4.1 Introduction

In continuation with the detailed coverage of the designed and development of portable embedded device for bio-impedance measurement, the present chapter deals with the main intent of research i.e. wearable embedded set up to quantify the hydration of the body. The essential sub-parts for this system such as portable function generator and BIA measurement units are already been accomplished in Chapter 3 with the intended results. As reported in the concluding part of the previous chapter, the present chapter also presents analytical treatment, subsequent algorithm and system development to estimate the status of hydration level in the human body by using SFBIA method. The said design is based on the anthropometric parameter that estimates adequate amount of total body water. It is essential to find the gap between the present amount of water in the body and required amount of water to be refilled in order to maintain the perfect level. In order to achieve this standard percentage of water in the body subject wise, anthropometric parameter based popular Watson formula is used to calculate total body water (TBW).

Further section presents the design of final system to realize the hydration measurement by integrating all previous designed subparts. The said system has been implemented and tested on 16 bit high performance Texas Instrument’s microcontroller MSP430G2452. To quantify the real time hydration in the body, bio-impedance based most popular Lukasi formula has been applied in the system which gives the TBW volume. Conclusively system tested on many subjects including both male and female category to measure the hydration of the body.
4.2 Anthropometric based Total Body Water Calculator

The adequate hydration level in the body is decided on the basis of anthropometric parameters such as height, weight, age and gender. In medical field, many times this type of anthropometry data are collected and necessary evaluations and calculation are done to adjudge the analysis of body conditions. Anthropometrically total body water estimation is commonly used by dialysis units and many researchers to predict the modeled urea volume as per patient and dialysis characteristics. These estimated volumes are further compared and processed by various standard statistical analysis and regression analysis techniques. This developed system is beneficial as assistance for medical diagnosis. Anthropometric based total body water (TBW) calculator, the basis of the present system is based on equations which are detailed out in chapter 2. The following section covers the design details and experimentation.

4.3 Design and development of Portable Anthropometric based Total Body Water Calculator

Figure 4.1 presents the block diagram of portable unit of anthropometric based total body water calculator.

![Block Diagram of Portable Anthropometric based TBW calculator unit](image)

**Figure 4.1: Block Diagram of Portable Anthropometric based TBW calculator unit**
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

The TBW calculator unit is made up of following hardware subparts explained in the following section:

1. Keypad Unit:
Keypad unit is the set of 5 keys which takes actions as shift left, shift right, increment, decrement and enter to set the users anthropometric parameters value. The left shift key and right shift key are used to change the digit position, up and down key function to increase and decrease the value of digit and enter key is apply to freeze the value and change the next event as per programming algorithm.

2. Display Unit:
The 16*2 numerical LCD display is used for system interaction with the user and works with the keypad unit to acquire the requisite database of user. It also displays the results calculated by the system. The separate programming header file handles the complex routines of keypad and LCD unit.

3. Microcontroller Processing Unit
The 20 pin MSP430G2452 series has chosen herein which features 12 I/O pins, 8 KB flash and 256 byte RAM. The added internal pull up resistor facility of MSP430 has been utilized for keypad interfacing to minimize the external components. The Low Power Mode 0 (LPM0) is set to reduced the power consumption.

4. Power Management Module:
The power management module provides 3.3 V and 5V supply for MSP microcontroller and LCD Display respectively. Constant voltage regulator IC7805 and IC78M33 have been used to regulate in this module.

4.4 Design Aspects of anthropometric TBW calculator

This section elaborates on the logical sequence of events pertaining to anthropometric TBW calculator
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

- Initialize the I/O pins as per the keypad input and LCD input/output pins. The separate programming header file manages the keypad and LCD display routines.

- After the power up or reset state, the first string displayed on the LCD is “TBW Calculator”. After some delay the onwards string is displayed on first line of LCD to suggest the user to input the weight parameter through the message: “Insert Wt in Kg” and second line string: “Wt: _ _ _” prompts the user to insert the value with the 5 keys keypad module.

- After interrupting by means of any one of the keys, the appropriate action is taken according to specific key functions mentioned above and the respective changes are displayed on the LCD.

- Subsequent to the above, the user is prompted to furnish the information regarding age through message: “Insert Age in Yr” and second line string: “Age: _ _ _”. Further to fetch the height parameter similar routine is displayed.

