of Things

The Internet of Things (IoT) [5] is ideal for developing systems that help manage end-user energy demands. By definition, the IoT provides almost continuous digital access to geographically dispersed physical objects. The use of physical objects to represent digital information has an advantage over other modern technologies, such as a flat two dimensional computer screen, in that the object can be both something handcrafted by the user, and be something familiar to the community. Handcrafted and familiar objects make for easy-to-learn user interfaces [6].

A passive physical object is integrated into the IoT by adding modern technology to it, either embedding the modern technology below the surface of the object, or attaching the modern technology to the outside surface of the physical object.

Examples of technology that could be embedded below the surface are active/passive radio frequency identification (RFID) tags, and near field communication (NFC) tags [7]. Examples of technology that can be attached to the outside surface of the physical objects are passive optical (fiducial) markers, and active optical markers. Passive optical markers may take the form of black-and-white markings on paper. Active optical markers may be light emitting diodes (LED's) that emit unique code sequences.
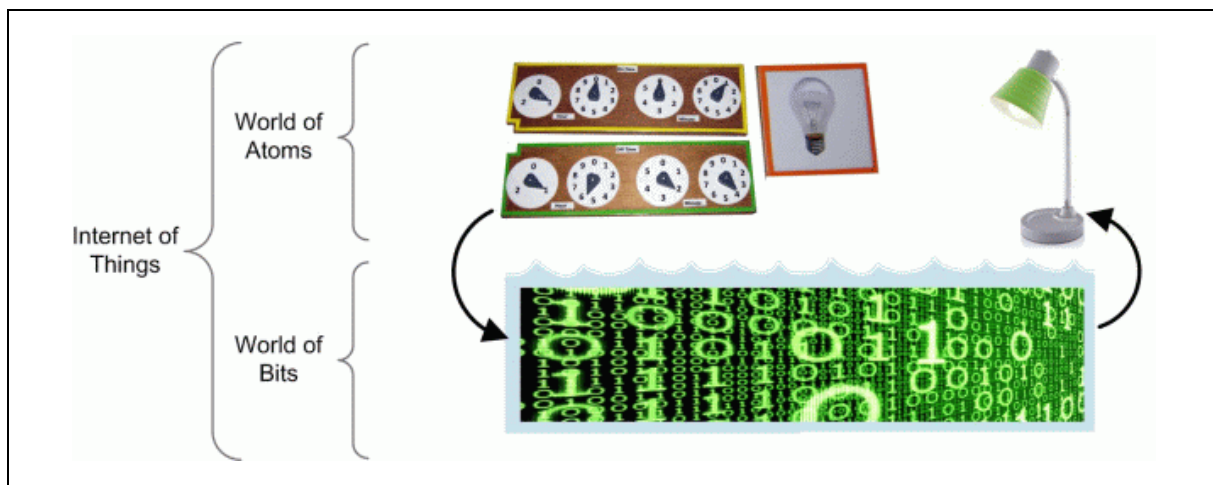

Figure 1: The IoT integrates the 'world of atoms' and the 'world of bits'.

Identification technology is one of many IoT-system dimensions. Another dimension is the integration of the physical objects with the IoT. Integration requires an interrogation mechanism that can identify the physical object and update the object's virtual presence in

the IoT. An object can thus be both physical and virtual.

The dualism of physical object, and its virtual presence, is referred to as the 'world of atoms' and the 'world of bits' [8] (Figure 1).

5. Technology Description

The system consists of a number of components:

- a collection of physical representations of the electrical appliances that have to be controlled (Figure 2, right),
- a collection of physical representations of the time an appliance should be turned on (similar to Figure 2, left),
- a collection of physical representations of the time an appliance should be turned off (Figure 2, left),
- an input surface with which the user interacts (Figure 3),
- a display for providing feedback to the user,
- a collection of executing computer code distributed across three computers,
- a collection of electrical appliances that are controlled, and
- an electrical circuit to switch the appliances on/off.

These components are elaborated on in the following subsections.

5.1 Physical Representations

Physical, handmade objects are augmented with printed black and white fiducials on the bottom surface.

A time-indicator set consists of ON-time and OFF-time (Figure 2, left) objects; the user rotates four dials to indicate the time that the controlled object should be switched.

