SMART AND ENERGY-EFFICIENT HOME AUTOMATION

Project A

Submitted in partial fulfillment of the requirements
for the degree of

BACHELOR OF ENGINEERING

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Project entitled: Smart and Energy-Efficient Home Automation

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ABSTRACT

The project proposes to show the benefits of a smart house and the areas of usage of smart living Systems. Details about the technical substructure and application of the designed home automation system through Gesture Recognition are described. This report presents the extension of existing vision based gesture recognition system using an algorithm that combines the classical and novel approach for gesture recognition. Under future work, several improvements and support structures may be implemented in order to increase the capabilities and the functionality of the system. These improvements include position independent recognition, rejection of unknown gestures, and continuous online recognition of spontaneous gestures. These gesture matches when obtained are used to control technologies deployed in an Intelligent Room. They may either be power or utility related devices and thus centralizing their control gives rise to a truly dynamic Home Automation system. This is because rather than pull people into the virtual world of the computer we are trying to pull the computer out into the real world of people. The highest level application we aspire to achieve is to build application systems that provide occupants of the room with specialized services for command and control of ambient conditions.

1. INTRODUCTION

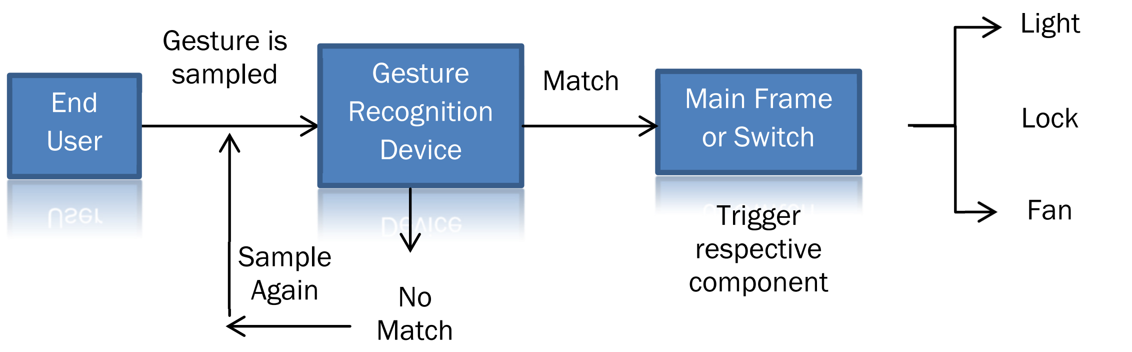
Technology has advanced with leaps and bounds over the last decade thus giving rise to computerization of our everyday living environment. A time progresses, the development of IT technology further adds luxury to common devices that merely served utilitarian purposes in the past. Commonplace devices like the washing machine come with “sixth sense” that can inform the end user about what stage of operation the appliance is on. Further, as networking of the home appliances is being realized and they are become even more intelligent. Therefore, for such appliances frequently used in everyday life, intuitive operation is desirable for a user. This is where a non-contacting interface based on man's natural actions comes into play. Gestures, which we use frequently and intuitively in our everyday communication, are one of such man machine interfaces.

Our project proposes to demonstrate a functional automation based on Gesture recognition using the following:

- Video content analysis and multi-frame type of processing
- Image enrollment and skin color registration
- Combination of classic and novel approach to Image processing
- Portable computational devices
- Communication with handheld hardware mainframe module

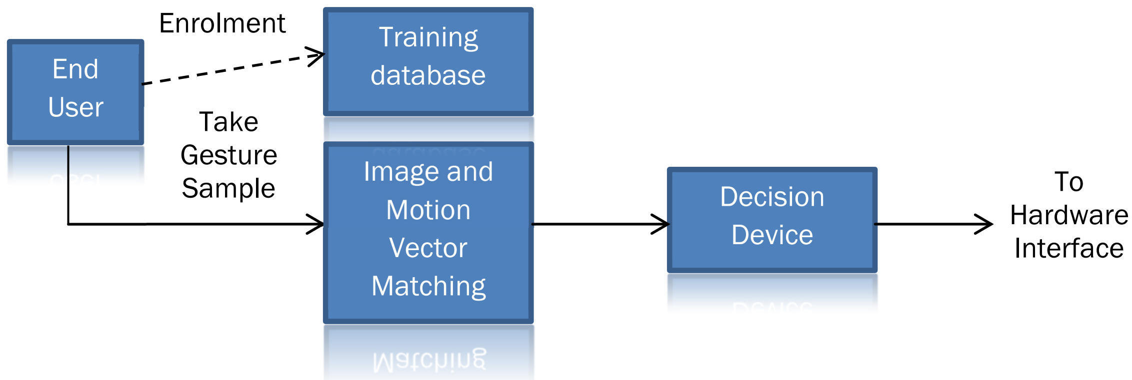
The vision behind the project was to put forth a practical, commercially feasible and easily implementable home automation system that puts the entire control in the hands of the end user, literally. The system can be better understood by judging the software and hardware modules on their individual merit and their performance on conjunction with each other.