- The gender information is acquired through the message: “Select Gender: _”. Alternate choice options are displayed “M” or “F” that is male or female.

- By collecting all the subject anthropometric parameters, the Watson TBW formula is selected as per the gender and total body water is computed. The Watson TBW formula for male and female is as follows:

\[
TBW (\text{Male}) = 2.447 - (0.09156 \times \text{age}) + (0.1074 \times \text{height}) + (0.3362 \times \text{weight})
\]

\[\text{Eq. 4.1}\]

\[
TBW (\text{Female}) = -2.097 + (0.1069 \times \text{height}) + (0.2466 \times \text{weight})
\]

\[\text{Eq.4.2}\]

After processing through the BCD to ASCII conversion routine, the desired amount of TBW water in body in terms of liter is displayed on LCD.

4.5 Software flow of the system

The following figure 4.2 presents the flow chart of the programming system.
• Define and Initialize the LCD Data pins RS, EN and Data lines D4 to D7 as an configured as output for P2.0, P2.1, P2.4, P2.5, P2.6, P2.7
• Define and initialize keypad Right, Left, Up, Down and Enter Key respectively for P1.0, P1.1, P2.2, P2.3 and P1.4 as an input.
• Enable the internal pull up resistor for the keypad pins.
• Enable the interrupt of keypad input port pins to key press detection

• Configure software flag register1 as event flag register to detect key pressed, display change and display value event
• Configure software flag register2 as set parameter register to detect set parameter position of weight, age, height and gender

• Configure the Display Digit, Digit No. and Display character in LCD Display Structure

• Start up the LCD initialization and configure the LCD step by step as set function, entry mode, display on cursor on and clear display
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

1. Set the cursor position on LCD at first line
2. Run the data write routine to display the string “TBW Calculator” for 2 Sec

- Clear the LCD Display
- Set the weight bit of Set parameter Register

Set Loop:

Switch
(Set parameter Register bit check)

- Weight
  - Yes
  - Age
    - Yes
    - Height
      - Yes
      - Gender
        - Yes
        - Calculate total body water

- No
  - Height
    - Yes
    - Gender
      - Yes
      - B
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

Gender is Male?

Yes

Run Watson Male TBW formula

Convert result into binary to decimal format

- Clear LCD
- Set the cursor position on LCD at line 1, position 2
- Run the data write routine to display the string "Your TBW is:"
- Display string "Your TBW is : " on line 1, position 2

No

Run Watson Female TBW formula

- Set the cursor position on LCD at line 2, position 4
- Run the data write routine to display the decimal 1, decimal 2, decimal 3
- Followed the display string "Lt ", STOP
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

- Clear LCD
- Set the cursor position on LCD at line 1
- Display the string “Insert Wt in kg”

- Set the cursor at line 2 position 0
- Display the string “Wt.”

- Set the cursor at line 2 position 4
- Display default value 000

Function of get value to collect keypad data

- Data value is = 0?
  - Yes: Set Loop:
  - No: Set the age bit of parameter register

- Clear LCD
- Set the cursor position on LCD at line 1
- Display the string “Insert Age in Yr.”

- Set the cursor at line 2 position 0
- Display the string “Age.”

- Set the cursor at line 2 position 5
- Display default value 000

Run Function of get value to collect keypad data

- Data value is = 0?
  - Yes: Set Loop:
  - No: Set the height bit of parameter register
Figure 4.2: Software Algorithm of anthropometric based TBW Calculator
4.6 Hardware set up of the TBW calculator unit and consequence of the system

Figure 4.3 reveals the detailed construction of design. Figure 4.4 shows the hardware prototype of TBW calculator and initial state of the system.

