Smart Bed and Battery Driven Auto Warm Bolster based on Raspberry Pi and Arduino

Lorenzo Niro, Addo Hermawan, Rico Wijaya, Zener S. Lie, and Rinda Hedwig*

***Abstract*—Sleeping quality is one of the main issues in the health problem and this research aims to help user to get better sleeping quality by making a smart bed that can give comfort according to the user's needs. The smart bed is able to identify the user, adjust its comfort according to the user's need by using Arduino as the input-output controller and finger print sensor. Raspberry Pi was used as the microprocessor to control the whole systems and it comes in the form of smart module which can be assembled and customized in any type of bed, old or new. This bed was tested by 10 users and it gained 83% satisfaction rate. As an additional to the smart bed, a battery driven auto warm bolster was assembled as part of bed accessories which can maintain its temperature at 32ºC to provide comfortable warmth to the user.**

***Keywords*—smart bed, smart home, Arduino, finger print sensor, smart bolster**

I. Introduction

THE need of good sleeping quality is one of our basic needs [1-5], where it is believed that a good quality of sleep also enhance the ability of self-healing in most patients in hospital [6], also affect the health-related behavior [7-8], and influence the poverty . Patel et al. observed that health indicators naturally influenced sleep quality most noticeably in poor individuals. Factors such as employment, education and health status, amongst others, undoubtedly interfere this effect only towards poor subjects [9]. There are several factors that affect the sleeping quality such as anxiety or stress, stomach discomforts due to the food consumed, medical conditions, noisy environment, light influence, and age [10-14].

Many people are willing to pay more to get the best comfort during their relaxation time. People choose different varieties of spring to be installed in the mattress to get different kind of softness and comfort to support the backbone [15-16]. The inventions of air bed also lead to the exploration of sleeping comfort [17-19] as one of the alternative solutions for having appropriate level of softness according to user's needs. Some studies showed that aromatherapy can give comfort during sleeping and promote sense of well-being [20-22]. Moreover, lightings [23-25] and background music [26-27] also plays role in enhancing sleep quality.

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Based on these studies, we tried to build a smart bed that able to provide comfort according to the user needs. This bed was assembled with a smart system module, fingerprint sensor, air mattress system, aromatherapy module, light module, and music module that user can adjust Moreover, the smart bed is also equipped with battery driven auto warm bolster that can give a stable and comforting temperature to the users. The desired temperature will be determined by the user and the bolster will maintain the temperature for at least 1 hour.

When this smart bed was first launched for testing, it was used to help an elderly woman who must spend most of her time in bed for weeks due to knee injury. The smart bed was not only giving the best support to the backbone according to her need, but it could also give comfort by reducing her insomnia, so she can have 6 hours sleeping without interruptions. This paper will give explanation about the system design, data taken, discussion and conclusion in general.

II. System Designs

Figure 1 shows the diagram block of the system where the data inputs are processed by a mini computer, Raspberry Pi. The inputs are fingerprint sensor, user database, and touchscreen LCD. Later, the data will be processed in a micro controller, namely Arduino, to control the stiffness of the air mattress, aromatherapy humidifier, and LED.

User identification is done by fingerprint sensor so that the smart bed comfort level can be adjusted according to the user's needs. The user's profile stored in user database consists of name, age, music selection, aromatherapy selection, mattress stiffness selection, and LED brightness selection. The LCD touchscreen is used in this design that user can use to control the output of the systems. The selection menus and the input were processed by Raspberry Pi before finally sent to the Arduino for controlling the outputs, such as air mattress, music player, aromatherapy humidifier, and LED brightness.

Motor servo will turn the pump to fill the air into the air mattress, which control the stiffness of the mattress. According to the studies [28-30] about effects of mattress stiffness in musculoskeletal pain, it is suggested that the stiffness of the mattress should be adjusted according to the user's backbone structure, gender and age.