1.1 BLOCK DIAGRAM OF THE PROPOSED SYSTEM



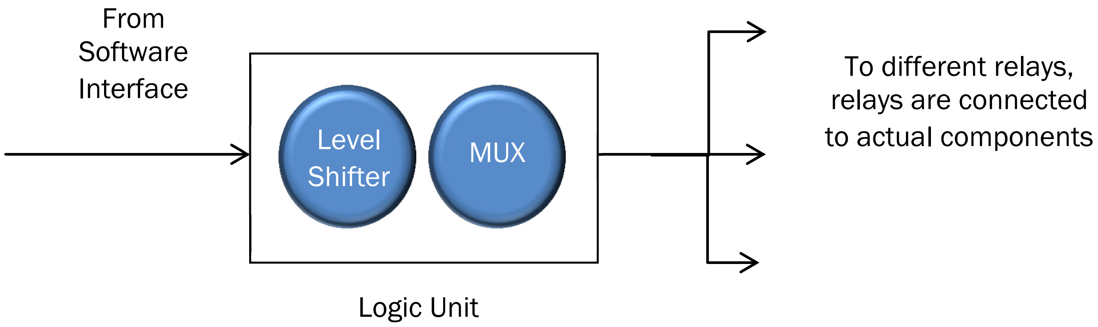
The above figure shows the basic flow of control. It starts with image samples of the end user. These images may also be individual frames after splitting a video stream. This data is then sent to the software module where the matching takes place. The control signal generated by decision device is converted to suitable data packet format and sent to hardware module. Here, depending on the data packet received, high power appliances like refrigerators or low power appliances like CFLs may be switched on or off. Further, depending on desired complexity of the system, additional states like "dim the light", "slow the fan" etc. may be added alongwith plain ON and OFF commands. The Hardware and software blocks are complimentary in function. The signals are generated on the software module and executed on the hardware module.

1.2 SOFTWARE SIDE IMPLEMENTATION



The software side module breaks down the entire complicated Recognition process into simple steps. The first of which is to enroll the user samples into the training database so that for all test gestures there exists a reference within the system. All test gestures will be matched with these training samples at a later stage and the output of this will be used to drive the decision device. The actual process of image matching starts with what is known as feature extraction; the feature vector may be in the form of Frequency domain components of the image, or difference image formed by subtracting two consecutive frames from each other or the motion trajectory of the entire gesture etc. Which method is used for feature extraction depends on the technique employed for image processing. Popular techniques and their corresponding software tools are discussed subsequently in the report.

1.3 HARDWARE SIDE IMPLEMENTATION



The Hardware module accepts the control signal or data packet from the software module through an interface and drives the actual components to action. The data packet undergoes level shifter to make the output from computational device compatible with on board hardware i.e. controllers and drivers. Then it is fed to the multiplexer which selects the relay for which the data packet was intended. The bias of the relay switches the actual device circuit ON or OFF. The level shifter and multiplexer together are known as the logic unit of the Hardware as it is here that based on logic levels the operation is actually implemented. Once the above basic module is realized successfully it can be ported to a more convenient wearable unit.

2. REVIEW OF LITERATURE

2.1 EXISTING SYSTEMS AND THEIR LIMITATIONS

In order to successfully implement the software module, the techniques in use currently for image processing must be taken into account. This is because Video content analysis and Gesture recognition, when broken down to the very basics are nothing but Image processing. Even background dependent movement detection, employs simple difference vector principle to find relative displacement between two frames and calculate the motion trajectory.

Popular transform-based Image Processing methods:

1. Discrete Cosine Transform: DCT is a well-known signal analysis tool used in compression due to its compact representation power. DCT is a very useful tool for signal representation both in terms of information packing and in terms of computational complexity due to its data independent nature. DCT helps separate the image into parts (or spectral sub-bands) of differing importance (with respect to the image's visual quality). DCT is conceptually similar to Discrete Fourier Transform (DFT), in the way that it transforms a signal or an image from the spatial domain to the frequency domain.