![Hardware setup of anthropometric based TBW Calculator unit](image)

**Figure 4.3 Hardware setup of anthropometric based TBW Calculator unit**

Figure 4.3 illustrates the functional modality of the calculator to acquire the subject body parameters, which is already been elaborated in the previous section. After collecting the information from user, the result of the total body water as per the Watson formula is displayed in Liter unit. Figure 4.4 shows the inserted weight, age, height and gender parameters and as per the calculated adequate amount of water displayed on the LCD. The board size is compared with the coin so as to highlight its miniature nature. The board is truly wearable and can be placed in the pocket of the subject.
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

Figure 4.4 Ordinal stages of the calculator

Figure 4.5 Calculated adequate amount of TBW displayed on LCD
4.7 Overall system integration

As the hydration is the dynamic process, and gets heavily influenced by the biological processes, the same poses challenges in its measurement. Though there are different methods to monitor the hydration status they differ in precision, accuracy, amenability with expertise solution, practicability and budgetary constraints. However it is beyond any doubts that about the hydration condition of the body is not only required to be monitored in clinical perspective but also in day to day life to promote the health and maintain well being. Our research design and development aim is commensurate with these demands and the solution synopsis is capable to sync with the body hydration needs by assessing own hydration database whenever required. Entire design focus is on getting the synergy of the hardware and software. The changes of water level in the body are measured by sending 50 KHz frequency throughout the body to determine the bio-impedance of the subject.

The system is also computationally intensive. Regression formulae have been implemented to calculate the total body water based on the bio-impedance measurement. The calibration and measurement aspects have been validated with the BIA. The most popular reference method i.e. Dual energy X-ray absorptiometry (DXA) has been used for better correlation. One of that, best low error formula is included in the system to measure the total body water at SFBIA frequency i.e. 50 KHz. Through the set of equations used herein we can easily predict the requisite amount of water in the body and give warning to the subject to refill the shortfall. Bird’s eye view of the system is presented in the following section.
4.8 Overview of system vis a vis with the bird’s eye view

Figure 4.6: Overview of the system vis a vis with the bird’s eye view

Figure 4.6 reveals the bird’s eye view of final set up. Analog signal conditioning parts such as ADC and DAC, Programmable DDS Core unit and digital signal processing engine are concatenated on a single chip IC AD5933 based on on-board technology solution. Design metrics related to portability such as reducing the footprint of design area, low power hungliness, longer battery time along with the cost effective smart embedded solution just to name a few. The bio-impedance value is measured through this block by utilizing the inbuilt DDS core, ADC and DAC unit and DSP engine core. DDS block produces programmed 50 KHz sine wave frequency and consecutively converts this digitized coded signal into analog nature to transmit through the body. The receiver section comprises of ADC to convert the signal into digitized coded format and calculate the impedance and phase value by processing through the DSP engine. The analog front end circuitry has been deployed for amplifying and biasing purpose so as to detect the
small impedance range value. The medical standard AgCl type electrodes used to sense the impedance response of the subject. The ultra low power microcontroller MSP430 variant has been used as a brain of the system which processes data, controls the peripherals unit, undertakes input output display management and thus inculcates smartness in the device. MSP430G2452 type variant of value line series by Texas Instrument vendor is opted for the system realization. It features 256 Byte SRAM, 8 KB Flash, 16 I/O pins, universal serial interface (USI) communication peripheral for SPI and I²C and 3 timer. The detail functionality of microcontroller with respect to this system design has already been explored in previous sections. Keypad module with 5 key combinations is used for inputting the anthropometric parameters of the subject. The 16*2 LCD module is used for demonstrating the calculated result and also to give the instructions to user in the step by step manner. The system metrics such as high performance, low-power, system incredibility in appropriate cost have been given due diligence in the entire design process. Inclusion of the advanced technology in the system, Network analyzer IC AD5933 and the high performance MSP430 microcontroller have made the system efficaciously and proficiently. The entire system integrated in portable fashion which is of the very necessity of any wearable medical device. Following section covers the analytical treatment and the same has been used in the programming to measure TBW, besides other parameters such as body fat mass and body mass index.