The physical object being controlled is represented by a picture (Figure 2, right), a light bulb in this example.

Figure 2: Physical representation of (left) time, and (right) an appliance.

5.2 The Input Surface

The physical objects that represent the controlled domestic object and the switching times must be identifiable and have to be interrogated.

We implemented the identification and interrogation functionality using passive optical markers. These markers are also used in reacTable [9], medical research [10], and human-computer interaction (HCI) research. Markers are encoded with patterns that, when interrogated, provide both a unique number as well as its orientation in two dimensional space. Based on these properties of the fiducial markers, we have designed a system that comprises of a flat sheet of glass placed on a wooden frame (Figure 3, left), and a low cost web camera placed below the sheet of glass pointing upwards. When properly positioned, the camera has a clear view of the fiducial markers that have been placed on the sheet of glass.

Figure 3: The input surface: (left) the glass sheet being added during assembly, and (center + right) the completed unit.

5.3   Display

A display is updated when the state of the controlled appliance changes, thus keeping the user informed. The same display is used for screening a short instructional video when the object marked with '?' is placed on the input surface.

5.4   Timing States

Whilst there are no controller objects on the input surface, the system remains in the IDLE state. When at least one controller object is on the controller surface (and recognised by the system), the system is in the OPERATION state .

The process flow is the same for each appliance being controlled. When an appliance physical representation and two TIME physical representations have been placed on the input surface, the indicated times and domestic object are identified and stored. Once the ON-time is reached, the appliance is switched on (Figure 4).
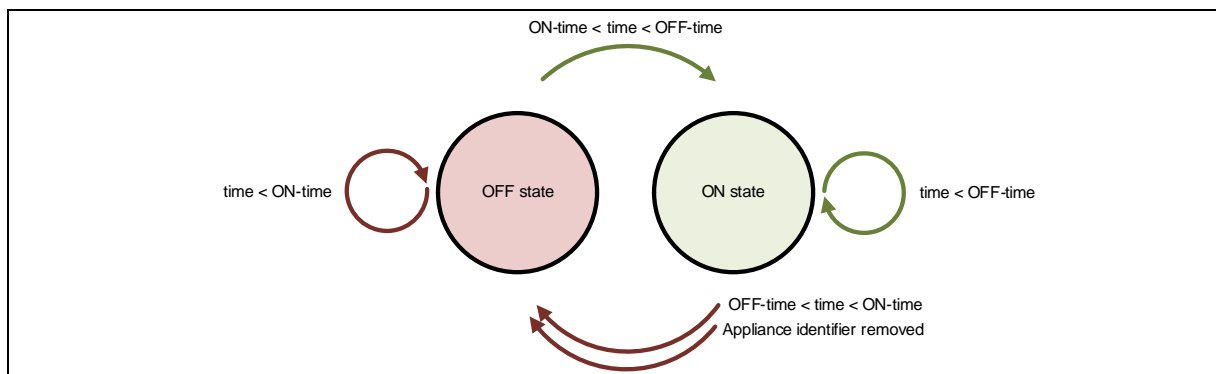

Figure 4: The timing state diagram.

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When the OFF-time is reached, the domestic appliance is switched off. If the physical object identifier is removed from the input surface, the domestic appliance is switched off.

5.5 Software Architecture

A 3-tier architecture was designed and implemented (Figure 5). The advantages of such an approach allows for loose coupling and better security. All tiers are independent of each other and can run on different platforms. Upgrading one tier will not affect others.
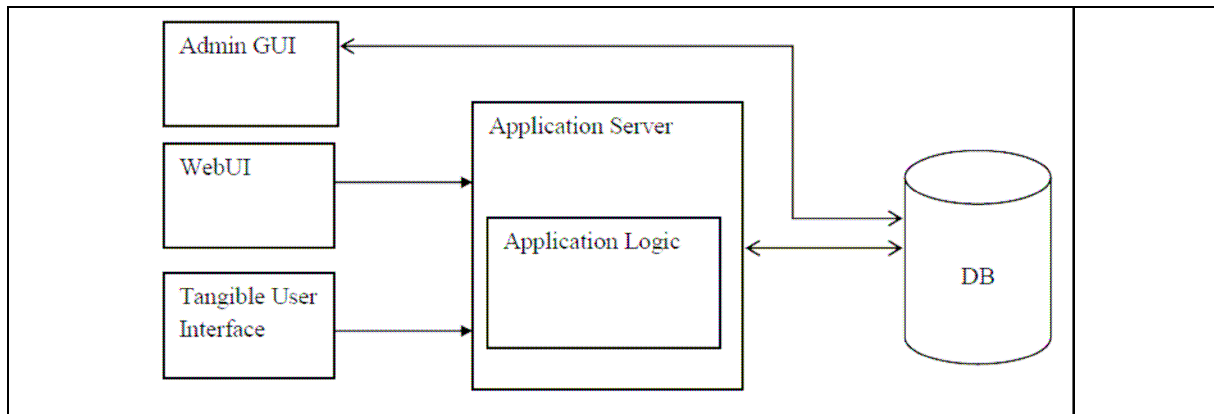