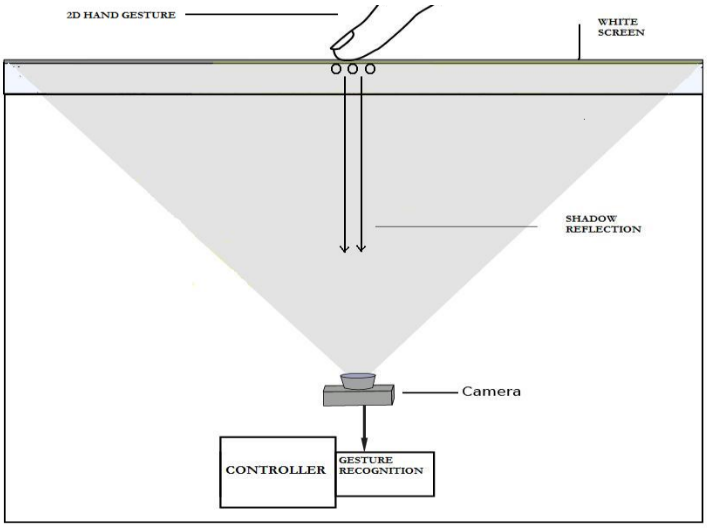
2. Discrete Wavelet Transform: DWT is a transform which provides the time-frequency representation. Often a particular spectral component occurring at any instant is of particular interest. In these cases it may be very beneficial to know the time intervals these particular spectral components occur. For example, in EEGs, the latency of an event-related potential is of particular interest. DWT is capable of providing the time and frequency information simultaneously, hence giving a time-frequency representation of the signal. In numerical analysis and functional analysis, DWT is any wavelet transform for which the wavelets are discretely sampled. In DWT, an image can be analyzed by passing it through an analysis filter bank followed by decimation operation. The analysis filter consists of a low pass and high pass filter at each decomposition stage. When the signal passes through filters, it splits into two bands. The low pass filter which corresponds to an averaging operation, extracts the coarse information of the signal. The high pass filter which corresponds to a differencing operation, extracts the detail information of the signal.

3. Discrete Sine Transform: The discrete sine transform (DST) is a Fourier-related transform similar to the discrete Fourier transform (DFT), but using a purely real matrix. It is equivalent to the imaginary parts of a DFT of roughly twice the length, operating on real data with odd symmetry (since the Fourier transform of a real and odd function is imaginary and odd), where in some variants the input and/or output data are shifted by half a sample.

4. Hidden Markov Model Based: In the research area of dynamic gesture recognition, Hidden Markov Models are one of the mostly used methods. The movements of a person over a sequence of images is classified. The first approach for the recognition of human movements based on Hidden Markov Models has been described in a paper by Volder. It distinguishes between six different tennis strokes. This system divides the image into meshes and counts the number of pixels representing the person for each mesh. The numbers are composed to a feature vector that is converted into a discrete label by a vector quantizer. The labels are classified based on discrete HMMs. The system described in the paper by Rochelle is capable of recognizing 40 different connected person dependent gestures of the American Sign Language. This system uses colored gloves to track the hands of the user, but can also track the hands without the help of gloves. The position and orientation of the hands are used for the HMM based classification.

5. Neural network based: An artificial neural network (ANN), usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Modern neural networks are non-linear statistical data modeling tools. They are usually used to model complex relationships between inputs and outputs or to find patterns in data.

6. Touchscreen based: A white screen is used as the touch plate to give an input in the form of a symbol. The user needs to create a database of the various symbols required. A camera placed below white screen catches the reflected shadow of the symbol created and interprets it as particular action that is required in home automation using micro-controllers. The following figure explains the 2-D gesture recognition concept:



Apart from the above mentioned, there are techniques other techniques as well which are employed for gesture recognition. However, most of them are subject to conditions of surroundings. Thus for accurate and reliable results, a combination of the classic and novel approach with be used to finally implement gesture recognition.

2.2 ASPECTS OF IMAGE PROCESSING

It is convenient to subdivide different image processing algorithms into broad subclasses. There are different algorithms for different tasks and problems, and often we would like to distinguish the nature of the task at hand.

Image enhancement:

This refers to processing an image so that the result is more suitable for a particular application.

Examples include:

- Sharpening or de-blurring an out of focus image
- Highlighting edges
- Improving image contrast, or brightening an image

- Removing noise

Image restoration:

This may be considered as reversing the damage done to an image by a known cause, For example:

- Removing of blur caused by linear motion
- Removal of optical distortions
- Removing periodic interference

Image segmentation:

This involves subdividing an image into constituent parts, or isolating certain aspects of an image:

- Finding lines, circles, or particular shapes in an image, in an aerial photograph
- Identifying cars, trees, buildings, or roads

These classes are not disjoint; a given algorithm may be used for both image enhancement or for image restoration. However, we should be able to decide what it is that we are trying to do with our image: simply make it look better (enhancement), or removing damage (restoration).

