Vol. 7(25), Jul. 2017, PP. 3474-3487

Contents list available at IJMEC

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)

Journal Homepage: www.aeuso.org

PISSN: 2411-6173 - EISSN: 2305-0543

Mechatronics Automation using Remote DTMF Codes with Text Message Alert Feedback

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Abstract

With the current interest in household and industrial automation, developing a smart system that monitors and controls household appliances, industrial machines, military/hospital devices and security gadgets, etc, with low latency response is pertinent. This paper proposed Mechatronics based feedback vector control with Ardinuo IoT device. An embedded process lifecycle framework is employed in realizing the system. Dual tone multi-frequency (DTMF) codes and SMS feedback are applied. The system features Arduino UNO, GSM module with SIM card, ULN2003, DTMF decoder (MT8870D), buffer (74HC24), 12v-Relay, Bulb with lamp-holder, connecting wires, PCB, 16x2 LCD, Power supply unit, Mobile cell phone, and an external interface box module. A design algorithm that demonstrates the sequence of control operation is implemented. An initial satisfactory tests result has been obtained from Protus ISIS simulation. This work concludes that sensing and actuation dynamics with IoT edge computing offers the smartest capability for Industry 4.0.

Keywords: *Control, Automation, Fog/Edge Computing, IoT, Mechatronics, Embedded Computing*

1. Introduction

In today's disruptive computing era, the importance of controlling and monitoring electrical, electronic, and electromechanical systems remotely cannot be overemphasized. Modern electrical, electronic, and electromechanical systems with smart intelligence are referred to as Mechatronics systems [1]. These systems are recently driven by Internet of Things (IoT) [2]. This facilitates smart control engineering. Most physical systems require mechatronics enabled intelligence for optimal performance. For instance, non-automated systems can now be made flexible and dynamic such as [3]:

- Machine components (e.g., semi-active hydraulic damper, automatic gears, magnetic bearing, etc)
- Motion generators (e.g., integrated electric servo drives, integrated pneumatic servo drives, etc.)
- Power producing machines (e.g., brushless DC motor, integrated AC drives, combustion engines, etc.)
- Power Consuming machines (e.g., integrated multi-axis machine tools, integrated hydraulic pumps, etc.
- Automobiles (e.g., Anti-braking systems, (ABS), electro-hydraulic brake (EHB), Active suspension, Active front steering, etc.
- Trains (e.g., tilting trains, active boogie, magnetic levitated trains MAGLEV, etc.) Figure 1 shows typical mechatronics automated products for daily human activities.

Article History:
DOI: IJMEC/10.225136
Received Date: Dec. 03, 2016
Accepted Date: Apr. 14, 2017
Available Online: May. 01, 2017

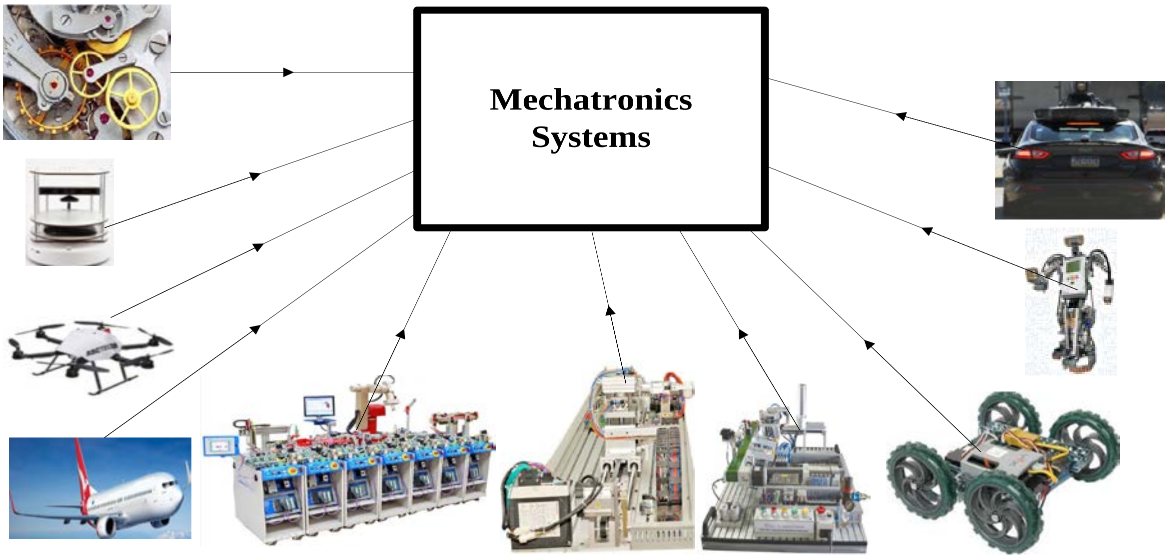

Figure 1: Dynamic Mechatronics Products.

Though smart automation in figure 1 is still evolving, intelligent control capabilities must be explored. Interestingly, recent developments in communication technologies have led to improved automated control strategies such particle swarm optimization (PSO); SMS based control (SBC), artificial intelligence (AI), cloud/edge computing, etc. Besides, most systems are distributed in nature; with wired and wireless communications in their control loops. This allows for networked systems intercommunications. Cloud based Fog/edge computing remains the most recent application paradigm [4] for dynamic automation of cyber-physical systems. For instance, electrical, electronic or electromechanical equipment installed in hazardous environment would need to be controlled and monitored remotely using intelligent networked sensors.

In the case of home/industrial automation systems, this requires convenient management of gadgets/equipment by switching ON and OFF remotely based on-demand. In these systems, to achieve remote surveillance, sensing and actuation of mounted interfaces is indispensible. A cascaded design technique from embedded process lifecycle framework can be adopted in the achieving remote automation. This is made in such a way that the output of a stage serves as the input for the next stage with some feedback loop. In context, there are four major stages viz: the input stage, the control stage, the output stage and the feedback stage. The input stage is made up of the control GSM handset, the DTMF decoder (MT8870D) and the buffer (74HC24). The control section is implemented by the Arduino microcontroller. The output stage consists of a network of opto-couplers, resistors, diodes, transistors and relays. While the feedback stage is made up of a network of transistors, resistors and opto-couplers, which act as the keypad switches for the feedback GSM handset.