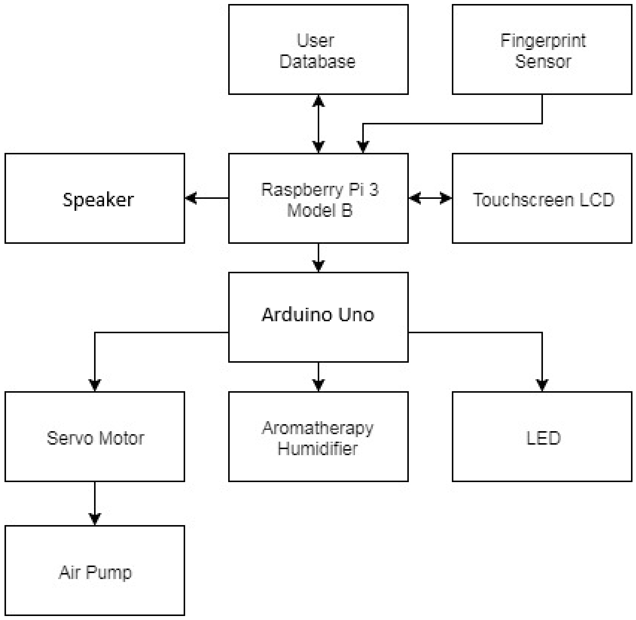

Fig. 1. The block diagram of the smart bed.

A music player, which can play 20 tracks of music, will be played along the sleeping period. It is believed that music will help the user to feel easy and relax [27]. While in the same time, the selection of certain aroma such as sandalwood, eucalyptus, apple, and rose will be diffused from aromatherapy humidifier to stimulate user's smelling and brain sensory to relax [31].

The brightness of the LED will be adjusted according to the comfort level of each identified user. Even though the study of brightness vs. sleeping disorder showed that it will lead to circadian phase [32], the system will not suggest any recommendation about the LED brightness, but it will adjust only to the user's sleeping habit. An alarm will be automatically turned on if the sleeping period of the user is considered adequate. An alarm will be activated according to the length of sleeping hour, which is set according to the user's age [33].

As an additional comfort to the user, a battery driven auto warm bolster is made to give a certain warm temperature as shown in figure 2. The bolster is covered with heating elements protected by insulator tape to avoid any electric current leakage. Since the bolster is powered by battery, it can be moved anywhere easily, and the batteries are rechargeable after running for 30 minutes. The bolster is also equipped with a sensor to maintain the temperature of 30ºC for the first 30 minutes of sleeping.

Figure 3 until 6 shows the flowchart of the overall system in detail. The main program is shown in figure 3, while searching the database is shown in figure 4. Once the user identification is successfully done, the system will run all the controls until the "wake" selection is chosen by the user. Figure 5 shows the "enroll" system for new user so that he/she can be identified. Figure 6 is showing the "interrupt" process of the alarm system which is working according to the user's age.

The flowchart of the bolster is shown in figure 7 where there is a temperature sensor, which will compare the surrounding temperature with the comfortable bolster's temperature that is set at the beginning. When the temperature is lower than the set temperature, the batteries will turn on the heating elements until it reaches the desired temperature and maintain it for the next 30 minutes. It is assumed that the user will fall asleep after 30 minutes and the bolster can be turned off automatically afterwards.

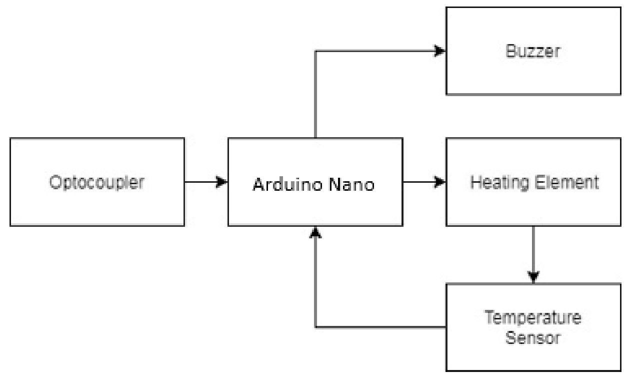

Fig. 2. The block diagram of auto warm bolster.