Figure 5: Software architecture.

5.6 The Appliance Controller

Controlling physical electrical appliances requires the use of electronic circuitry that is able to receive digital information from the IoT and convert it into a physical event. We applied the Arduino [11] as the interface between an internet-connected computer and the electrical switches controlling the electrical appliances (Figure 6).
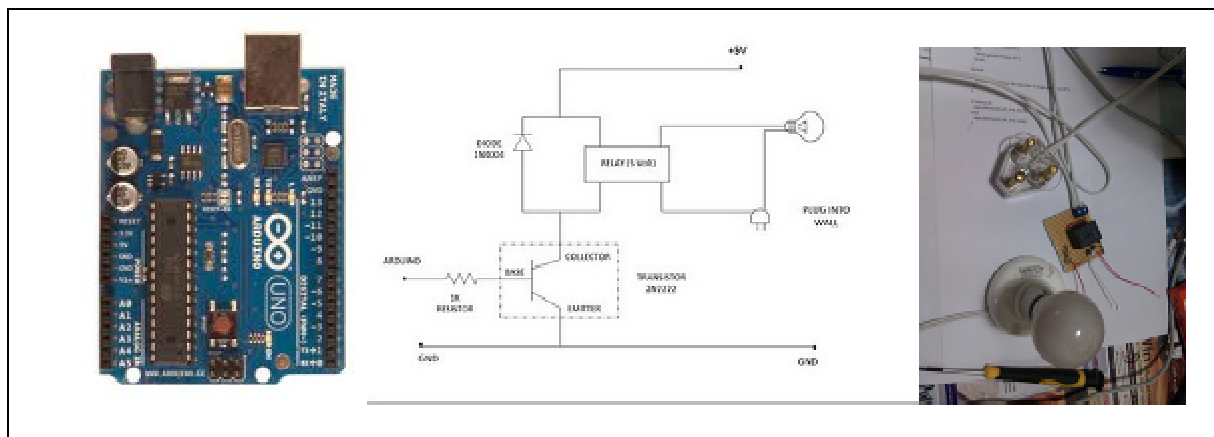

Figure 6: The appliance controller.
(left) Arduino. (centre) Electrical switch circuit diagram. (right) Electrical switch physical implementation.

6. Usage

The input surface has two areas, dividing the surface in a top and bottom section respectively (Figure 3, right). Each section is used to control one domestic object. The top left of a section is where the ON-time physical representation is placed, and the bottom left of a section is where OFF-time physical representation is placed. The physical representation of the domestic object is placed at the right of a section.

6.1   The User Interface

The user interface is the primary system component that makes this research project appropriate to developing regions. By simplifying the interface design and providing a one-to-one mapping between the input mechanism and the intended function, the cognitive burden on the user is greatly reduced when compared to conventional interfaces in current use in developed regions.

A user sets the on/off times of an electrical appliance using a three-step process: First, the user decides which appliance should be controlled and places a physical representation of the appliance on the controller's input surface. Second, the user decides when the appliance should be turned on and then places a physical representation of this time on the input surface. Third, the user decides when the appliance should be turned off and places a physical representation of this time on the input surface.

Feedback is provided to the user via a display. This display indicates the current state of the system and the devices being controlled. A 'help' facility is available in the form of a short video clip that is played on the display. This video is activated when the user places a physical representation of a question mark ('?') on the input surface. The video repeats until the '?' is removed from the input surface.