Using a smart device, calls & text messages can be used to achieve smart home/industrial automation. Actually, devices in the industries, homes etc, can be controlled by sending SMS through a smart device. Remotely activating ON and OFF states of devices from anywhere is part of the global best practices for green computing. Hence, leveraging GSM wireless communication for controlling anyhow-anywhere appliances is a smart concept. Simple commands such "#A.light on*", "#A.light off*" "#A.AC off*","#A.Smart_meter off*", "#A.Door_gate off*" etc, can be explored for controlling various appliances. Once, the GSM module ascertains the Arduino based commands, the exact DTMF signal is sent to relays that switch ON or OFF the related appliances using a relay driver. Mechatronics based feedback vector control with Arduino IoT device has better advantages for remote automation. Consequently, this paper focused on sensing and actuation using GSM-based remote control/monitoring of appliances. This makes use of GSM mobile handset which captures the DTMF signals from a remote GSM handset; a DTMF decoder decodes DTMF codes coming from the remote GSM handset and transforms its signal into a digital format. A central Arduino microcontroller is used to coordinate all the control functions involved in the system while using another GSM handset to sends feedback after executing the expected operation. Related efforts are discussed below.

2. Related Works

Various efforts have been made by authors in literature. This section highlights the contribution in the context of DTMF based security automation.

E.S Mbonu et al [5] proposed a microcontroller based DTMF based wireless control and monitoring system for automation of home equipment. Md. Shariful Islam [6] used PIC16F628A microcontroller in DTMF tone is detected using the Goertzel algorithm for wireless remote switching system. More and more smart systems have been used in modern residential areas. Such smart household control system realization procedure is based on DTMF remote transmission [7], [8], [9]. In [10] DTMF signaling was suggested to control water flow for irrigation.

The paper in [11] demonstrated a general process of device control by using GSM network. Web based remote exploration and control system using android mobile phone has also been developed in [12]. The work used a DTMF detection circuit, interfaced with mobile phone, to automatically detect the DTMF tone signal, and generates 4 bit digital code output. Their digital output code can be utilized to control any electrical device.

The work in [13], developed an Automated Home Control System (AHCS) based on DTMF and PIC controller. In [14], a detailed classification of smart home security was presented. This include: context-aware home automation systems, central controller-based home automation systems, Bluetooth-based home automation systems; Global System for Mobile communication or mobile-based home automation systems, Short Messaging Service-based home automation systems, General Packet Radio Service-based home automation systems, DTMF based home automation systems, and Internet-based home automation systems. Existing works on process automation have not explored embedded design framework in Mechatronics sensing and actuation of objects/things from remote sources.

3. Design Methodology

3.1. Embedded Design Framework

As shown in Figure 2, the embedded design framework highlighted in [15] was adopted in this research. Starting with steps 5 through 9, Protus ISIS software tool aided in creating and debugging the system model. This approach consists of modeling and simulation, prototyping and the development life cycle. This framework is presents a generalize overview of the design used in the realization of this work. These base circuits consist of the GSM Modem, DTMF Decoder, Ardinuo microcontroller stage, switching and power supply stage. In achieving this work, stages 1 to 11 are significant.

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)
Universal Scientific Organization, www.aeuso.org
PISSN: 2411-6173, EISSN: 2305-0543

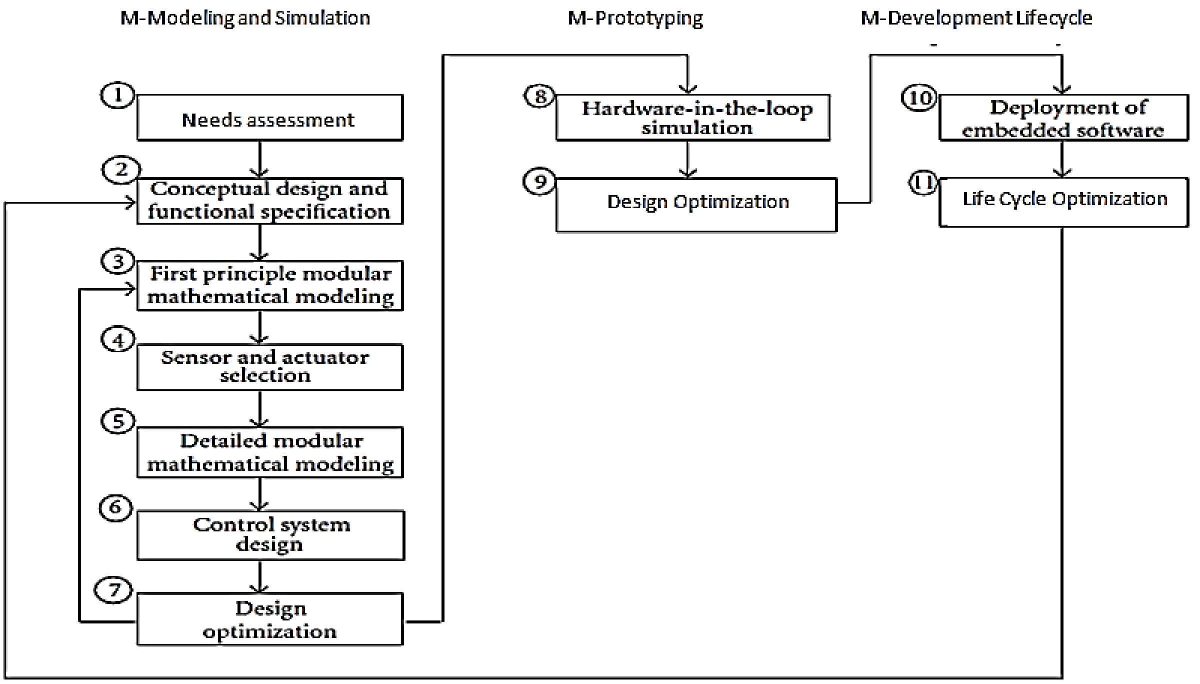

Figure 2: Mechatronics design [15].