2.2 IMAGE PROCESSING USING MATLAB

MATLAB is a data analysis and visualization tool which has been designed with powerful support for matrices and matrix operations. As well as this, MATLAB has excellent graphics capabilities, and its own powerful programming language. One of the reasons that MATLAB has become such an important tool is through the use of sets of MATLAB programs designed to support a particular task. These sets of programs are called toolboxes, and the particular toolbox of interest to us is the image processing toolbox. MATLAB supports a range of image formats including BMP, HDF, JPEG, PCX, TIFF, XWB etc.

When you start up MATLAB, you have a blank window called the Command Window in which you enter commands. A command line style interface is used and the prompt consists of two right arrows:

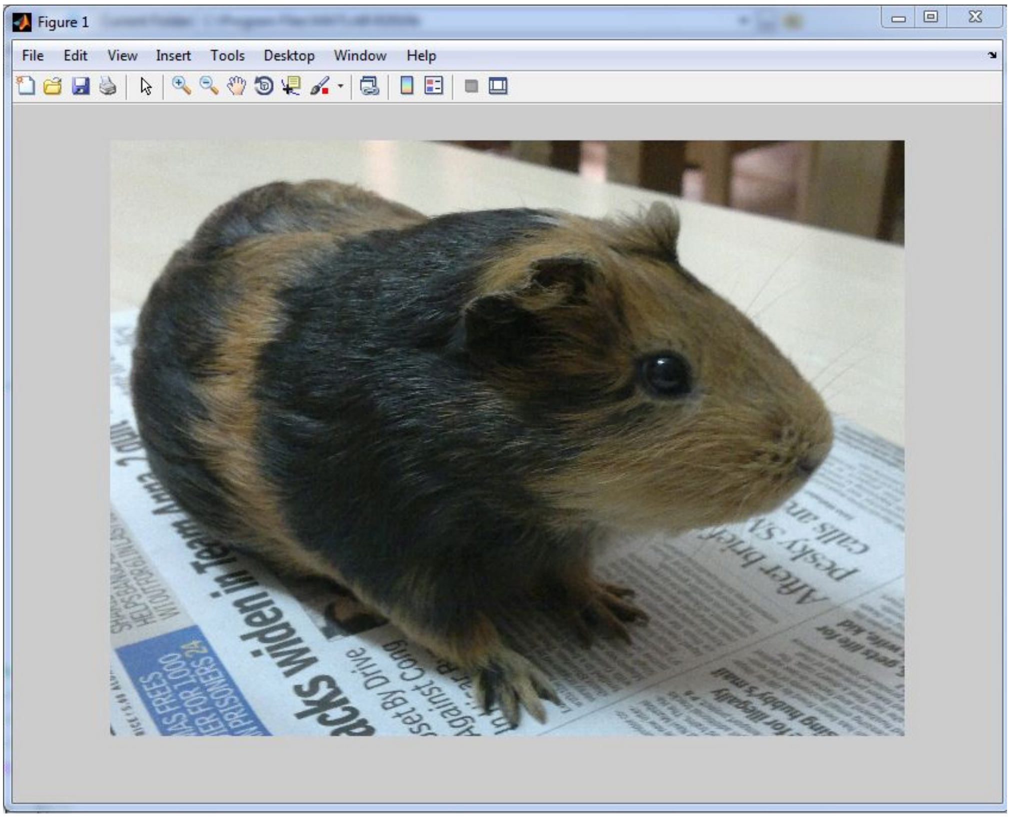
>>

MATLAB supports several image types like Grayscale images, RGB images, L*a*b* space images etc.

Basic Image Commands in MATLAB

a. <variable name>=imread('filename'): Reads the image into a variable\

b. imshow(g): displays the matrix g as an image.



c. size(a): returns three values: the number of rows, columns, and _pages_ of a, which is a three dimensional matrix, also called a multidimensional array.

d. impixel(a,200,100): returns the red, green, and blue values of the pixel at column 200, row 100.

e. imfinfo('emu.tif'): Returns several information fields of the image

ans =
Filename: 'emu.tif'
FileModDate: '26-Nov-2002 14:23:01'
FileSize: 119804
Format: 'tif'
FormatVersion: []
Width: 331
Height: 384

```
BitDepth: 8
ColorType: 'indexed'
FormatSignature: [73 73 42 0]
ByteOrder: 'little-endian'
NewSubfileType: 0
BitsPerSample: 8
Compression: 'PackBits'
PhotometricInterpretation: 'RGB Palette'
StripOffsets: [16x1 double]
SamplesPerPixel: 1
RowsPerStrip: 24
StripByteCounts: [16x1 double]
XResolution: 72
YResolution: 72
ResolutionUnit: 'Inch'
Colormap: [256x3 double]
PlanarConfiguration: 'Chunky'
TileWidth: []
TileLength: []
TileOffsets: []
TileByteCounts: []
Orientation: 1
FillOrder: 1
GrayResponseUnit: 0.0100
MaxSampleValue: 255
MinSampleValue: 0
Thresholding: 1
```

Data Types and Conversions

Elements in MATLAB matrices may have a number of different numeric data types; the most common are listed as below.