4.9 Analytical Treatment

Various formulae to calculate total body water (TBW), fat mass (FM), fat free mass (FFM) and body mass index (BMI) are detailed herein and their interpretation is covered in table 4.1.
Table 4.1: System used regression formulae for assessment of body compositions

<table>
<thead>
<tr>
<th>Characteristic Symbol</th>
<th>Source Formula</th>
<th>Function</th>
<th>Equation</th>
</tr>
</thead>
</table>
| TBW<sub>AP</sub>       | Watson         | To measure as reference of desired amount of total body water in the subject body based on anthropometric parameters | TBW<sub>AP</sub> for Male:  
  \[= 2.447 + (0.1074 \times Ht) + (0.3362 \times Wt) - (0.09516 \times Age)\]  
  TBW<sub>AP</sub> for Female:  
  \[= -2.097 + (0.1069 \times Ht) + (0.2466 \times Wt)\] |
| TBW<sub>BIA</sub>      | Deurenberg     | To measure current state of total body water in the subject body based on the single frequency bio-impedance analysis at 50 KHz | TBW<sub>BIA</sub> = 6.53 + (0.36740 \times Ht^2 / Z_{50}) + (0.17531 \times Wt) - (0.11 \times Age) + (2.83 \times Sex) |
| FFM                    | Standard constant | To measure the Fat Free Mass from the TBW<sub>BIA</sub> | FFM = TBW<sub>BIA</sub> \times 0.73 |
| FM                     | -              | To measure the Fat mass | FM = Wt - FFM |
| BMI                    | -              | To calculate the ration of body mass index | BMI = \text{Weight in Kg / Hight}^2 \text{ in meter} |
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

Where the consideration parameters in unit range as,

Ht: Height in cm, Wt: body weight in Kg, Age in years, Sex: gender (For male = 1, female = 0), $Z_{50} =$ impedance at 50 KHz

4.10 Holistic Integration of the System

The final integration of the system is accomplished by amalgamating the individual sub-designs which have already been dealt in depth previously. The Microcontroller MSP430G2452 has 2 port with 16 I/O pins in which 13 I/O pins have been utilized. P1.0

Figure 4.7 Holistic Integration of the System
to P1.4 pins are used for the keypad interfacing functions namely Left shift, right shift, up shift, down shift and enter. The internal pull up register and high to low edge triggered interrupts are enabled as per the respected pins of keys. Port 2 has been used for the LCD interfacing, RS and EN key are linked with P2.0 and P2.1 pin; the upper nibble of port 2.4 to P2.7 are connected to the upper data lines of LCD. P2.6 and P2.7 are multiplexed with USI peripheral module function and to determine its selection register P1SEL and direction register P1DIR are configured according the input-output direction needed for the USI module. The feedback register and calibration register are calculated as per the equations details derived in the previous chapter in view of human bio-impedance range and the same have been fixed in the circuitry. As per the settled register value the gain computed and the calibration value at 50 KHz frequency is set in the software for magnitude calculation. With the details of sub design modules in place now we cover the logical flow for the entire system.

4.11 Sequence of Events for the wearable embedded hydration realization unit

- Initialize the directions of input/output pins of port 1 and port 2 as per the keypad, LCD and USI module requirements. Enable the internal pull up register of correspondingly interfacing pins of keypad and I²C by setting the high bit of P1REN resistor. Configure the high state of 7th and 8th bit of P1SEL register to select the multiplexed port pins for USI peripheral module.
- Configure the set up of USI module by setting the appropriate bit of USI control register USICTL0 and USICTL1. Choose the SMCLK clock for I²C communication (SCL) at 125 KHz and enable the interrupt of I2C.
- The separate header file is defined in the project for managing the input/output routines of Keypad and LCD. The cursor of digit position is switched with the right and left operation of keys, up and down keys for increased and decreased the digit value of settled the digit position. After inserting the enter key, the value is fixed and fetch in the processor for computing and also it goes to the next event as per the algorithm steps of programming.
Upon powering up or reset state, display the string on first line of LCD as “Hydration Analyzer” for 10 second. Onwards the string displayed on LCD to notify the user “Insert parameters” for 5 Sec.

The keypad is enabled to capture the required anthropometric information from the user to display the string to insert the weight parameter is “Insert Wt in Kg” on first line of LCD and second line string display and fetch the inserted value is “Wt:000”. Accordingly after detecting the interrupts of any key, the respective action takes place and changes are pointed out on the LCD display.

After this capturing the height parameter is fetched by displaying the string on first line “Insert Ht in cm” and on second line “Height:_ _ _”.

To receive the age parameter, display the string on first line of LCD is “Insert Age in Yr” and second line “Age:_ _ _”

At last, the string is displayed on LCD as “Select Gender:_”. The special key pressed routine is processed here to choose alternate options between “M” or “F” corresponding to male or female. All above entered subject parameters are stored in register.