3.2. Description of DTMF Vector control

A vector based DTMF signal was employed for control signalling. This is a method of representing digits with tone frequencies, in order to transmit them over an analog communications network. This represents the effective algebraic sum of two different audio frequencies, obtained from a well arranged DTMF keypad matrix in figure 3. In DTMF encoding, the digits 0-9 and the characters A-D, */E and #/F are represented as a combination of two frequencies discussed later in this work.

Figure 3: DTMF Keypad matrix [3].

From Table 1, the column is represented by a frequency from the upper frequency group (Hi-Group: 1209-1633 Hz), and the line by a frequency from the lower frequency group (Lo- Group: 697-941 Hz). The tone frequencies are selected such that harmonics are avoided. The frequencies are chosen such that they are not the harmonics of each other. Vector based DTMF Keypad with LOW and HIGH Frequency Groups is then generated.

Table 1: DTMF Frequency allocation

Frequency (Hz)	1209Hz	1336Hz	1477Hz	1633hz
697	1	2	3	A
770	4	5	6	B
852	7	8	9	C
941	*/E	0	#/F	D

3.3. DTMF Signal Generation

In most designs, the DTMF digit entry is achieved with the keypad. In this case, a 74C922 16-key encoder chip is used in conjunction with a 16-key SPST switch matrix and address decoding circuitry. From figure 3, the DTMF analogue signals consist of two sine waves which are independent of each other. To generate the signal in digital format, Digital-to- Analog Converters DAC with filters is used to generate the desired sinusoidal waveforms. By generating the DTMF signals from square-waves, the hardware and software needs are minimized. The recurrent waveform must have cycle duration of *T* can be represented by a Fourier series consisting of the infinite sum of individual sine and cosine waveforms derived below.

The fourier series of a function f(x) is given by:

$$y(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}[a_0 * Cos(n\omega_0 t] + b_0 * Sin(n\omega_0 t)] \quad (1)$$

Where $\frac{a_0}{2}$ is the direct component of the signal. The partial component with the lowest angular frequency (ω_0) is referred to as the fundamental, and the others are known as overtones or harmonics.

A recurrent waveform that could be easily generated with a microcontroller is the square wave, whose Fourier series is as follows

$$f(t) = \frac{\hat{y}}{2} + \frac{\widehat{2y}}{\pi}\sum_{n=1}^{\infty}[Sin(n\omega_0 t) + \frac{\hat{1}}{3}Sin(3\omega_0 t) + \frac{1}{5}Sin(5\omega_0 t) + \frac{1}{7}Sin(7\omega_0 t) \dots\dots\dots\dots\dots] \quad (2)$$

Equ 2 can further be expressed as follows:

$$f(t) = X_0 Sin(2 * \pi * f_a * t) + Y_0 Sin(2 * \pi * f_b * t) + \quad (3)$$

Where f_a and f_b are two different audio frequencies with X_0 and Y_0 as their peak amplitudes and f as the resultant DTMF signal. f_a belongs to the low frequency group and f_b belongs to the high frequency group. The combination of the low and corresponding high tones gives the desired DTMF code. This matches with the DTMF keypad. This implies that two different frequencies, one from the high frequency group and another from the low frequency group are used to produce a DTMF signal to represent the pressed key. The amplitudes of the two sine waves should be such that: (0.7 < (A/B) < 0.9) V.

Now, let $\omega_0 = \frac{\pi}{c}$ and f(t) = f(x) such that from Equ. 1,

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}[a_n * Cos(n\frac{\pi}{c}\, t] + b_n * Sin(n\frac{\pi}{c}t)] \quad (4)$$

Where

$a_{0,}$ a_n and b_n are given by

$$a_{0,} = \frac{1}{c}\int_{-c}^{c} f(t)dt$$

$$a_n = \frac{1}{c}\int_{-c}^{c} f(t)\, Cos\, \frac{n\pi t}{c}dt$$

$$a_n = \frac{1}{c}\int_{-c}^{c} f(t)\, Sin\, \frac{n\pi t}{c}dt$$

By substituting for $a_{0,}$ a_n and b_n in (4), this gives

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)dt + \sum_{n=1}^{\infty}\frac{1}{c}\int_{-c}^{c} f(t)Cos\frac{n\pi x}{c}Cos\frac{n\pi x}{c}dt + \sum_{n=1}^{\infty}\frac{1}{c}\int_{-c}^{c} f(t)Sin\frac{n\pi x}{c}Sin\frac{n\pi x}{c}dt$$

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)dt + \sum_{n=1}^{\infty}\frac{1}{c}\int_{-c}^{c} f(t)\left[Cos\frac{n\pi x}{c}Cos\frac{n\pi x}{c} + Sin\frac{n\pi x}{c}Sin\frac{n\pi x}{c}\right]dt$$

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)dt + \sum_{n=1}^{\infty}\frac{1}{c}\int_{-c}^{c} f(t)\left[Cos\left(\frac{n\pi t}{c} - \frac{n\pi x}{c}\right)dt\right]$$

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)dt + \sum_{n=1}^{\infty}\frac{1}{c}\int_{-c}^{c} f(t)\left[Cos\frac{n\pi}{c}(t-x)dt\right]$$

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)\left\{1 + 2\sum_{n=1}^{\infty} Cos\frac{n\pi}{c}(t-x)\right\}dt \qquad (5)$$

Since cosine functions are even functions, i.e., $Cos(-\emptyset) = Cos\emptyset$, the expression

$$1 + 2\sum_{n=1}^{\infty} Cos\frac{n\pi}{c}(t-x) = \sum_{n=-\infty}^{\infty} Cos\frac{n\pi}{c}(t-x)$$

Therefore Equ.5 becomes

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)\left\{\sum_{-\infty}^{\infty} Cos\frac{n\pi}{c}(t-x)\right\}dt$$

$$f(x) = \frac{1}{2c}\int_{-c}^{c} f(t)\left\{\frac{\pi}{c}\sum_{-\infty}^{\infty} Cos\frac{n\pi}{c}(t-x)\right\}dt \qquad (6)$$