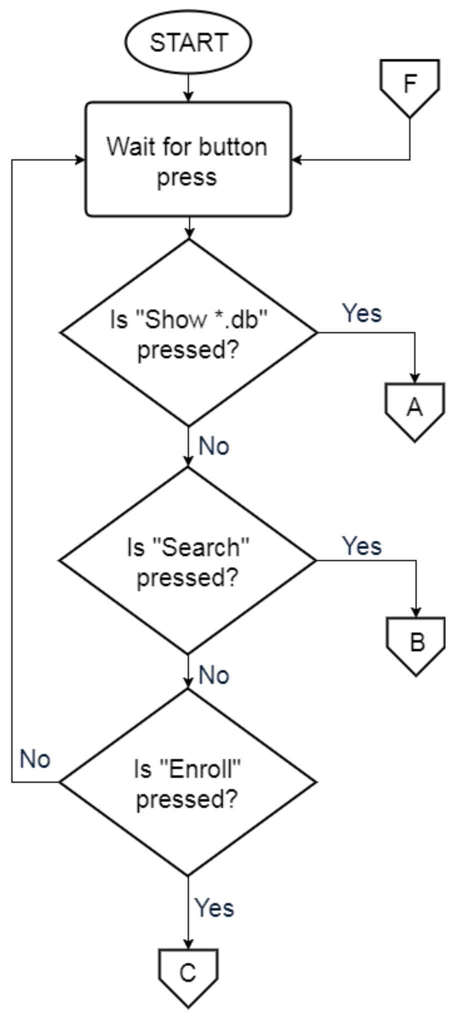

Fig. 3. Flowchart of the main menu.

The age selection in figure 6 was determined according to the study of K. Fukuda and K. Ishihara in concerning sleep-related lifestyle and mental health among junior high schools, high schools, universities students, and adults [34]. It is stated that children tend to sleep 8 to 10 hours a day, while adults 6 to 8 hours a day. For elderly, usually needs 6 hours or less for sleeping. Therefore, the alarm was set according to the age of the user.

In this research we select Raspberry Pi as the microprocessor since it is a small computer that fully functioned for database processing and output control, which can run in LINUX as well [35]. The Raspberry Pi is an open source device with low-power consumption and it can be combined with Arduino as microcontroller of the system output. Although it is slower than any general computer, this affordable minicomputer can provide all the expected abilities.

III. Results and Discussion

To understand the quality of smart bed and bolster, we derive some data to prove its stability, accuracy, and user satisfaction index upon the products. When we set the potentiometer in the motor servo, we measure the accuracy between the stiffness of the mattress and the potentiometer value by using deviation standard.

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad \ldots(1)$$

S is deviation standard of sample.

$\{x_1, x_2, \ldots, x_N\}$ is the value of the sample.

$\overline{x}$ is the average of the sample.

The average value that we get is 1.92 which means that the consistency of each value setting is similar between the potentiometer and the stiffness of the mattress. Therefore, whenever the user set the digital value in the menu, the exact stiffness will be determined.

The similar measurement also done to the LED control to check its accuracy between the input value and the brightness of the LED. According to the result, we even find the deviation standard value is 0, which means that the consistency between the input values with brightness output is 100% accurate. The 100% accuracy also happens to the music control and aromatherapy selection. The next measurement is done in order to find the successful rate of user identification. The 10 users are tested and repeatedly identified by the fingerprint sensor. We found that the successful rate is 95%, which was mainly caused by the condition of the finger such as dirty, had a scar, and the finger orientation.

The next measurement that we do is to measure the bolster temperature after heating by comparing the reading status between temperature sensor DS18B20 and FLIR TG165 as shown in figure 8. In the beginning, the bolster is activated in order to achieve temperature of 32ºC and will be steady in ±1.2%. The reading takes place as long as 5 minutes with time interval of 4 seconds. It is shown that the reading differences between two measurement tools are quite negligible or around 0.29%. Therefore, the bolster can work accurately and maintain the desired temperature constantly until the batteries finished. Nevertheless, when the room temperature goes down until 18ºC it will take more time for the bolster to go to the desired temperature. The average time to reach the desired temperature is usually less than 1 minutes but when the room temperature goes down to 18ºC, it will take more than 10 minutes to warm up the bolster. For the next development of this system, we will use a bigger battery capacity with wireless charging capability.

A questionnaire is developed and delivered to 10 users in order to see how this product can satisfy the user's need. We ask them about their satisfaction upon the smart bed, whether they will recommend the product to others, their loyalty to use the product, and any open inputs.

The result shows that 67% of the users feel satisfied and likely to use the product repeatably, 16% feel very satisfied and very likely to use the product repeatably, and the rest feel neutral. All of the users declared that they will recommend the product to others as well. The product itself had been tested for more than a month to the elderly woman who suffered from knee injuries and had to stay in the bed for recovery. The woman felt very satisfied because she could have more than 6 hours sleeping and felt comfortable without severing from the back injury.

