Presentation of a Home Automation Solution with Potential for Seamless Integration and Vast Expansion

G. Sawyer
Department of Electrical and Electronic Engineering
Stellenbosch University
Western Cape, South Africa
Email: 15655903@sun.ac.za

M.J. Booysen
Department of Electrical and Electronic Engineering
Stellenbosch University
Western Cape, South Africa
Email: mjbooysen@sun.ac.za

***Abstract*—The ever-increasing existence of electronic systems and devices within the residential environment, along with the human desire to simplify life and daily routine, is generating increased interest in the field of Home Automation and intelligent environments. A large variety of HA solutions have been conceptualised or developed. However, many of these solutions are designed by experts and therefore require professionals to install and/or operate them. Furthermore they lack the potential for seamless integration into an already functioning home environment. This paper presents a HA solution with seamless integration potential. The system can be installed and configured without professional skills or physical alteration of the environment itself. There is also large potential for the expansion of the systems capabilities and functions due to the hardware and software platforms utilised. This paper concludes with an analysis of performance tests results, and a discussion of the potential avenues for expansion.**

I. Introduction

Home Automation (HA) is the integration of electrical and electronic devices within the residential household, via a centralised control system, which provides the habitant with control over the devices, either locally or remotely, as well as the ability to automate certain processes or functions within the home [1]–[3]. For a system to be considered a successful HA system, it must integrate a number of application areas. These application areas are listed below:

- Device function automation
- Intelligent control
- Power consumption management
- Sensor rich environment
- Sensible user interface

HA has received a lot of attention recently due to the ever increasing number of electronic and electrical devices within the home. Along with an increased interest in Machine-to-Machine communication networks, there is a lot of support in the field of HA. The ability to host communications between a number of devices and a centralised intelligent control system, opens the door to a lot of potential for growth [4]. An area of HA which has received significant interest recently, has been that of augmenting HA networks with a multitude of sensors. An environment which hosts the integration of devices and sensors in an interconnected network with an intelligent control system, is known as an intelligent environment. With the addition of communications and an awareness of a humans presence and location, users could be empowered by a digital environment that is sensitive, responsive and adaptive to their behaviour and needs [5], [6].

A. Home Automation Currently

1) Driving Factors: One of the largest driving factors behind HA is the human desire to simplify and improve life in the home environment. Intelligent environments create a lot of potential for cutting the cost of living by removing the need for human intervention in power saving routines that would otherwise seldom be performed (such as turning the hot water cylinder off when leaving the home). Safety and security would also benefit by, for example, the use of CO2, gas and motion sensors coupled with alarm and notification systems. These are but a few areas in which HA can offer benefits to not only the occupant, but also the industry upon which the occupant relies.

2) Challenges: One of the largest challenges to HA is overcoming the lack of consumer support. In the eyes of the consumer, automating the household is an expensive and unnecessary endeavour. The HA systems available today are purpose-built to spec for each home and therefore require professional intervention to install and setup. This inflates the cost of HA and also creates the illusion that it is intended as a luxury, ie. used with media and entertainment alone. This illusion along with the high cost of these systems drives consumers away and this has resulted in a lack of positive end-user generated data (or consumer sentiment) to support the financial advantages, and other benefits of HA. The solution proposed in this paper addresses this issue directly as it is not only cost effective, but it integrates each of the application areas that constitute a HA system. Also, it is capable of

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seamless integration into any home without the need for professional assistance resulting in a lower cost, and the ability to easily reconfigure the system as the home environment evolves.

On the other hand, design of an HA system with seamless integration potential is challenged by the lack of a universal development platform. Currently, most HA solutions are developed as a closed box. For this field to progress in the future, focus must be placed on integration with a large variety of systems and devices. The solution proposed in this paper addresses this challenge as it serves to be a HA platform upon which there is much room for expansion.

3) Generic HA Network: The generic architecture for a HA network consists of sensors/actuators, an intelligent controller and a gateway through which the network can access the internet or be accessed by a user. The sensors and actuators are deployed throughout the home to monitor and control the in-home environment. Information is communicated to and from the sensors/actuators by the intelligent controller. The controller provides sensor information to the user and also allows the user to carry out control actions on devices within the home. The intelligent controller is capable of independently carrying out control actions based on events monitored and translated into triggers. Fig. 1 depicts how the ideal HA architecture might look when connected to a variety of devices, using a variety of network technologies.