Data type	**Description**	**Range**
int8	8-bit integer	-128 to 127
uint8	8-bit unsigned integer	0 to 255
intl6	16-bit integer	32768 to 32767
uintl6	16-bit unsigned integer	0 to 65535
double	Double precision real number	Machine specific

We can convert images from one image type to another. The table below lists all of MATLAB's functions for converting between different image types. Note that the gray2rgb function does not create a colour image, but an image all of whose pixel colors were the same as before. This is done by simply replicating the grey values of each pixel.

Image Type Conversions

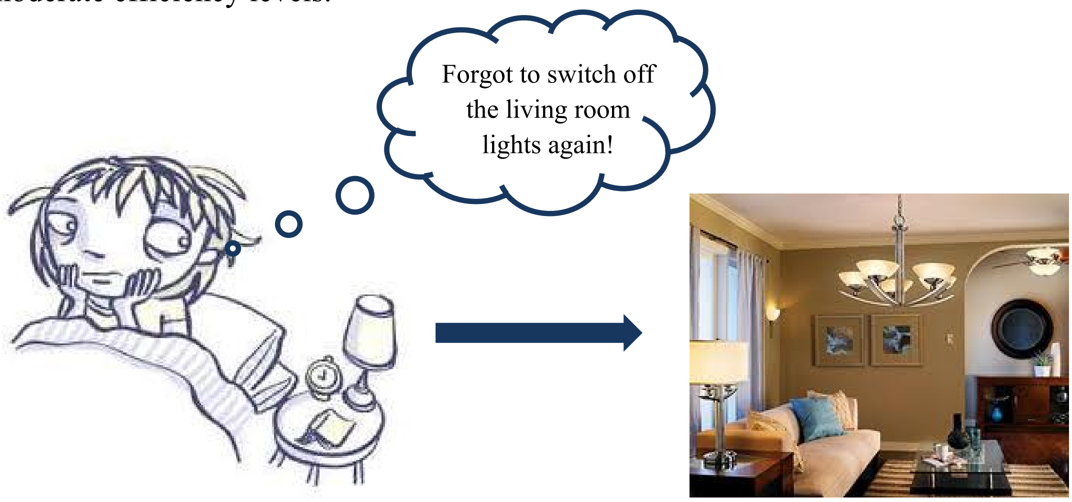
Function	**Use**	**Format**
ind2gray	Indexed to Greyscale	y=ind2gray(x,map);
gray2ind	Greyscale to indexed	[y,map]=gray2ind(x);
rgb2gray	RGB to greyscale	y=rgb2gray(x);
gray2rgb	Greyscale to RGB	y=gray2rgb(x);
rgb2ind	RGB to indexed	[y,map]=rgb2ind;
ind2rgb	Indexed to RGB	y=ind2rgb(x,map);

It is important to make the distinction between the two functions double and im2double: double changes the data type but does not change the numeric values; im2double changes both the numeric data type and the values. The exception of course is if the original image is of type double, in which case im2double does nothing. Although the command double is not of much use for direct image display, it can be very useful for image arithmetic. We have seen examples of this above with scaling.

3. PROBLEM FORMULATION

In the urban setting, the high standards of living have encouraged automation to come on the forefront and be an integral factor of any home design. At the same time, the environmental concerns have ensured that energy efficient housing models and appliances are used. We reckon that given the above concepts, it would make sense to integrate them and give rise to a model smart, energy efficient home with employs device control using a technique as intuitive as gestures.

For decades now remote controls have enabled us to dictate the working and immediate functions of everyday appliances like the AC, TV etc. However, consider a scenario where a person say Carol, is all tucked in her bed and she realizes that she has forgotten to switch off the lights and fans of the living room, or the heating system. In such a scenario and many more, it would indeed help to have a centralized control unit located at a convenient location from where Carol could command any and all of the electrical or electronic devices connected to the mainframe. This is where the need for centralized automation comes. Also imagine, if Carol needed to find the remote to control the main GUI that controls all the other devices, then the purpose of automation would be lost, thus, it was concluded that Gestures being an intuitive means of expression are the best way to control household appliances at moderate efficiency levels.