6.2   Setting the Time

By turning the four knobs on two physical time representation objects, the user can set the time a device should turn on/off. These time representation objects are interchangeable, with only their physical position on the input surface determining their roles as either representing the 'on' time, or representing the 'off' time. A physical representation of the object being controlled is placed to the right of the 'on' and 'off' objects. When these three physical objects are placed in these relative positions, the system associates them as comprising a group that should be interpreted as a unit.

7.   Results

The results of this concept demonstrator are satisfactory for the purpose it was designed and constructed. Two appliances were successfully controlled using the physical representations. Adding and removing the physical representations of both time and the domestic appliance was simple and intuitive. When using the system, the user had no need to interact with a computer at all.

The concept demonstrator makes provision for two appliances to be controlled simultaneously. More appliances may be controlled simultaneously if a larger input surface is used. However, the size of the input surface is limited by the camera resolution and the distance between the camera and the glass surface; the larger the required input surface, the further the camera needs to be from the glass surface, and the higher the camera resolution needs to be.

Our tests revealed problems with the optical sensing mechanism; the mechanism requires careful alignment of the camera onto the glass surface from below. Also revealed is the importance of fiducial illumination. Too much illumination results in the resulting image being overexposed. Conversely, too little illumination results in underexposure. In both cases the result is that the fiducials are either not detected or properly decoded by the software.

8.   Business Benefits

Not only can our system be applied to control energy consumption in the environment local to the user (domestic level), but it holds the potential to integrate with multiple other

domestic-level systems into a region-level, and potentially national-level, electrical energy monitor-and-control system. This integration across various levels is possible due to the internet architecture of the system.

With the potential of controlling domestic appliances remotely, it becomes feasible to manage regional and national energy consumption centrally. Central energy consumption is beneficial when fine grained data is available on the energy requirements at the domestic level.
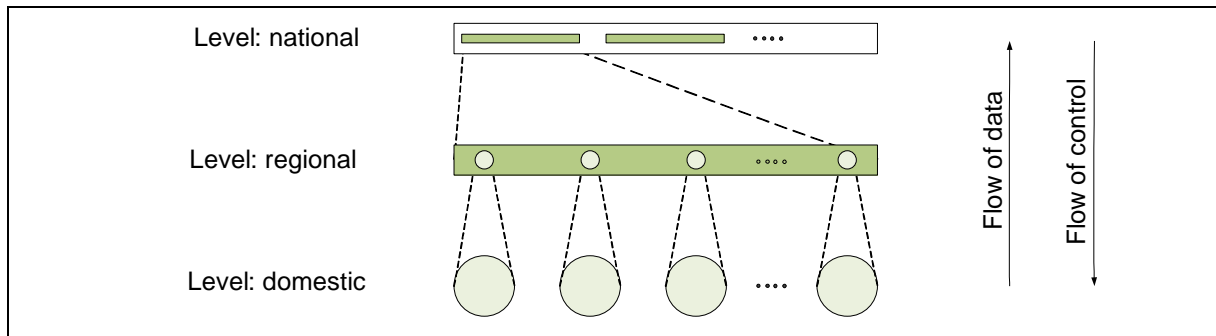

Figure 7: Electrical energy consumption can potentially be monitored and controlled at various levels.