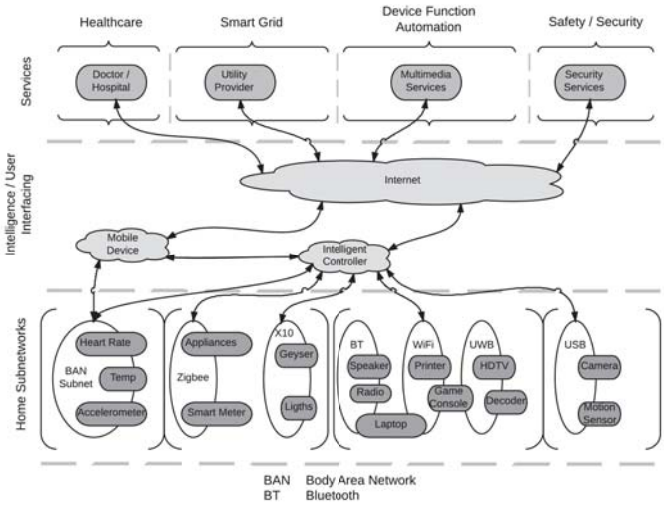

Fig. 1. Generic Home Automation Architecture

B. Contribution

This paper presents the design and development of an easy to use, highly expandable and seamlessly integratable, proof-of-concept Home Automation solution. The system provides users with the ability to automate appliances and processes within their home without the need for complex instalments and connections. The goal can be to lower power consumption of a hot water cylinder or to improve safety, it is up to the user how the system is deployed. Interfacing the user with the system is designed to be effortless. A web server, hosted locally on the system, provides device and sensor status information to the user allowing them to monitor the status of their home and carry out control of the connected devices. The web-server can be accessed from a remote location over the internet, and status information is automatically pushed to the user and updated live. In the event a user decides to change the device connected to a particular switch, they are also able to change the name of the device on the user-interface and this information is retained, even after a power outage. Lastly, on top of the ability to control devices directly, it is possible to generate intelligence based control loops. An event (such as temperature or time) can be used to trigger a control output (such as a light switch or geyser control). Furthermore, a control output can also be triggered using two events that are linked by a logical AND or logical OR.

The proof-of-concept presented in this paper is small in terms of its array of sensing and control abilities. But it has been developed to serve as a platform upon which expansion is made simple. With a modular design, the addition of more complex control functions and sensor capabilities requires little work.

C. Document Layout

The rest of this paper is organised as follows. Section II presents a brief survey of the literature on HA. Some of the important application areas are discussed along with proposed HA solutions. Challenges facing the progress of HA are also presented. Section III proposes a HA solution addressing the drawbacks of solutions proposed in literature. Section IV presents the design of the HA solution proposed and finally section V concludes this paper.

II. Literature Survey

HA has received substantial attention in the past decade or so and as a result there is a lot of research to support all areas of the field. The application areas that have received the most attention are discussed as well as some of the solutions proposed by researchers in the field. This survey gives us a clear indication of some of the important challenges that face the future of HA.

A. Most Common Home Automation Application Areas

The typical HA network is comprised of appliance devices, sensors, smart grid components, healthcare devices and security systems. The goal of a HA network is to improve the quality of life, experienced by the user, by performing tasks based on intelligence which holds to a set of rules. These tasks can be anything from toggling lights when motion is detected, to preparing the home for vacancy when the users go on holiday. In order to realise a HA system that can fulfil this goal, focus must be placed on key application areas. Some of these application areas are discussed here.

An important application area is that of device automation (such as lights, heaters, appliances etc.). The benefits that come

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with device automation are obvious, and consumers notice these benefits easier than those in other application areas. This area concentrates on devices carrying out functions without intervention from the user, and allowing the user to control these devices, over the Internet, from outside their home [7]. Much of the research in the field of HA is dedicated to device automation [4], [8], [9].