After fetching the entire parameters of subject body, the string “place electrodes” is displayed on LCD at first line and run the delay for 15 Second. Further clear the LCD and display the string “Wait” up to the processing is over.

Run the initial I²C communication routine by sending the specific 7 bit device address of AD5933, transmit and receive the data by using the commands of block read, block write, address pointer.

Generate the 50 KHz sine wave of peak to peak 2.2V amplitude by programming and setting the appropriate frequency sweep parameters of AD5933 relevant register as per the explanation mentioned in previous chapter. Passed this produced frequency throughout the subject body.

Read the Real and Imaginary data and converted it into magnitude value by processing formula with the calibrated gain factor. Store the calculated bio-impedance value into register as variable name R_{BIA}.

Run the Watson formula to calculate the total body water (TBW_{AP}) as for measure adequate amount of body water as per the characteristic of subject.
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

Watson equations for male and female are given as,

\[
TBW_{AP}(Male) = 2.447 - (0.09156 \times \text{age}) + (0.1074 \times \text{height}) + (0.3362 \times \text{weight})
\]

……….. Eq.4.3

\[
TBW_{AP}(Female) = -2.097 + (0.1069 \times \text{height}) + (0.2466 \times \text{weight})
\]

……….. Eq. 4.4

The calculated reference TBW amount is saved in the register as one of the parameters.

- Run and calculate the present amount of TBW by putting the gained bio-impedance value of the subject in the Deurenberg formula. Deurenberg equations for male and female are given as,

\[
TBW_{BIA} = 6.53 + 0.36740 \left( \frac{\text{Ht}^2}{\text{R}} \right) + (0.17531 \times \text{weight}) - (0.11 \times \text{age}) + (2.83 \times \text{gender})
\]

……….. Eq. 4.5

For Male, gender = 1
For Female, gender = 0

- Demonstrate the calculated TBW\(_{BIA}\) amount on the LCD display after processing the BCD to ASCII conversion. The string is displayed on the first line of LCD is “Your TBW amount:” and the calculated body water is displayed on the second line of LCD in Lt unit is “_ _ _ Lt” for 10 Second.

- To give the information of the current and desired count of the body hydration condition as per the types such as mild dehydration, moderate dehydration and severe dehydration, compute it in terms of lack of percentage amount. The formula designed for this is,

\[
\text{dehydration in } \% = \frac{TBW_{BIA} - TBW_{AP}}{TBW_{AP}} \times 100
\]

………..Eq. 4.6

- The system gives alerts to the user on the LCD display as per the dehydration percentage expressed in Table 4.2,
Table 4.2: System Calibration and alerts

<table>
<thead>
<tr>
<th>Percentage level</th>
<th>Alert string display on LCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 1 %</td>
<td>Well hydrate</td>
</tr>
<tr>
<td>Above 1 % to 2%</td>
<td>Mild dehydrate</td>
</tr>
<tr>
<td>Above 2 % to 5%</td>
<td>Moderate dehydrate</td>
</tr>
<tr>
<td>Above 5% to 10%</td>
<td>Severe dehydrate</td>
</tr>
<tr>
<td>Above 10%</td>
<td>Emergency</td>
</tr>
<tr>
<td></td>
<td>Consult to doctor</td>
</tr>
</tbody>
</table>

- Supplementary body parameters are obtained by pressing the next key (right shift key) and prior information by pressing the previous key (left shift key). Other additional parameters calculated and displayed orderly as FFM (Fat Free Mass), Fat Mass (FM), Body Mass Index (BMI).

4.12 Core Algorithm of the system

The detailed software flow of the system is portrayed in the algorithm in a step wise manner.
Set internal DCO at 1 MHz
- Define and Initialize the keypad pins right shift, left shift, up, down and enter in that order of P1.0 to P1.5.
- Initialize the upper data lines of LCD are linked with the upper nibble of Port 2. Define and connect RS and EN control lines of LCD to P2.0 and P2.1 pin.

- P1DIR register set as input directions for the keypad pins. Also respected internal pull up register enable by setting the bit of P1REN. Also enable the port interrupt for high to low edge detection when key is pressed.
- Set P2DIR register for output directions for LCD pins.
- Respected bit of P1.6 and P1.7 are defined for USI module SCL and SDA lines. Enable the internal pull up register bit of P1REN register. Configure the 7th and 8th bit of P1SEL register to select multiplexer lines of USI module.