By assuming that c increases indefinitely, let write

$u = \frac{n\pi}{c}$ and $du = \frac{\pi}{c}$

This assumption gives

$$\lim_{c\to\infty}\left\{\frac{\pi}{c}\sum_{-\infty}^{\infty} Cos\frac{n\pi}{c}(t-x)\right\} = \int_{-\infty}^{\infty} Cosu(t-x)du$$

$$= 2\int_{0}^{\infty} Cosu(t-x)du \qquad (7)$$

Substituting Equ.7 in Equ. 6, this yield

$$f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(t)\{2\int_{0}^{\infty} Cosu(t-x)du\}dt \qquad (8)$$

Thus , Assuming *t-x = t, we can have*

$$f(x) = \frac{1}{\pi}\int_{0}^{\infty}\int_{-\infty}^{\infty} f(t)Cosu(t)dudt \qquad (9)$$

Equ. (9) gives the composite DTMF signal for relay switching of loads. DTMF digits are read sequentially out of a linear buffer. The variable *(t-u)* defines the signal duration in milliseconds which sets the length of time that a DTMF digit is generated.

Figure 4 shows the DTMF state machine chart. This is partly controlled by IRQ2 in the microcontroller which is normally wired to a debounced switch.

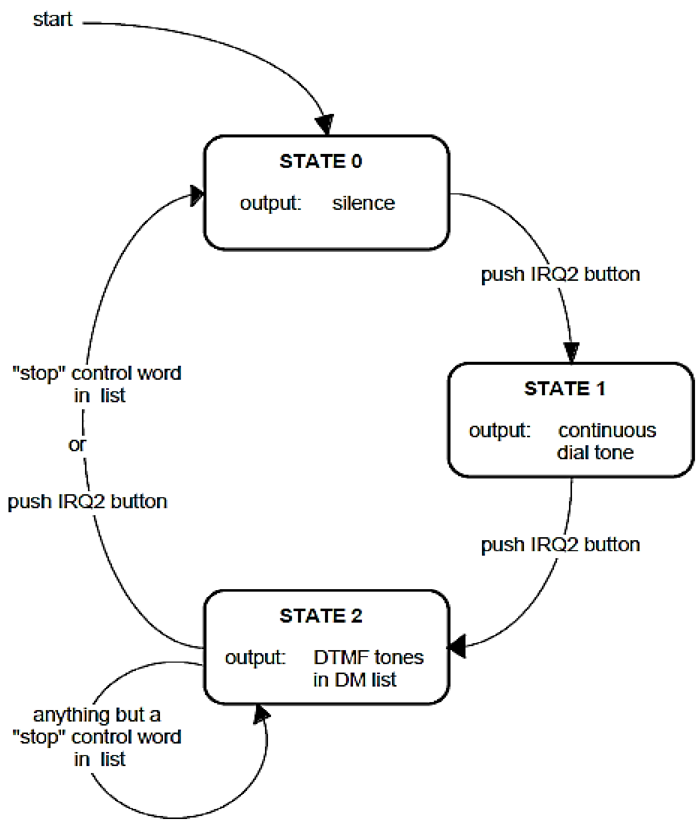

Figure 4: Vector based DTMF State chart.

The state machine has three states. Pushing the IRQ2 pushbutton moves the state machine into the next state. The current state of the machine is stored in data memory variable state. In the demonstration of program's state machine, the program starts in state 0. In this state, no digits are generated. Pushing the IRQ2 pushbutton moves the machine into state1, in which a continuous dial tone (350Hz + 400Hz) is generated. The state machine moves to state-2 when the IRQ2 pushbutton is pushed again. In state 2, the DTMF dialing list is sequentially read and DTMF digits generated. The state machine stays in state 2 until IRQ2 is pushed again or a "stop" control word is read out of the dialing list, in which case the machine jumps back to state 0.

4. Proposed System Architecture

The block diagram of the proposed system is shown in Figure 5. The system comprises decoder subsystem with MT8870D, control subsystem with keypad keys for system's operation, output interface subsystem, feedback subsystem, and the final output devices. The main subsystems for figure 5 are briefly discussed below.

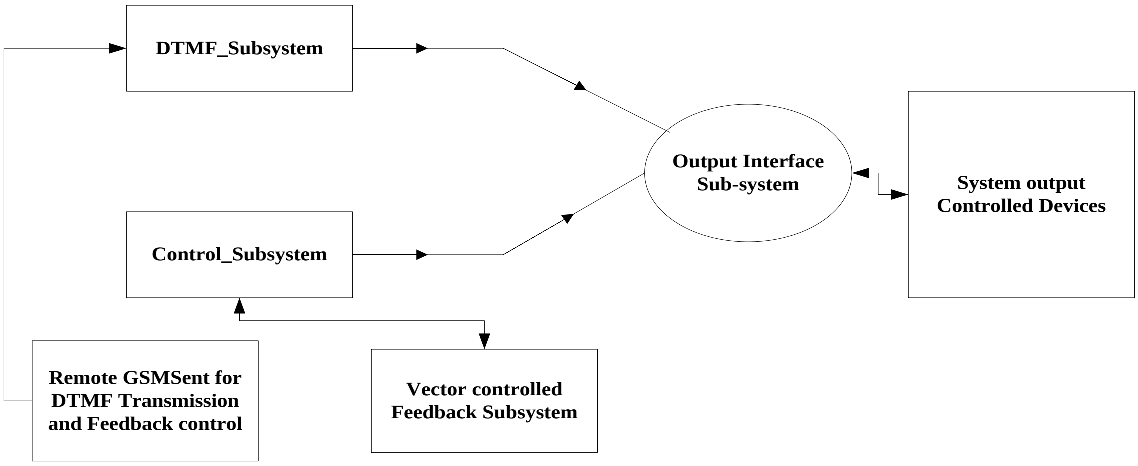

Figure 5: Basic System Architecture.