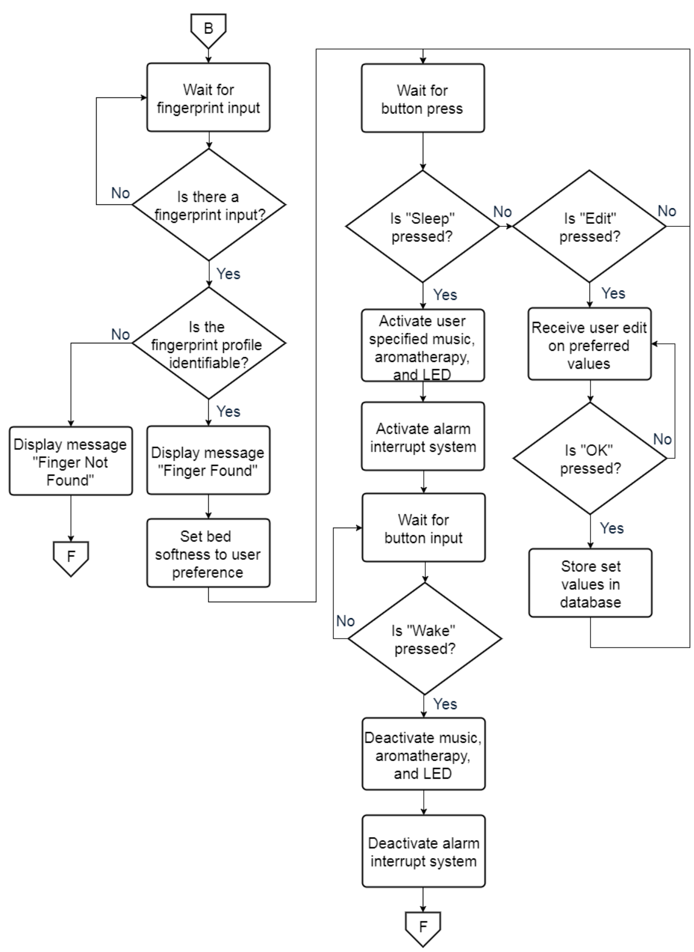

Fig. 4. Flowchart of “search” function.

TABLE 1. POTENTIOMETER VALUE ACCORDING TO MATTRESS STIFFNESS.

Softness Value	*Repetition* (KΩ)										*Mean* (KΩ)	*Deviation Standard* (KΩ)
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**		
1	53.7	53.2	53.7	53.3	53.6	52.8	53.3	53	52.6	52.9	53.21	0.38
10	110.3	110.9	108.7	107.8	107.4	106.4	107.9	110.3	112.7	111.7	109.41	2.06
20	166.5	168.6	168.3	165.9	167.9	168.6	167.2	166	165.2	168.2	167.24	1.26
30	224.1	223.1	217.4	216.6	217.2	218.6	215	216.2	216.4	215.8	218.04	3.09
40	282.6	281.4	277.5	279	278	278.1	275.5	274.1	274.2	275	277.54	2.92
50	324.1	329.6	328.5	329.2	324.8	329.1	325	323.2	324.2	324.6	326.23	2.53
60	380.3	379.4	379.3	379.6	379	378	375	377.6	377.4	378	378.36	1.52
70	432	427	431	429	428	430	428	425	432	425	428.7	2.58
80	479	479	481	478	479	480	475	478	477	475	478.1	1.97
90	516	514	515	514	514	515	512	512	510	512	513.4	1.84
100	558	560	559	558	558	558	557	557	557	557	557.9	0.99
											Average	1.92