- Initialize the setup to configure USI module for I²C peripheral and enable the USI interrupt by using USI control register
- Set USI SCL clock at 125 KHz by dividing SMCLK clock
- Enable USI and clear the pending flag
• Set software flag register name as ‘event flag register’ to handle the events of key pressed, display change and display value event
• Configure another software flag register name as ‘set parameter register’ to detect events of parameters set of weight, height, age, gender

• Configure the Display Digit, Digit No. and Display character in LCD Display Structure
• Initialize the LCD Display structure for Display Digit, Digit No. and Display character.

• Start up the LCD initialization and send set function command for configure 4 bit data mode
• Run step wise command as entry mode for auto increment, display on cursor on and lcd display to clear the LCD

• Set the cursor place on LCD at first line position 0
• Run the data write routine to display the string “Hydration Analyzer” for 10 Sec
• Clear the display and write next sting for 5 Sec to notify is “Insert Parameters”
- Clear the LCD
- Set the weight bit of flag register of set parameter register

SetAP_Loop:

Switch (Set parameter register)

- Weight
  - Y: P
  - N
    - Height
      - Y: Q
      - N
        - Age
          - Y: R
          - N
            - Gender
              - Y: S
              - N
                - Break

- Clear the LCD and set cursor position on first line
- Run data write routine to display string “Place electrode” for 15 Second.
\[\text{C}\]

- Clear the display and set cursor at first line 7 position
- Run the data write routine to display the string “Wait” up to processing is over.

Reset the AD5933 IC by sending the appropriate commands through I2C communication

- Run the function to set up the sweep parameter registers for 50 KHz frequency by sending through the command format at relevant register addresses of AD5933

Run the function for initialize with start frequency command

Run the function to read the status register bit

DFT Conversion process is complete? No

Yes
Run function to read the result value of Real and Imaginary registers of AD5933

Concatenation of 8 bit real and imaginary registers value in 16 bit register and converted into float format

Run the formula to calculate the impedance magnitude value by gain calibration processing

Store the calculated impedance result value in variable

Is gender Male?

Yes

Run the Watson Male TBW_AP formula

Store the calculated reference TBW_AP result amount in variable register

No

Run the Watson Female TBW_AP formula
- Run the Deurenberg formula to calculate current TBW_BIA amount and store it in variable register name as TBW_BIA
- Set Display_State = 0

Run the dehydration percentage formula

If dehydration < 1%?
- Warning string is “Well hydrate”

If dehydration > 1% & < 2%?
- Warning string is “Mild hydrate”

If dehydration > 2% & < 5%?
- Warning string is “Moderate hydrate”

G
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

Warning String is "Severe hydrate"

If dehydration > 5% & < 10% ?

Warning String is "Emergency - Consult Doctor"

If dehydration > 10% ?

Run the formula and calculate Fat Free Mass (FFM)

Calculate Fat Mass

Calculate BMI Index

Display Loop:

Switch (Display State)

Run routine for Display TBW_AP amount on LCD

Case 0

Y

I

N

H
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

H

Case

Y

Display warning string on LCD

Case

Y

Display FFM amount on LCD

Case

Y

Display FM amount on LCD

Case

N

STOP

Case

Y

Display BMI amount on LCD

My_Loop:

Enter LPM4 mode & enable the keypad interrupt

Right key press or up key press?

T

Display State by +1

F

Lef key press or down key press?

T

Display State by -1

F

My_Loop:
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

- Clear LCD
- Display the string on 1\textsuperscript{st} line “Insert Wt in kg”
- Display the string “Wt:” on 2\textsuperscript{nd} line
- Followed on 2\textsuperscript{nd} line initial value 000 displayed

Function of get value to collect keypad data

\[
\begin{array}{c}
\text{Data value is } 0? \\
\text{Y} \\
\text{Set_AP Loop:} \\
\text{N}
\end{array}
\]

- Set the height bit of parameter

\[
\begin{array}{c}
\text{Data value is } 0? \\
\text{Y} \\
\text{Set_AP Loop:} \\
\text{N}
\end{array}
\]

- Set the age bit of parameter register
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

R

- Clear LCD
- Display the string on 1st line “Insert Age in Yr”
- Display the string “Yr:” on 2nd line
- Followed on 2nd line initial value 000 displayed

Function of get value to collect keypad data

Data value is = 0?