Smart grid implementation is one of the predominant focusses of HA. This is because smart grids will not only assist the consumer financially, but will also allow for much better provision of services by their providers [10]. The main objectives of smart grids are to increase the efficiency of power transmission, increase the quality of service to utility users and to reduce the economic and environmental cost of power generation and consumption. With a HA system a user is able to monitor their homes energy usage as well as limit the consumption of particular devices. Providing this information to the utility generators would ultimately give them the ability to provide the consumer with energy on demand, as well as offer them benefits based on consumption.

Intelligent environments is another of the most common application areas. An intelligent environment is defined as one where computing technology is embedded within the environment in such a way that it becomes virtually invisible [11]. Through the use of M2M communications and intelligent control systems, as well as an awareness of a humans presence and location, the aim is to empower users with a digital environment that is sensitive, adaptive and responsive to their behaviour and needs. Most modern day automation systems are designed to carry out a predetermined process [1], [12], triggered by an event; such as time, user action, a sensor reading or the result of a previous process (by process we mean actuation of a device in the home such as switching lights or changing the temperature of the air conditioner). The aim of developing an intelligent environment is to eliminate user interference as much as possible and increase the benefits to the user living within the environment [13].

B. Research to Support Home Automation Development

HA consists of a wide array of application areas and while a lot of effort is put into researching these areas individually, there is not a lot of focus on a HA system that incorporates everything. A capable HA system must integrate with all types of hardware within the home, and allow for addition and removal of devices to and from the network. That is to include devices with logic and communications, such as a smart television, and also devices without, like a toaster or lights. It must be designed with a user friendly interface that is easily accessible while also aiming to lower user intervention as much as possible.

The most common application of HA is that of the appliances and devices within the home. The switching of lights based on occupancy or preparing the kitchen for the morning routine are both attractive capabilities of HA however, no two homes use the same appliances, nor do they use them in the same manner. The challenge is therefore to develop a HA system capable of integrating seamlessly into any home no matter the appliance type or function. In [12] and [7] similar systems capable of interfacing with electronic hardware in a HA system are proposed. In [12] an Arduino development micro-controller is used to drive relays that are connected to electronic devices, and control is carried out via a smartphone with Bluetooth connection. In [7], some slightly more complicated, purpose-built hardware was used but the end result was much the same.

In [10] the authors present a proof-of-concept system to monitor and control household water heating on a large scale, using a web based interface. The system gives a user the ability to monitor and alter the HWC temperature and also safely empty the HWC in the case of failure or maintenance. The pressure of the HWC is also monitored to detect failures.

C. Challenges Facing Future Progress of Home Automation

HA is faced with many challenges hindering future progress, one of which is the standardisation of the technology being used. The home environment is populated by a wide variety of devices and systems all being controlled by a multitude of communication protocols, and producing a vast array of information types. Many concepts have focused on developing software capable of handling the broad variety of data when dealing with HA networks [9], [14] while others have focussed on hardware capable of integrating with many different devices. The main challenge to HA is incorporating all the application areas into one solution. The research mentioned in the previous section along with other existing solutions focus on one aspect of HA but fail to consider how they might all be integrated with each other. From here we go on to propose a HA proof-of-concept, providing the functions detailed in the contribution, capable of addressing these challenges.

III. Design Requirements

An expandable and seamlessly integratable HA proof-of-concept is proposed. The system must be capable of interfacing with simple electrical appliances as well as devices that require some communication protocol (such as IR). Expansion and community development must be possible to prevent limitation to a small group of unique users. The system must also make use of a modular design allowing users to add and remove devices to and from the system since no two home environments are the same. Lastly the system must give a user the ability to control devices directly, and also to generate intelligent rules that govern the control of devices based on sensor or event data.

A. Functional Requirements

Key factors that are to be addressed in the design of the proof-of-concept are; cost effective and open source hardware/software, slave hardware with modular capabilities, master software with adaptive capabilities, non-intrusive and off-the-shelf installation, and an easy to use and universal user-interface.

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B. System Requirements

Hardware used in this HA system must be cost effective to keep the end user cost low. It must also run open source software to allow for vast expansion and support potential from the developer community. For a fully integrated HA solution to succeed, it cannot only rely on a small group of paid support staff. As mentioned earlier, each user may want their HA system to behave in a different way to the next. This requires the support of the open source community.