4.1. Decoder Subsystem

The decoder subsystem takes care of receiving the DTMF codes from the remote phone, sending it to the DTMF decoder and decoding the received DTMF code to equivalent digital format which the buffer sends to the controller for its control operations. The GSM handset key pad is decoded according to the Table 1 [17].

Table 1: Functional Decode Table for MT8870D

Digit	TOE	INH	EST	Q4	Q3	Q2	Q1
Any	L	X	H	Z	Z	Z	Z
1	H	X	H	O	O	O	1
2	H	X	H	O	O	1	O
3	H	X	H	O	O	1	1
4	H	X	H	O	I	O	O
5	H	X	H	O	I	O	I
6	H	X	H	O	I		O
7	H	X	H	O	I	I	I
8	H	X	H	I	O	O	O
9	H	X	H	I	O	O	I
O	H	X	H	I	O	I	O
*	H	X	H	I	O	I	I
#	H	X	H	I	I	O	O
A	H	L	H	I	I	O	I
B	H	L	I	I	I	I	O
C	H	L	I	I	I	I	I
D	H	L	O	O	O	O	O
A	H	H	L	X	x	X	X
B	H	H	L	X	X	X	X
C	H	H	L	X	X	X	X
D	H	H	L	X	x	x	X

L = Logic Low; H = Logic High; Z = High impedance; X = Don't care.

4.2. Vector Control Subsystem

This is the control section involving the Arduino microprocessor which coordinates the control operations. The control operations involved include: receiving the decoded DTMF codes (which is now in digital format), comparing the received codes with the preset codes for the different switching operations, if the code matches any of the preset codes, the designated switching operation is performed. Also a feedback text message is sent to the user at the remote end confirming that the desired operation was performed. Table 2 shows the GSM keys used to carry out designated operations. The control algorithm and system flow chart showing the sequence of control operation in the system are shown in Table 2 and Figure 4a and 4b respectively.

Table 2: GSM keypad Keys for System's Operation

DEVICES UNDER CONTROL	ACTION	PHONE KEYPAD USED	FEEDBACK MESSAGE
AIR CONDITIONER	ON	1	Device 1 is switched ON
	OFF	2	Device 1 is switched OFF
SECURITY LIGHTS	ON	3	Device 2 is switched ON
	OFF	4	Device 2 is switched OFF
WASHING MACHINE	ON	5	Device 3 is switched ON
	OFF	6	Device 3 is switched OFF
STANDBY GENERATOR	ON	*	Device 4 is switched ON
	OFF	#	Device 4 is switched OFF

Table 3: System Vector Control Algorithm

START
Initialize all memory locations to their starting values
Check for the DTMF bit for a high
***If** DTMF bit goes high **Then** Check the Data in input port and compare the codes received*
***If** codes are for Key1 **Then** switch ON device 1*
Send the feedback message for device1 to Designated Phone Number
Elseif
***If** codes are for key2 **Then** switch OFF device 1*
Elseif
***If** codes are for key3 **Then** switch ON device 2*
Send the feedback message for device2 to Designated Phone Number
Elseif
***If** codes are for key4 **Then** switch OFF device 2*
Elseif
***If** codes are for key5 **Then** switch ON device 3*
Send the feedback message for device 3 to Designated Phone Number
Elseif
***If** codes are for key6 **Then** switch OFF device 3*
Elseif
***If** codes are for key* **Then** switch ON device 4*
Send the feedback message for device 4 to Designated Phone Number
ElseIf
***If** codes are for key # **Then** switch OFF device 4*
End If
End