Most techniques systems currently employed for automation have the following drawbacks:

1. The one-time cost of installing the systems is ginormous
2. The maintenance costs further add on to overall expenses on devices

3. Due to extravagant prices such systems are affordable only to the upper class in society
4. Most automation systems cannot be ported or made compatible for all appliances of use in a house, thus very flimsy levels of automation are achieved
5. Human Computer Interface (HCI) based automated homes are designed for lavish spacious houses but are often found to work better for smaller spaces

The proposed project is targeted to reduce the implementation cost of a simple central automation system. Thus, the generic idea requires minimal hardware and any simple computational device like laptop, smart-phones etc. for its complete working and operation. At the same time, Gesture Recognition under Human Computer Interaction specially that using Hidden Markov Models (HMMs) is a highly sought after and researched upon field. The report subsequently explains the algorithm and design considerations to realize the above defined target.

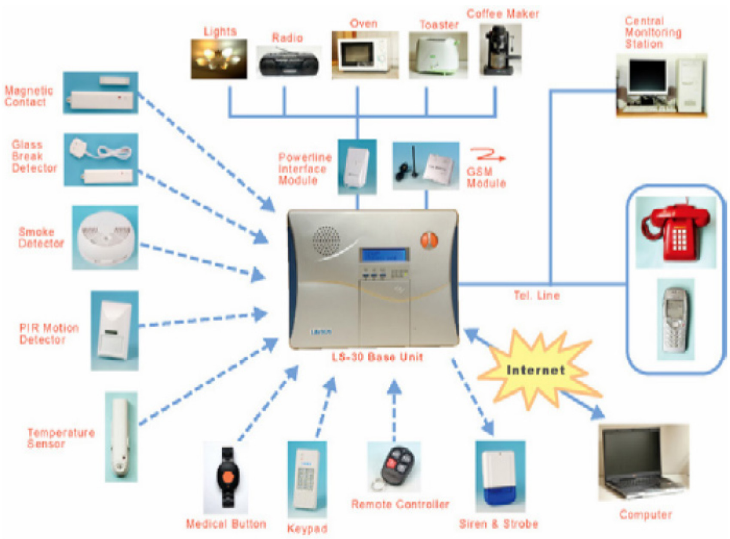
4. IDEA OF PROPOSED SOLUTION

4.1 SMART, ENERGY EFFICIENT AND AUTOMATION CONSIDERATIONS

The proposed project aims to integrate advanced Image Processing techniques with their plausible application to a real world scenario. In recent years the introduction of network enabled devices into the home environment has proceeded at an unprecedented rate. Moreover, there is the potential for the remote or centralized control and monitoring of such network enabled devices. Thus, the project undertakes the task of coupling common household devices with gesture recognition based decision unit. This will provide high levels of automation using next to none additional cost.

Elements of a Smart Home

A Smart home is usually centrally controls most of its devices. To realize such a case first consider some of the electronic and electric appliances which can be installed in a house or flat, such as light, heating, home entertainment, motorized window blinds, telephone system or security devices. Now imagine that a user of our system could control all of this functionality from her convenient spot at home i.e. her bed or even do it remotely while in the car. This, concept of applications which facilitate the remote control of home appliances are the essence of Smart Homes. Apart from the above mentioned applications the above apparatus comprises of home control and automation hardware. In most cases these appear in the form of a small web server which is installed on the home server available for the particular system. The user can observe and control the installed devices via these web interfaces.



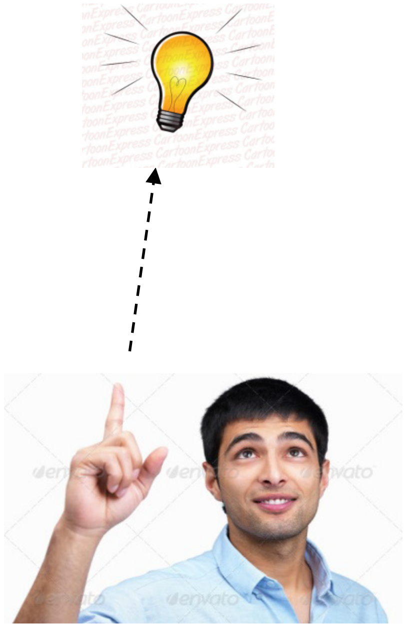
Smart Home Elements

Elements of Energy Efficient Home

Often the brunt of the busy lifestyle in today’s world is borne by energy consuming appliance. This may happen if the inhabitant in a haste cannot switch off the light and fans of the entire house. Or if the refrigerator is left on normal mode even if the owners are out for the week end, etc. Such scenarios lead to needless energy wastage. To avoid this, a carefully connected system of relays may be implemented to centrally trip power supply to parts or whole of the house through a central gesture controlled server. Such an application scenario can be implemented based on profiles. For instance, imagine an “I'm leaving now" gesture from the door which turns off all the lights and lowers the heating. Before going for dinner, the user could initiate a "Coming back in 90 minutes" function which will switch heating back to comfort level, including the preparation of hot water necessary for a relaxing bath. Besides the obvious comfort enhancements, this promises significant energy savings by allowing centralized adjustment of resource intensive appliances.