This concept proposes a master, slave configuration for the HA proof-of-concept. This means that slave nodes are placed throughout the home, and each one reports information to, and receives commands from a master node. The master node handles communication to and from the slaves, as well as interfacing with the user. This allows the incorporation of a modular slave design, and gives the ability to add and remove slaves from the system seamlessly. Furthermore, slaves can be customised to perform a unique set of functions or report a unique set of sensor readings, and added to the system without the need to alter the system itself. The software on the master node must be adaptive. It must be able to detect when new slaves are added, and when they are removed and it must also be able to identify these slaves and the devices they are connected to.

The HA solution must not require that wiring and other electrical installations need to be embedded within the walls of the home. It must also not leave wires running throughout the home in a fashion that it becomes a burden on the user. For this reason, all communication between slaves and master must be wireless. Slaves must also require as little wiring as possible (such as between the slave and an array of relay switches).

The user interface must be simple to use with distinct sensor outputs and control inputs. It must also be accessible to all users whether they are using a mobile phone, tablet, or pc (running any operating system).

IV. System Design

This section details the design of the HA proof-of-concept solution based on the requirements set out in the solution proposal.

A. System Layout

Fig. 2 shows the system layout. Blue arrows indicate information flow between slave nodes and master node. This information consists of sensor readings and control commands. Red arrows indicate flow of information between the user and the master node. This information consists of the providing the user with the web server interface, as well as allowing the user to view sensor reading and perform control commands. Using this system layout, the user can access their HA system either by connecting directly to their home gateway, or by accessing it through the internet from anywhere in the world. Also, if internet connectivity is dropped, the system will continue to function and can still be accessed with a local connection.

This system layout also takes full advantage of the proposed modular slave design. If one slave goes down, the system will continue to function without a disruption of communication. Also, slave can be added and removed without the need to reset the system. More detail will be given on how this is achieved in the section on software.

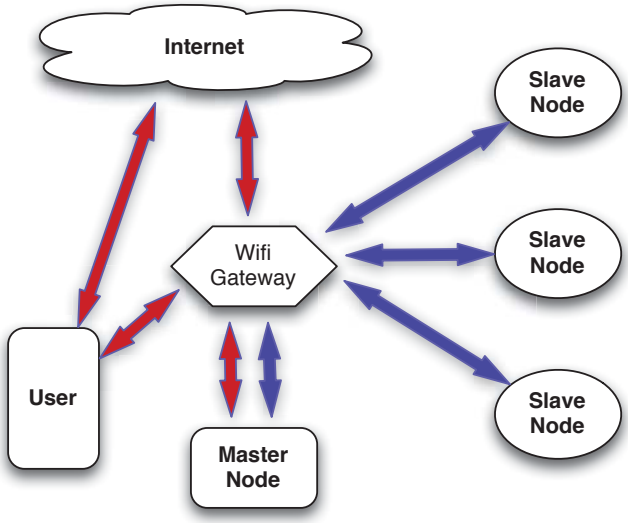

Fig. 2. System Layout

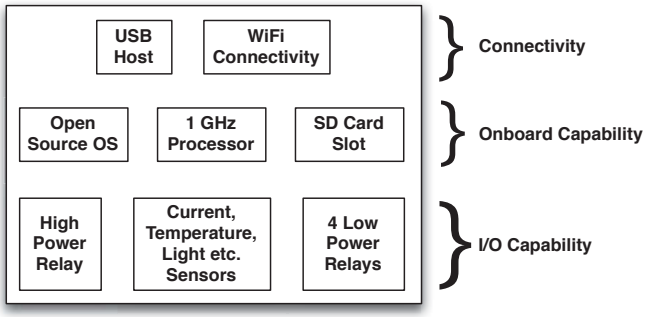

Fig. 3. Functional Slave Layout

B. Hardware

Hardware choice is of large importance in the success of this proof-of-concept and consists of the selection of a microcontroller to serve as the master and slave nodes. The hardware must be cost effective, but also be capable of fast, wireless communication (using IP to facilitate the modular system design where slaves are treated as clients) and processing of accurate sensor information that may require a fast CPU. Also, the selected component must be open to third party development in order to promote the growth and expansion of this concept as well as HA in general. Hardware options were considered after deciding on the required capabilities of the slave node. Fig. 3 shows a layout diagram of the functional capability of the slave node.