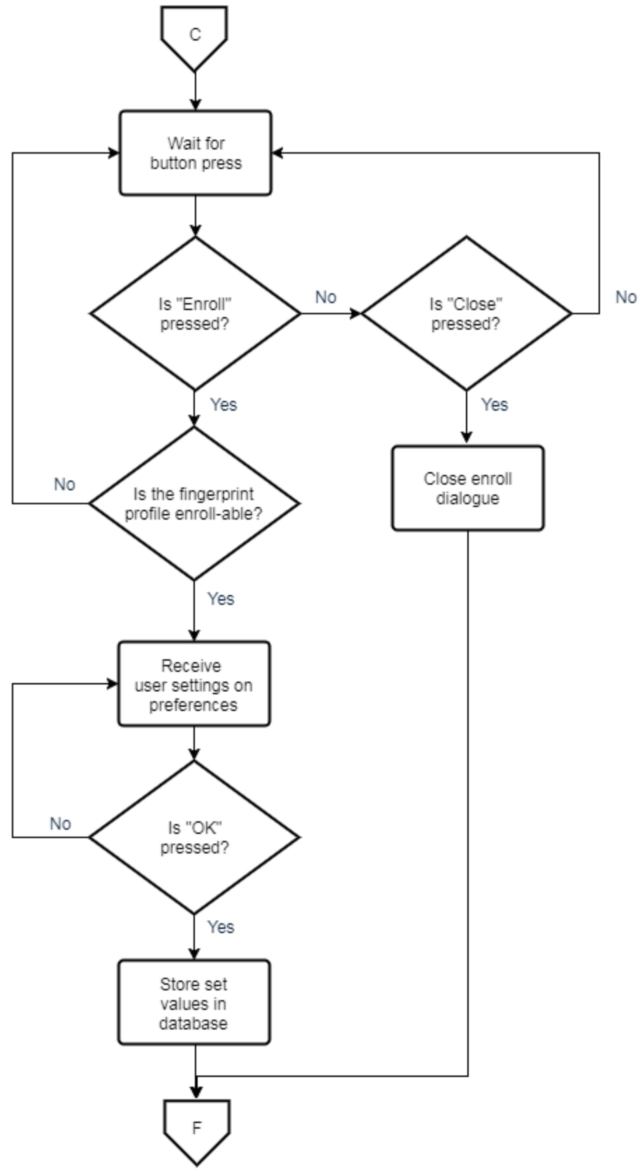

Fig. 5. Flowchart of alarm “enroll” system.

Table 2 shows the successfulness of finger print sensor in identification of user. It showed that the identification of user’s identification is 95%. Once the finger print sensor failed to recognize the pattern, the whole system will not run accordingly.

TABLE 2. SUCCESSFULNESS OF USER IDENTIFICATION.

Repetition	User										Success Count	Success Percentage
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
I	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕	9	90%
II	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
III	✓	✓	✕	✓	✓	✓	✓	✓	✓	✓	9	90%
IV	✓	✕	✓	✓	✓	✓	✓	✓	✓	✓	9	90%
V	✓	✓	✓	✕	✓	✓	✓	✓	✓	✓	9	90%
VI	✓	✓	✓	✓	✓	✕	✓	✓	✓	✓	9	90%
VII	✓	✓	✓	✓	✓	✕	✓	✓	✓	✓	9	90%
VIII	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
IX	✓	✓	✓	✓	✓	✓	✓	✕	✓	✓	9	90%
X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XI	✓	✓	✕	✓	✓	✓	✓	✕	✓	✓	8	80%
XII	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XIII	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XIV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XVI	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XVII	✓	✓	✓	✓	✕	✓	✓	✓	✓	✓	9	90%
XVIII	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XIX	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10	100%
XX	✓	✓	✓	✓	✓	✕	✓	✓	✓	✓	9	90%
											Average	95%

(✓ = Succeed, ✕ = Fail)

User can adjust the temperature sensor which is assembled in the bolster and it took 5 minutes of the heater to achieve the desired temperature which was set at 32°C. Once the temperature sensor failed to read the setting temperature, the heating process did not run or stayed in the room temperature. In order to get the most effective steady state condition for auto warm bolster, we set the best proportional gain as shown in table 3.

TABLE 3. RESPOND TIME OF BOLSTER IN DIFFERENT PROPORTIONAL GAIN.

Proportional Gain	Steady-state Response		
	Rise Time (s)	Settling Time (s)	Percent Overshoot
0	N/A	N/A	0
50	160	N/A	0
100	156	N/A	0
150	140	N/A	0
200	152	N/A	0.5937
250	152	N/A	0
300	124	516	0
350	128	340	0
400	120	228	0.5937
450	116	N/A	0
500	100	N/A	0.7813

(N/A = Data is not available)

It is shown that the proportional gain of 400 is the fastest respond time for the heating elements to achieve its steady state. However, there is less than 1% overshoot which is negligible for the system to respond since the tolerable temperature changes was ± 1.2% of the desired temperature.

Furthermore, this product has been submitted to get its simple patent and has been exhibited several times, which gain interest among the industries as well. The next development of this product will be the integration of smart bed and smart wardrobe, which can be seen in figure 9.