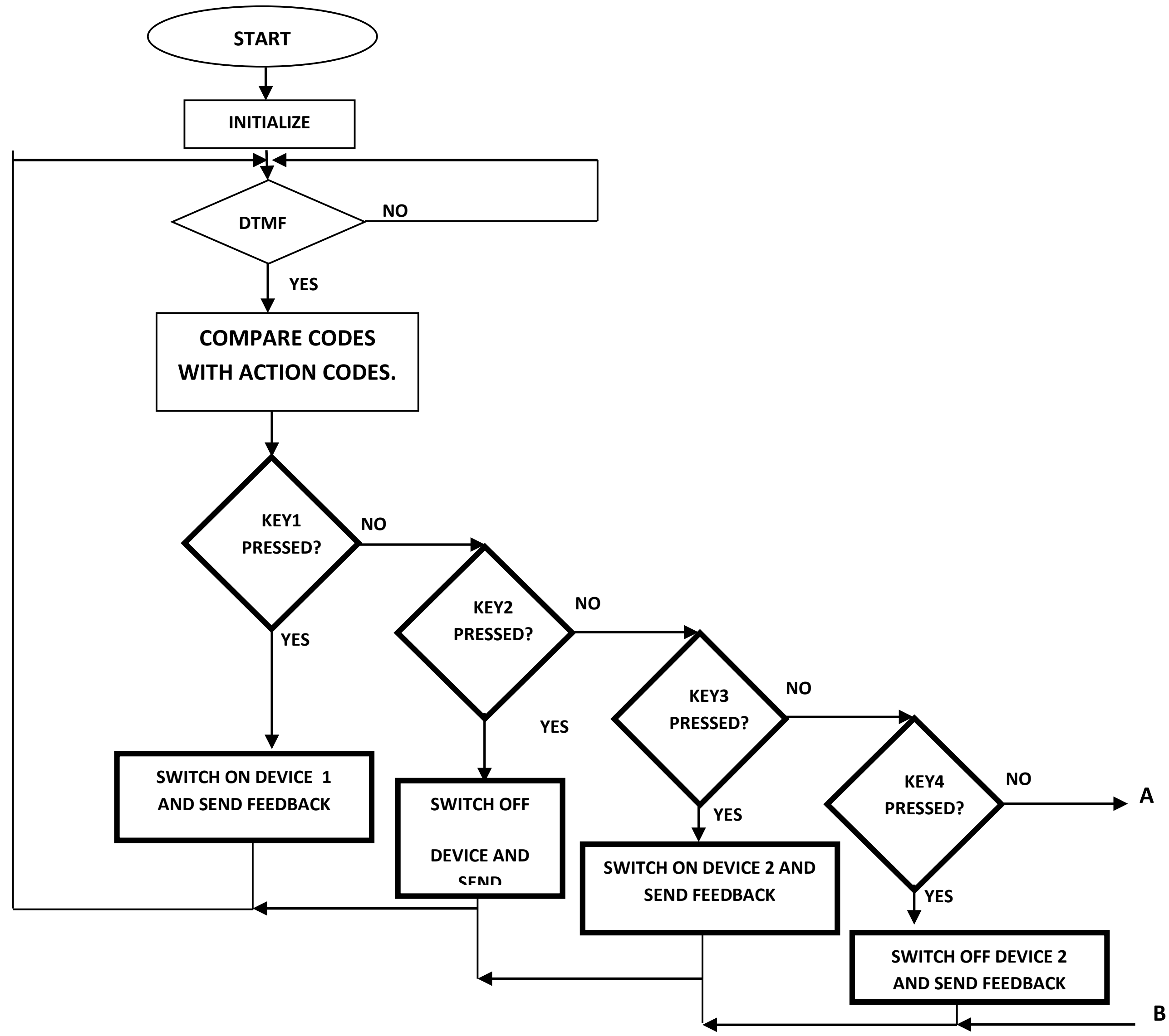

Figure 4a: System Flowchart of the control operation

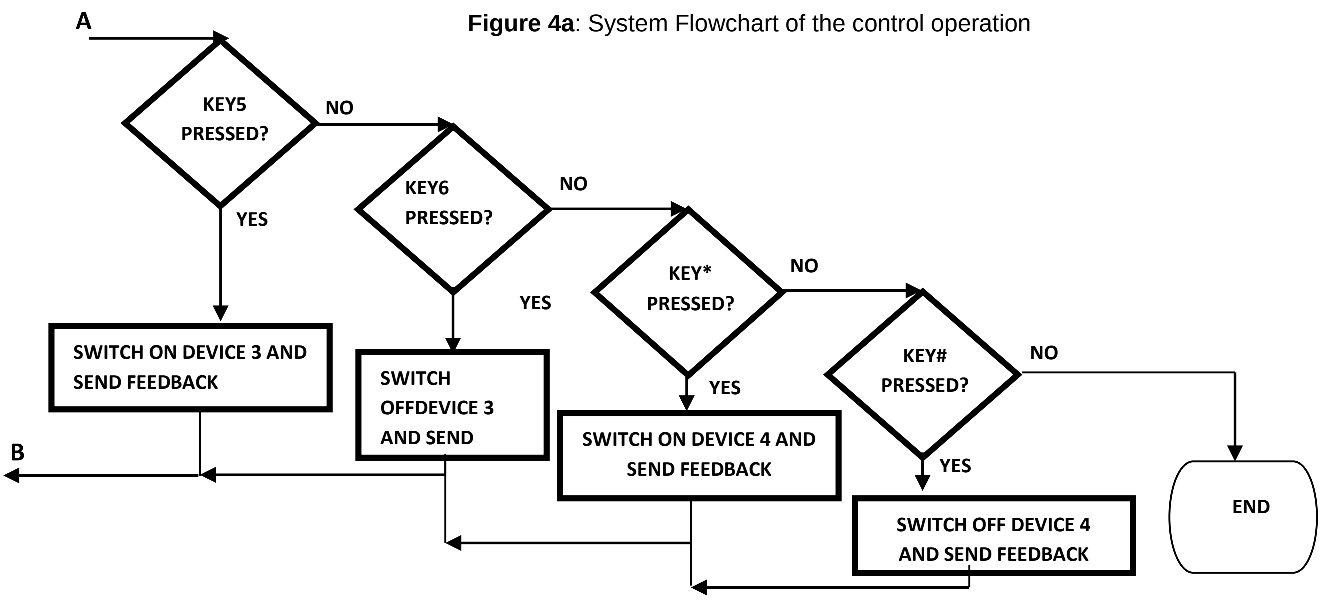

Figure 4b: System Flowchart of the control operation

4.3. Output Interface System

The output interface is responsible for executing the desired control. The interface receives instructions from the output bits and carries out the desired actions. The output interface is made up of the following components; resistors, opto-couplers (4N35), transistors (BC337) and relays (12v by 30A). The opto-couplers are necessary to ensure that there is no interference between the 12Vd.c supply, and 5Vd.c supply. They also help to protect the controller from undesired "kickbacks" that may be triggered by the relay contacts. Figure 5 shows the schematic diagram for the output interface derived from Figure 3.