Based on these functional requirements, the Beaglebone Black [15], made by CircuitCo [16] was selected. The Beaglebone Black has the processing power required, as well

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as a multitude of input/output pins capable of digital and analog I/O and many forms of serial communication. The Beaglebone Black is also compatible with Arduino shields making it open to a wide variety of expansion. Lastly, the Beaglebone Black is capable of running Linux, Android and Ubuntu making it a suitable development platform.

C. Software

Three main design areas were taken into consideration when choosing the platform on which to run the software, along with the language in which to program the software. The first, and main consideration is that of the modular design requirement. After extensive research into the available software packages and languages, as well as ongoing projects in this field, it was discovered that an ongoing community project existed with software capable of fulfilling this requirement. The developers of The Thing System [17] designed a software package called the Steward [18]. The Steward connects the things (devices such as lights and electrical appliances) in the home, whether those things are media players such as the Roku or the Apple TV, a Nest thermostat, INSTEON home control system, or the Philips Hue lightbulbs whether these things are connected together via Wi-Fi, Zigbee, Z-Wave, USB or Bluetooth LE. The Steward is capable of identifying these things, and allowing them to talk to one another. What's more important about this software package is that devices can be programmed to communicate with the Steward API using any language. Also, the Steward API is open source and extensively documented. However, the Steward cannot currently interface with devices that have not been designed to communicate with the Steward API or are not equipped with any communication protocol at all. This proof-of-concept design makes use of the Steward for its capabilities as well as add the ability to integrate the simple devices, that exist in within the home environment, to the automated network. Fig. 4 depicts the master/user and master/slave flows of information, while Table I details the specific functions carried out by the browser, master software and slave software.

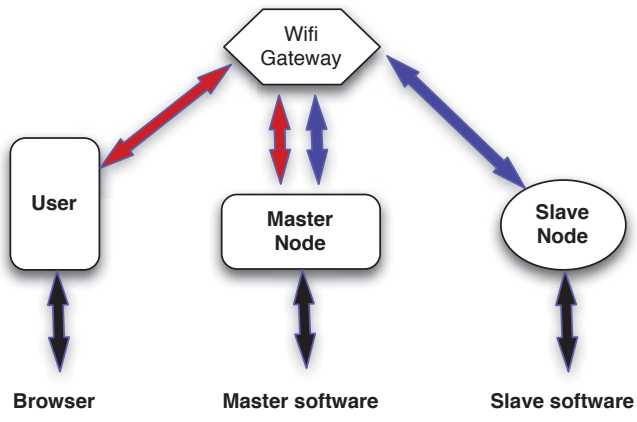

Fig. 4. Functional Software Layout (note. Only one slave is depicted in this figure).

TABLE I
DESCRIPTION OF FUNCTIONAL SOFTWARE COMPONENTS.

Browser	Master Software	Slave Software
- Requests web interface from client.	- Runs Steward software	- Aggregates sensor readings and reports to Steward.
- Allows user to view status informations and carry out control operations	- Runs client software that provides web interface to user.	- Carries out control functions received from Steward.
- Allows user to create, monitor and delete intelligent rule.	- Receives sensor statuses from Steward.	
	- Receives control commands from user.	

The second consideration was the language in which to write the master and slave nodes. The Steward is written in Node.js [19], a portable and extensible open source language. To keep things uniform, both the master and slave nodes will be written in Node.js, and at the same time, this is desired as it will help to promote the growth and development of this concept, and HA in general, within the open source community. The master and slave nodes must also be capable of bi-directional communication. Node.js proves to be a good language choice as there is a large support community constantly developing packages for use in Node.js. One of these packages supports WebSocket [20] communication in Node.js. WebSocket is a protocol providing full-duplex communications channels over TCP connection. This protocol allows a communication channel to be opened, and remain open for the duration of two-way communication.

The third consideration was the operating system on which to run the master and slave software. In keeping with an open source and expandable design, Debian [21] is selected as a suitable operating system. It has a large support community as well as the ability to run on development micro-controllers.