In the envisaged system, data is propagated from the domestic level, to the regional level, and ultimately to the national level (Figure 7). The various sources of data that send local information to the regional level provide systems at a national level with sufficient input to enable it to make useful deductions regarding the current state at a national level. In addition to the current state, the system that operates at national level can realistically also make predictions regarding future electrical energy requirements.
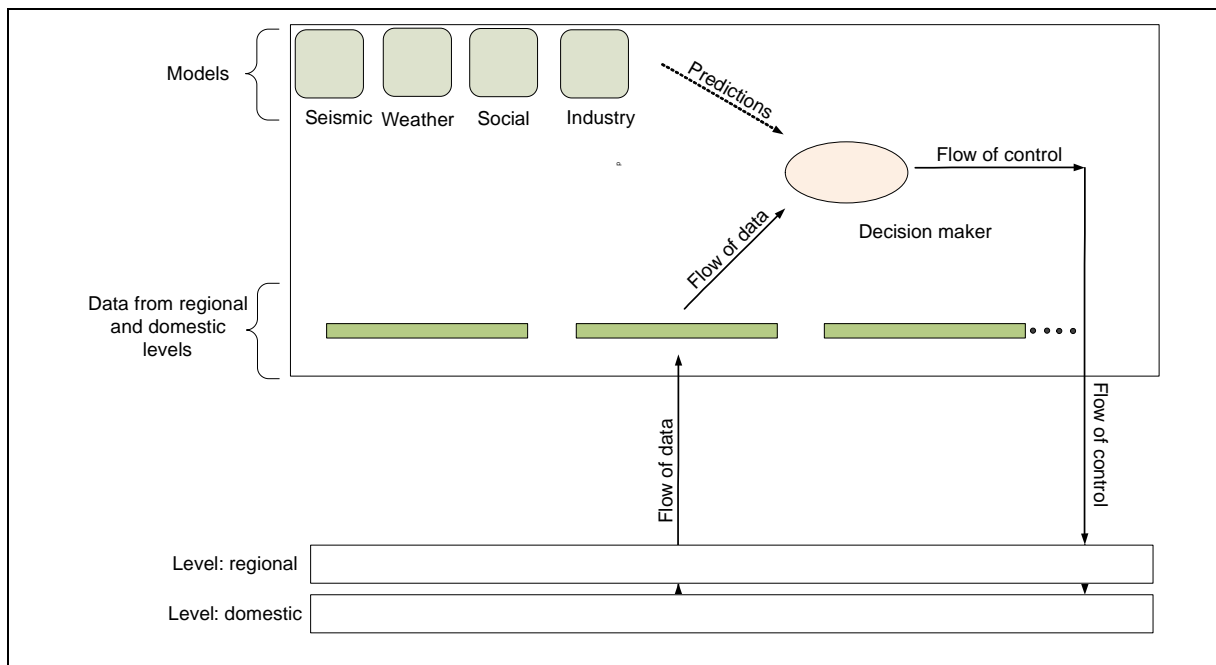

Figure 8: Informed decisions can be made at national level.

Of course a good model, that incorporates multiple facets of the operating environment, is required to make good predictions. Dimension to be considered in the model include social interactions in the communities, existing models of natural events such as the weather and seismic activity, and a model of industrial operations (figure 8).

Control flows from national level to domestic level, passing through the regional level. At the regional level a decision can be made whether the control message should be modified or relayed, without modification, to the domestic level.

9.   Conclusions

In this paper we have presented a concept demonstrator of a system that aims to support societies in developing regions to control their electrical energy consumption. When design the system, we emphasised the incorporation of (1) a user interface appropriate to a developing region, and (2) a networked architecture that holds the potential for integration into a larger energy monitor-and-control system.

Although our motivation for applying this system in developing regions is based on the simplicity of the user interface, there still remains complex parts of the system that require expert operators to configure and manage properly. We anticipate that a small number of experts in a large community will be able to meet this requirement. Such experts will map the physical appliance representations to the actual appliances.

In addition to its application in the domestic environment, the user-friendly and tactile approach of our input mechanism might also benefit industrial operations in low literacy areas where machinery has to be controlled.

Another area of possible improvement is the required placement of the ON and OFF-time objects. The current system assumes that the ON-time object is placed above the OFF-time object. This requirement places an unnecessary mental burden on the user and it would be advisable to eliminate this in a future design.

The greatest constraint on the current demonstrator is the sensitivity to changing light conditions. Due to the image processing required to recognise and classify the fiducial patterns at the bottom of each physical object, the lighting conditions should be well controlled. We have found that by frosting the glass surface and illuminating the surface from below, this dependency on ambient light conditions can be greatly reduced. Because of this sensitivity, it can be argued that the chosen mechanism is not suitable for domestic use in developing regions.

Usability tests have not yet been done and we plan to still evaluate the implemented system with the targeted end-users.

Our previous experience with local communities indicates that researchers should ideally acknowledge the community's research contribution by offering something in return. In exchange for their participation we offered, and executed, a week-long basic computer training workshop using the community's existing computer facilities.

Acknowledgements

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