Elements of Home Automation

Home automation can be achieved with embedded computing power and memory within dozens of pieces of domestic equipment, each of which can communicate with the user and with other equipment. The connected web of these devices forms a system that works as a smart home automation. Namely, it enables the user to control several home security and electrical devices by the concept of smart life system. This concept means the routines about house are realized automatically, the ideal comfort conditions, and probable malfunctions and danger warnings in a living area can be managed by the system. There are many classical definitions of home automation available in the literature and often home automation is described as the introduction of technology within the home to enhance the quality of life of its occupants, through the provision of different services such as telehealth, multimedia entertainment and energy conservation. The project is designed to achieve this automation through Gestures.



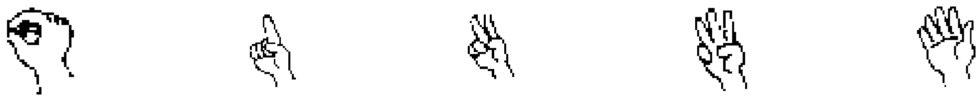
Gesture controlled appliances

4.2 COMMONLY USED TECHNIQUES FOR GESTURE RECOGNITION

The actual gesture may comprise of several simple or complex motion trajectories. A combination of the simple wrist/hand movements gives rise to complex gestures. The following basic movements may be combined in any order to form a decipherable gesture:

linear movement	circular movement	U-like movement	L-like movement
J-like movement	arm waving	wrist waving	wrist rotation

The following are the sample 3D gesture recognition templates that give a quantitative idea of the function of each gesture:



Switch off	Switch on Light 1	Switch on Light 2	Switch on Light 3	Future Programming

Gesture 1 is used to switch off all the lights, while Gestures 2, 3 and 4 are used to switch on Light1, Light2 and Light 3. Gesture 5 is reserved for future programming for complicated functions like dimming the light, switching it on and off in succession etc.

Switch off

Switch on Fan 1

Switch on Fan 2

Future Programming

Gesture 1 is used to switch off all the fans, while Gestures 2 and 3 are used to switch on Fan1 and Fan2. Gesture 4 is reserved for future programming for complicated functions like adjusting the speed inclination (in case of a table fan) of the fan etc.

Gesture 1

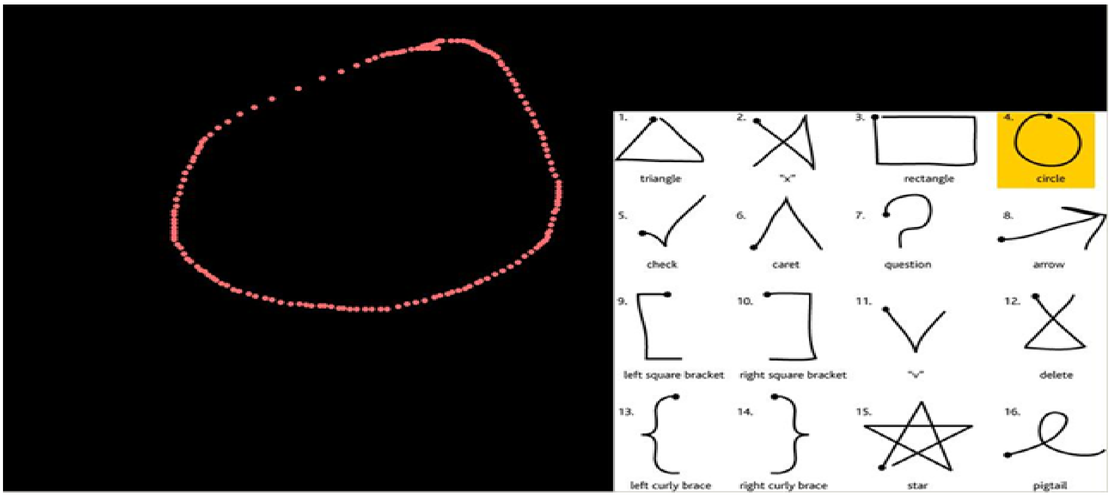
Gesture 2

Gesture 1

Gesture 2

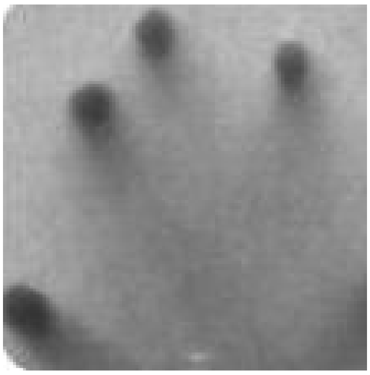
The above figures are general gestures which may be used to control auxiliary devices like water heaters, Refrigerators etc. Gesture1 may be used switch off all the appliances while Gesture2 may be used to switch on the appliance.