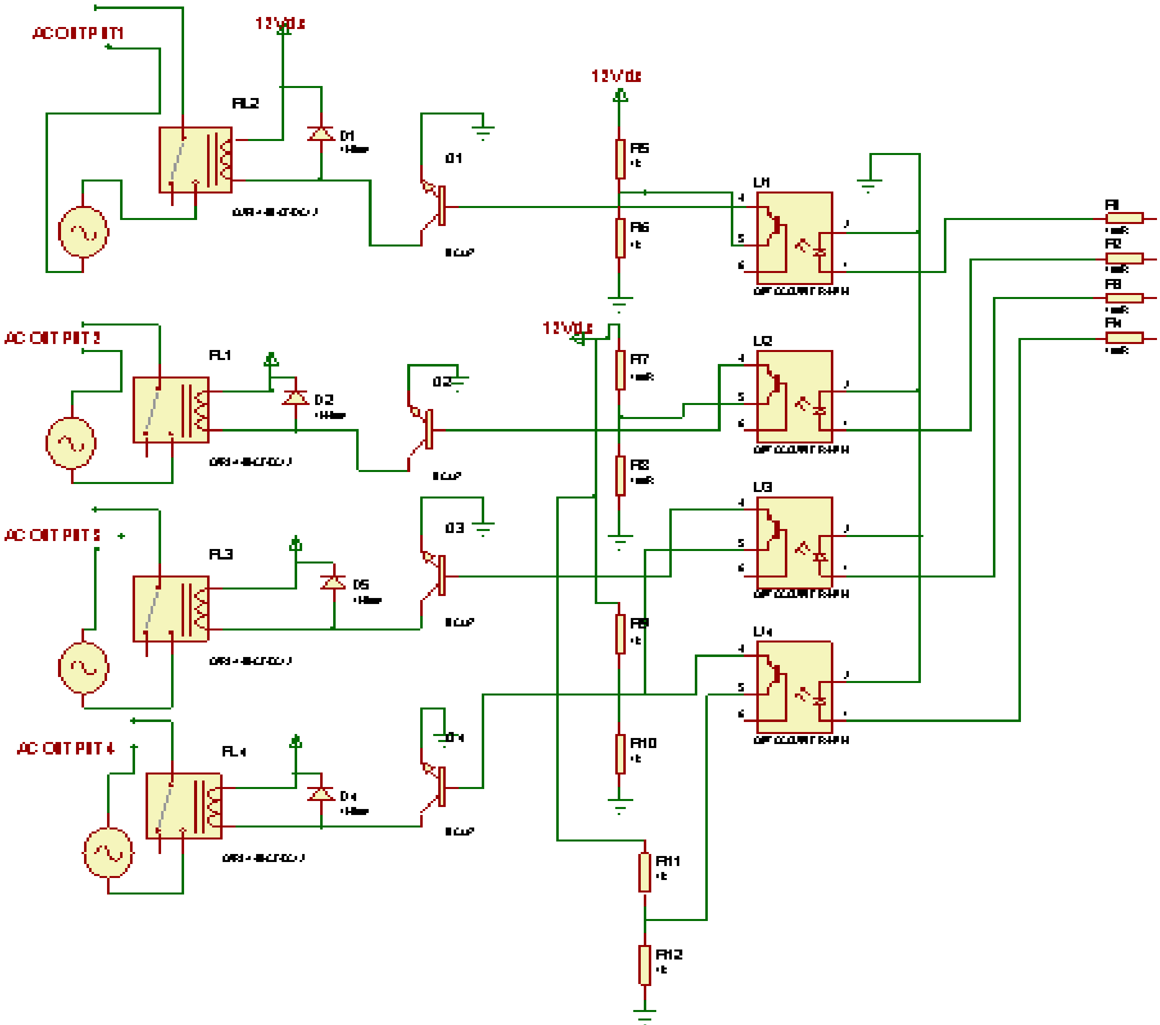

Figure 5: Output interface subsystem.

4.4. Feedback Subsystem

The schematic diagram for the feedback circuit is as shown in Figure 6. The final output devices are shown in Figure 7. These are the loads been controlled by the system. Examples are the air conditioner, security lights, washing machine and generator.

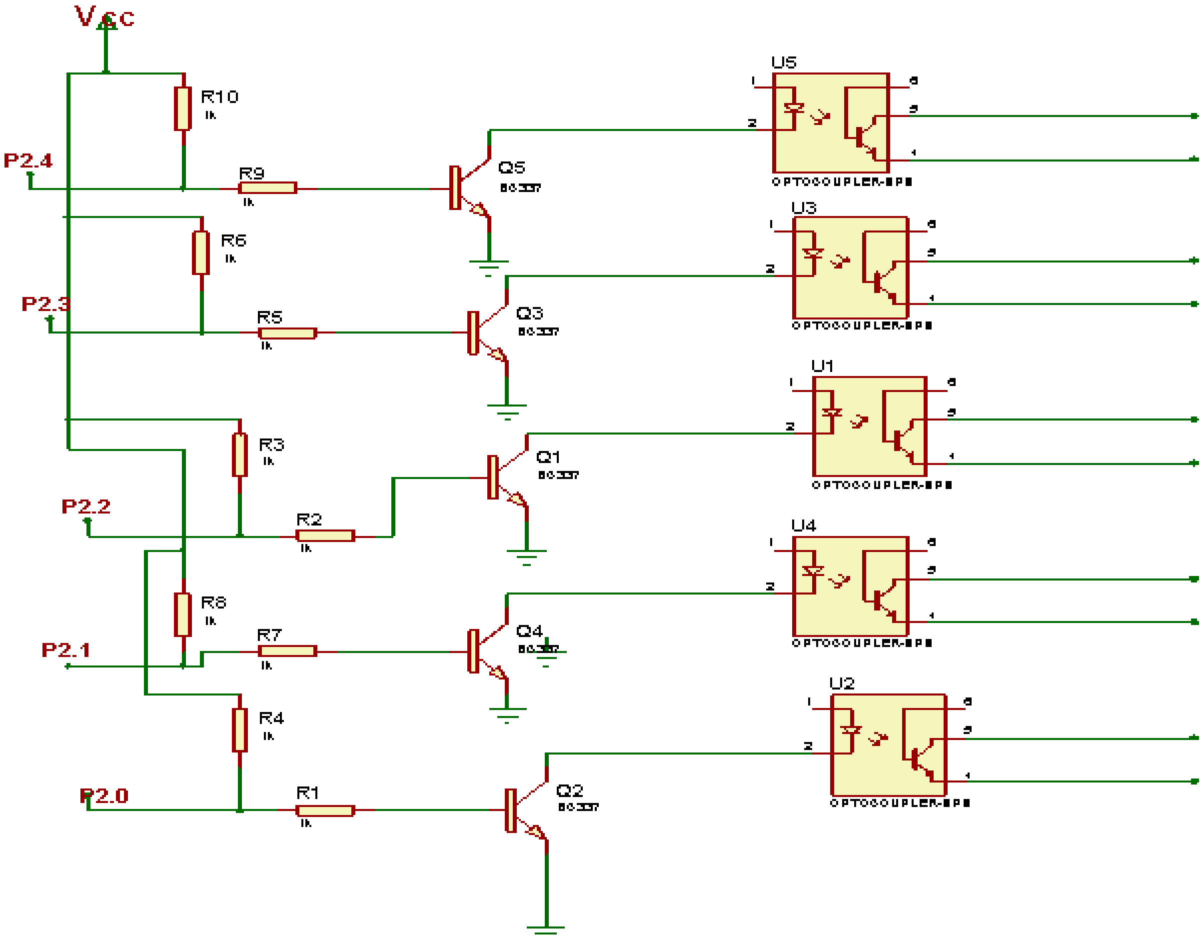

Figure 6: Cascaded Feedback section for actuation.