Y

Set_AP Loop:

N

Set the gender bit of parameter register

S

- Clear LCD
- Display the string on 1st line “Select Gender”
- Followed the display character ‘_’

Function of get value to collect keypad data

Data value is = 0?

Y

Set_AP Loop:

N

Break
Figure 4.8: Algorithm of entire integrated system of hydration analyzer unit
4.13 System software

System software design has been profound significance in the embedded system life cycle looking at the constraint of memory and time. For TI’s microcontroller and embedded processor portfolio there are many software development tools. Some of them are Energia, Code Composer Studio (CCS), IAR embedded workbench and Open source GCC. We have resorted to CCS an integrated development environment for design and development of the system software to achieve the best possible combination of performance that too in small development time. CCS v5.3.0 free license version software used herein which supports a 16KB code size limit for TI compiler or no limit with GNU compiler collection (GCC). This version is based on the rich development environment platform such as on Eclipse software framework with additional benefit of embedded debugging capability for embedded developer. It allows user to integrate broad range of 3rd party plug-ins and upgrade open source components including meliorations in performance and usability. It supports a unique and powerful set of plug-ins with MSP Series MCU to fully leverage the microcontroller. Some of the benchmarking improvement points of CCS v5.3.0 are listed below:

- Includes source code editor window, optimized C/C++ compiler, project build environment, debugger and its profile view.
- Separate C/C++ source code window and debug window are available by easily automatic or single click switching mode
- Debug window view is much simpler, cleaner and more customizable to display more or less of JTAG hierarchy
- Multi CPU variants are scheduled below the project and easily changed the target configuration mode.
- Commands can be sent as example load programming, run, halt, step into, run to line, reset and restart.
- Status information of all CPUs display in single view.
- Automatically highlights syntax errors, console view errors, C/C++ smart search works
Open up a web browsing window inside CCS and easily connecting with TIs resource explorer.

Eclipse open source framework benefited to managed make files, standard industry momentum to leverage work of others platform easily and cross platform support of window/Linux.

The following section briefly demonstrates the steps followed for creating the project file, target configuration and debugging mode session by using CCS integrated development environment.

### 4.13.1 Creating a project file

After double clicking the icon of the desktop - Code Composer Studio 5.3.0, workspace launcher window locate default CCSv5 workspace or selects the specific custom directory. Figure 4.9 shows the snapshot of CCS default opening TI resource explorer environment window.

![Figure 4.9: Code composer studio v5.3.0 opening and showing the launched default TI resource Explorer environment window](image-url)
System project is created by selecting the installation steps such as File → New CCS project and selecting the appropriate settings in the generated window ‘New CCS Project’. Project Name as → Hydration_analyzer, Output type → Executable, Family of microcontroller → MSP430, and Variant → MSP430G2452. Figure 4.10 demonstrates the GUI.

![Image of New CCS Project window with Project name set to Hydration_Analyzer, Output type set to Executable, and device settings for MSP430G2452.](image)

**Figure 4.10:** Code composer studio v5.3.0 ‘New Project Creation’ GUI
4.13.2 Adding header files

Generated project is entitled in the project explorer window. The bold project name in the list represents the active state of project. Separate header files declared in the respected project to interface the input/output parameters and peripheral controls. “lcd_keypad” and “I2C_AD5933” header file included in the directory of the main project and interfaced with the source file of the program. The functions declarations and macro definitions are defined in the related header file and to be shared betwixt source file. The figure 4.11 illustrates the procedure to follow at the time of including header file in the project.

Figure 4.11 Adding header files to the project
CCS records and keep tracks of the necessarily information to build a target program and included library. Source code file names, object libraries, include file dependencies, compiler, assembler and linker options are recorded in the concerned project. Further figure 4.12 and 4.13 exemplifies the included headed files with .h extension in the source folder: Hydration_Analyzer.