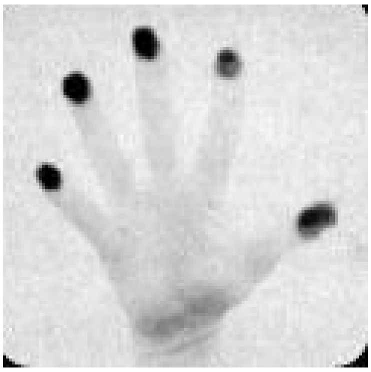
Gestures for the Touchscreen based Approach



The above diagram shows templates for the gestures as registered on the screen surface. Here, a circle can be interpreted to switch on the fans. A square can be interpreted to turn off the fans. Similarly, other symbols can be used to operate on the other circuits in a home.

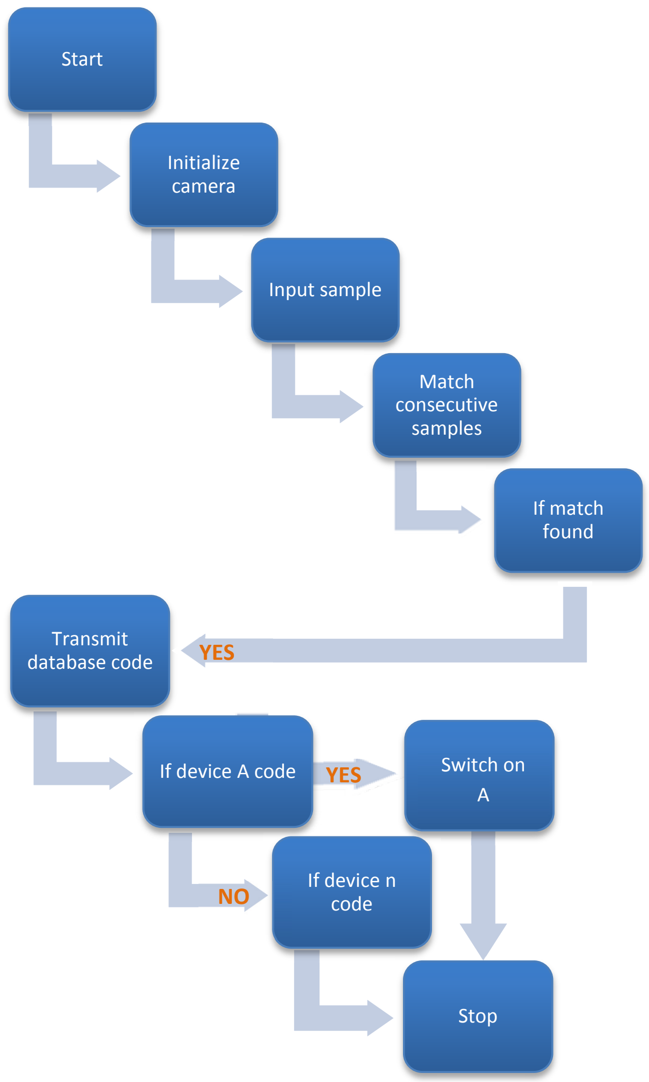
Also, symbols can be generated by just touching the finger on white screen. If one finger touch can be interpreted to switch on bulb, two fingers touch can be interpreted to switch on fan. Using the above concept 10 symbols can be created. The following figure gives the idea about this concept. For five fingers touch and four fingers touch.





The above diagrams show the actual images generated on screen surface.

4.3 SIGNAL FLOW DIAGRAM



4.4 PROPOSED ALGORITHM

Stage I

1. Take first sample image from user
2. After performing necessary normalization and resizing, enroll image in database
3. Calculate feature vectors from image
4. Save the matching parameters obtained above
5. Repeat process for all samples of all gestures under test

Stage II

1. Switch on and initialize appropriately both hardware and software modules
2. Obtain testing samples
3. Calculate feature vectors
4. Match with parameters stored during enrolment
5. Send result to decision device
    a. If match exists transmit unique code word indicating its recipient device
    b. If no match exists take next sample image and repeat above steps
6. Transfer control to hardware module

Stage III

1. Decode the received device code using logic circuitry
2. Check device codes of interfaced devices for a match
    a. If match exists command the device to perform designated function
    b. If no match exists check next device code for a match
3. Repeat the above steps till the required device is parsed
4. Enter power saving or idle mode

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