The feedback unit was implemented by switching the GSM keypad switches responsible for sending a text message to the designated remote GSM. This switching was achieved by using a pull up resistor of 1kΩ, BC337 transistor and 4N35 opto-coupler. The opto-coupler here is purely acting as a switch to control the key pad switches. The controller achieves the feedback by simply sending clock pulse to the designated bits at specified intervals.

From figure 7, the circuit components deployed include: Arduino UNO, GSM Module with SIM card, ULN2003, Relay 5 volt, Bulb with holder, Connecting wires, PCB, 16x2 LCD, Power supply unit, Mobile cell phone, external interface module box. Using the command prefix string such as "#*J*.", this will be used to identify that the main command is coming next to it; the "*", at the end of string indicates that message has been ended. Immediately, an SMS text, or voice call is sent to the GSM module via a mobile device, the GSM receiver decodes the SMS and sends it to Arduino that now decodes the SMS and extract main command from the received string and stores in a variable. The Arduino now compares this string with predefined string. If a match occurred then Arduino sends the DTMF signal to relay through low latency relay drivers for turning ON and OFF devices, objects or appliances, the results can be printed on a dashboard screen.

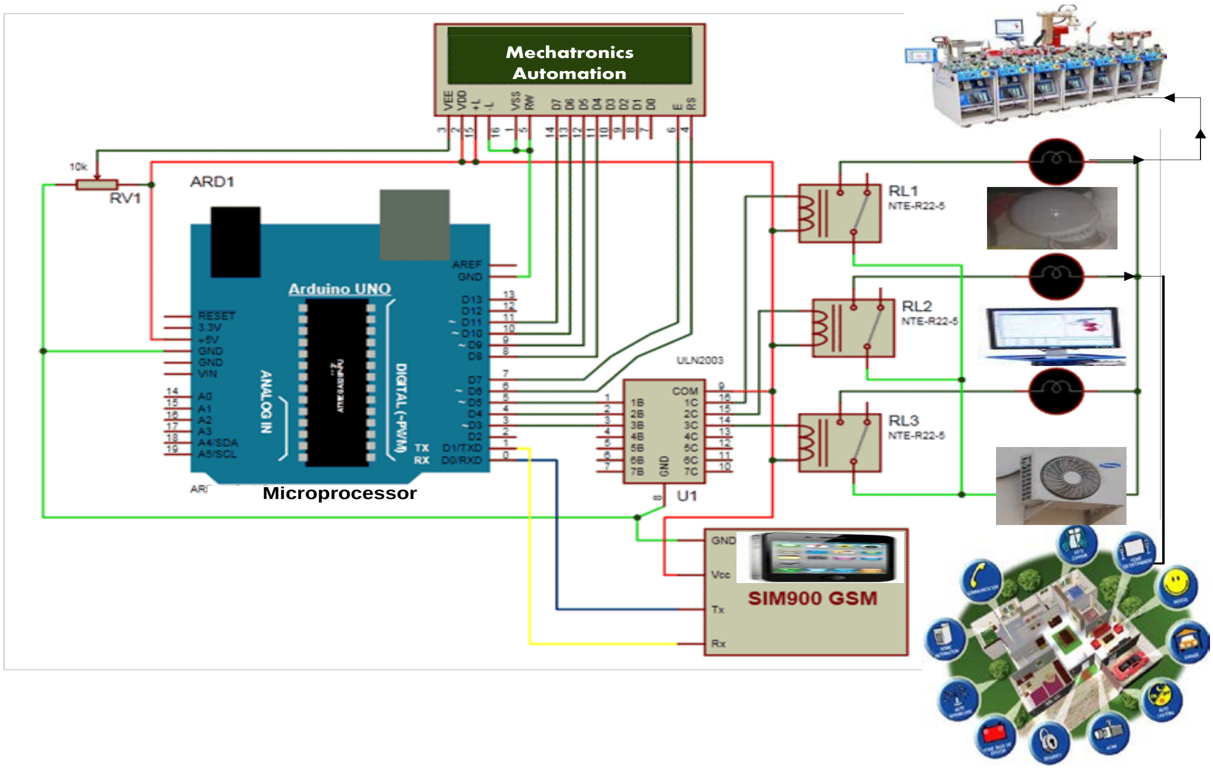

Figure 7: Complete system integration

5. Research Discussion and Implications

Considering Figure 7, a new trend of automation and data exchange in homes and industrial settings would include cyber-physical systems (CPS), the Internet of things (IoT) and cloud computing (CC). These elements are expected to change the way humans interacts with their immediate environments. Smart homes, smart factory, smart office, smart cars etc., will now depend fully on cyber-physical systems and its underlying processes to monitor physical systems while creating a virtual copy of the physical world. They can also make decentralized decisions with IoT. With IPV6 driving IoT, cyber-physical systems and machine automation can communicate and cooperate with each other intelligently. Such machine to machine interactions with humans in real-time, and via the Internet of Services sets the foundation for Industry 4.0 where mechatronics automation expresses super-intelligent capabilities.

Conclusion

In this paper, embedded system framework was used to develop Mechatronics system automation for the control of home/industrial appliances. Feedback vector control with Ardinuo IoT device was applied. This is particularly useful in environments were house owners, office users, industrial works etc., needs on-demand communication with gadgets or home appliance. The approach in this work offers major advantage over existing approaches outlined in [14] in terms of smartness and low latency. This approach supports low latency response from the core controller. Using remote DTMF codes with text message alert feedback, the developed system with survelliance capability can be installed in a remote location. This can be used monitor and deter intruders from invading secured facilities such as GSM base stations, power plants, etc. In such applications, the system basically detects the presence of intruders, and consequently alerts both the site managers and security operatives for emergency response. Protus simulation for the system was realized while observing that the applications of the system are limitless. Future work will introduce cloud analytics and trajectory data mining for query optimization. Also, experimental validation of low latency response will be carried out.

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