![Image of Figure 4.12: Including lcd_keypad.h header file in the project](image1.png)

Figure 4.12: Including lcd_keypad.h header file in the project

![Image of Figure 4.13: Including I2C_AD5933.h header file in the project](image2.png)

Figure 4.13: Including I2C_AD5933.h header file in the project
4.13.3 Programming and Debugging aspects

CCS provided two default perspectives, one is C/C++ perspective and another is debug perspective. These perspectives are arranged correspondingly with the set of windows, menus for specific set of tasks and views. The C/C++ perspective view of the concerned project is shown in the following Figure 4.14.

![Figure 4.14: CCS v5.3.0 C/C++ code perspectives window – Code views, project contents and editor]

After completing the codes as in the main source file and header files, the project is compiled by taking step as, Project → Build Project. Build configuration set up are managed and changed for the compiler and linker by setting through properties
window. The resulting executable notifications are displayed in the Console and Problems window.

TI provides a JTAG interfacing protocol for all MSP430 series to develop program, debugging the microcontrollers and flash programming. A specific serialized protocol called Spi-By-Wire based on 2 wires developed and provided by TI for their MSP430 MCUs. This debug mode in CCS software can be executed by choosing the path through Run → Debug or direct clicking on the symbol present on the toolbar. By clicking on it, debug session is start which automatically switched C/C++ perspective window to debug perspective window. Figure 4.15 shows the debug perspective window of the system code.

Figure 4.15: Debug perspective view of the CCS studio – Running code steps views, local variables and registers view, Disassembly
Emulator is used to debug directly into hardware so that Real time value of local variables, watch, registers and memory addresses are obtained. Debug view gives auxiliary information about the memory address, data type and value in various number formats. It supports many operations as Run, halt, step into, step over, assembly step into, run to line, restart, reset CPU and terminate which illustrated in the following figure. MSP-EXP430G2 Launchpad is providing an on-board emulation tool for flash programmer and debugging purpose which is used at time of system development. Figure 4.16 depicts the snapshot at the time of system testing issues and exemplifies the process using hardware software co-design methodology using the set up of CCS software and MSP-EXP430G series Launchpad debugger.

Figure 4.16: System testing process using hardware software co-design set up
4.14 Results and discussion

This chapter reported the fully customized total body water measurement set up based on the BIA principle for realizing hydration status of the body. Various snapshots of the system have presented underneath to realize the working stages of the device and usefulness of the setup. Figure 4.17 shows the entire view of the hydration measurement system with AgCl electrodes.

![Figure 4.17: View of Hydration measurement system with right and left segment electrodes](image)

Following snapshots of the set up gives the brief idea about the system respectively. As the system is required to acquire the body information from the user to predict hydration status, it displays the notifications on the LCD step by step. After start up the system, first of all it shows the notification for collecting the anthropometry parameters of the subject.
By delaying little time, next string is displayed on LCD to capture the weight parameters as shown in below figure 4.19. The keypad module is open at that time to insert the value. Further other parameters height, age and gender are inserted in same manner.

Figure 4.18: Communicate with the user through LCD Display

Figure 4.19: Collection of weight parameter value of the user through keypad assistance
Figure 4.20: System interactive notifications for the user

The system interacts with the user through the visualization display, some of them are demonstrated in above figure 4.20.

Figure 4.21: Results of the System displayed on the LCD
Figure 4.21 illustrates the system results - in terms of present water volume in the body, current hydration status of the body and other related parameters. In one of that parameter, body mass index (BMI) result of the subject is depicted clearly.

4.15 Conclusion:

The embedded device for hydration measurement is successfully carried out using the SF-BIA method. The device not only measures the TBW amount of body but also it verifies the hydration status and notify to the user with concerned decision. Other related body parameters namely fat mass, fat free mass, and BMI index also estimated and displayed on the LCD with the user’s preference. The device follows the medical safety standardization limits by passing the 50 KHz frequency with less than 800µA current. Used MSP430 ultra low power microcontroller is very much suitable for the wearable and portable medical application point of view along with the cost effectiveness.
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective

References


9. Annemarie Nieberg, Validity of formulas used in bioelectrical impedance analysis: which is most accurate in predicting changing amounts of fat mass during weight loss? Retrieved from,
Chapter 4: Realization of Hydration Measurement Setup: A System Perspective