D. Slaves: Sensors and Actuators

Slave nodes are required to capture sensor readings and perform actuator control in specific locations within the home. The slave nodes have been designed in such a way that one slave node is required per living area (in a reasonably sized residential home) and have been equipped with some standard sensor and control electronics. Each slave nodes is capable of monitoring motion, temperature (to within half a degree C), light and current. Sensor reading are taken once every second and subsequently reported to the master node. Each slave is also capable of switching one high power relay for use with any device requiring up to 10A (in the event more current is required, this relay can be used to switch a higher power relay), three standard relays capable of up to 5A and one dimmer switch capable of a maximum of 300W. Furthermore, the standard relays and dimmer switch are wireless radio frequency controlled. This way we are keeping with the non-intrusive requirement.

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E. Master: User Interaction

The master node simultaneously runs the Steward and client software. The client software is responsible for communicating with the Steward to provide sensor information, and receive control commands. The client is also responsible for running a web server which is provided to the user when they wish to monitor or control their home environment. The user-interface is designed to be easy to use, and universal across all platforms ie. mobile, tablet and desktop computer, and is accessed by pointing a browser to the IP address of the master node, and port of the web server. The user-interface also makes it easy to understand how the elements on the web page are linked to the physical devices within the home. This is done by allowing the user to customise device names upon connecting them to the system, or when interchanging the connected devices. Device name info is stored in an SQL database such that it is retained, even in the event of a power outage.

F. Intelligence

A crucial area of HA is intelligence. Intelligence means that a HA system must be capable of carrying out control functions based on sensor readings without intervention by the user. Along with the standard monitoring and control provided by the user interface, there is also capability for the creation of rules. In this area a user selects what sensor event they would like to monitor and what control function should be performed should that event occur. Sensor events include temperature or motion readings, as well as time. Events can also be linked together with a logical AND or a logical OR to create a more complex output control scenario. For example one may wish to switch the lights on in a particular room when motion is detected in that room and the ambient light level is below a certain threshold.

V. Conclusion

A. Proof-of-Concept Comparison

The resulting Proof-of-Concept realises a flexible HA system capable of integrating with all household devices and successfully achieving all the stated goals. This system differs, in a few key areas, from similar systems that were mentioned earlier. In [7] a similar HA solution is proposed. That system also makes use of a Master/Slave hardware setup, and also uses a web server to interface a user with the system. The largest difference is the use of a computer to store the database information and run the web server. The system proposed in this paper stores database information and also runs the web server on the master node. This results in both a lower complexity and cost of this Proof-of-Concept. The system proposed in [7] also makes use of RF communication between master and slave nodes, whereas the solution proposed in this paper utilises IP WiFi communication. WiFi, instead of RF, was implemented to allow for seamless expansion of system capabilities. The use of IP allows third party developers to produce and integrate slave nodes with a variety of capabilities into the HA system without needing to make changes to the master node of the system. The use of RF would require alterations to the master node each time a new slave was introduced to the system.

In [12] a similar but slightly less advanced system is proposed where an Arduino Bluetooth board is connected, via digital I/O pins, to devices within the home and controlled by a Bluetooth capable cellphone running a custom python script. There are a few large differences between this system and the system proposed in this paper. The system in [12] would require changes to the script each time a new device is added to the system. It is also not capable of providing a user with remote access due to the use of Bluetooth communication. Finally, it is not capable of automation but instead serves as an appliance remote control.

B. Future Work

The proposed HA solution holds a lot of potential for future expansion. It is recommended that the work be carried forward by developing the integration of more complex devices such as those requiring infrared control. Along with this added integration, it will be necessary to develop the user interface further. The user interface will need to be capable of adapting to whatever variety of devices are connected. When devices are added or removed, it should automatically reflect on the UI and, sensor information and control capabilities should also automatically be presented to the user without needing to conform to a predetermined layout. Lastly, an investigation into the use of CoAP communication protocol should be carried out in order to increase energy efficiency of the system.

C. Conclusion

This paper presents the design of a solution to HA integrating all the important application areas. Focus is placed on developing a system capable of vast expansion and reconfigurability addressing some of main challenges of HA. Also, the system is designed to be simple to install and operate to promote consumer support of the technology. The paper discusses existing HA research and solutions identifying the drawbacks to these solutions and the challenges facing the field. A concept is proposed that addresses the challenges and is capable of compensating for the drawbacks of existing solutions. A detailed design of the system is presented and the capabilities and potential of the solution is discussed.

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