IV. CONCLUSION

A smart bed and auto warm bolster are built in this research in order to help people with sleeping disorder to get better sleeping quality. By setting up the bedroom environment and the bed itself according to the user's needs, it is believed that this product will improve user's sleeping comfort. User can adjust the stiffness of the bed, the music that will be played all night long including the aromatherapy that can stimulate relaxation of the body, the brightness of the room, and the warmest of the bolster as sleeping companion. From the questionnaire that we delivered to 10 users and a case study of an elderly woman who suffered from knees injury, we found that this smart bed did give them more comfort and relaxation during sleeping period. As for the elderly woman who has difficulties in having a good sleeping quality, she feels satisfied by this product.

There are some limits in this product such as the number of aromatherapy selection which was limited to only 4 scents, the music selection was not in a playlist mode, and there is only one reference temperature value in the bolster system. However, this smart module can be applied in any kind of bedding as long as there is an adjustable size of air mattress available for the bed size.

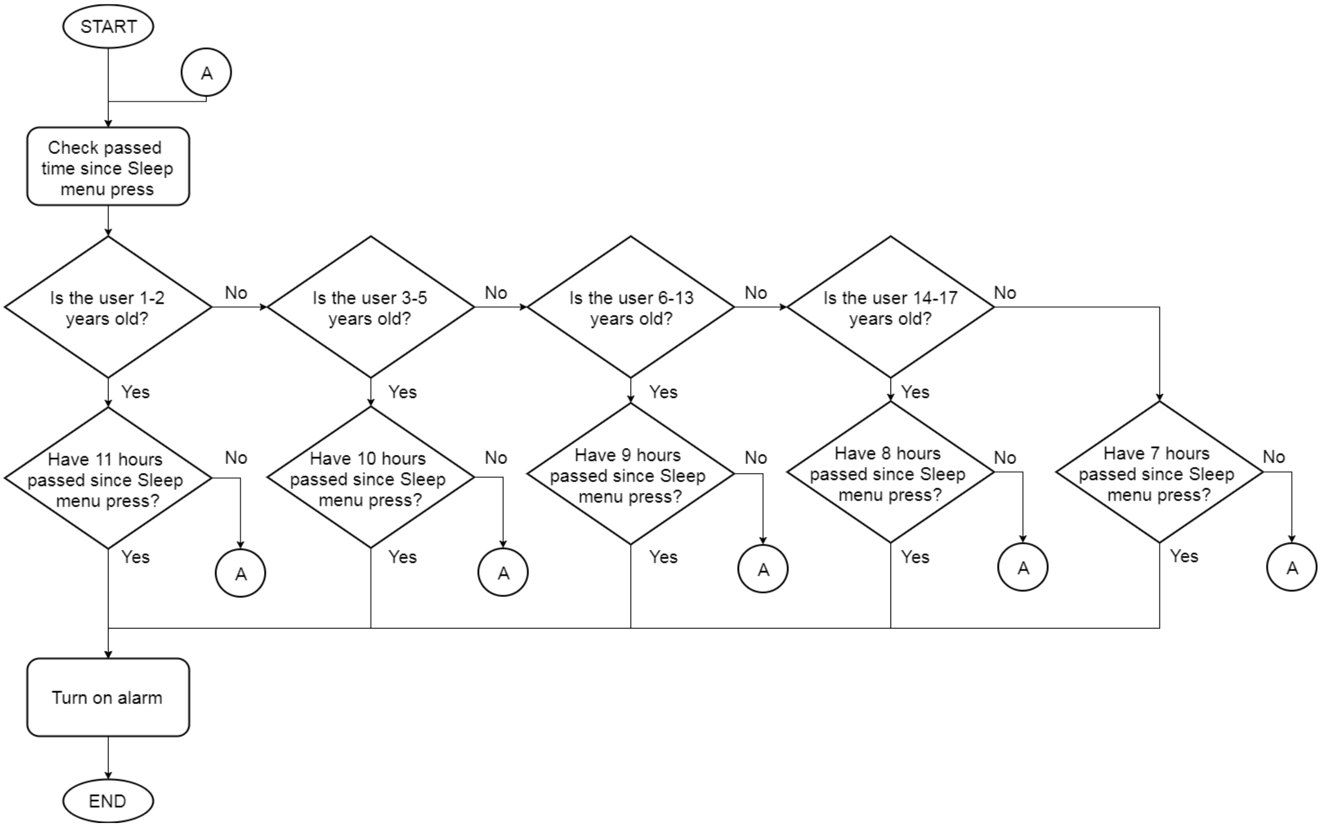

Fig. 6. Flowchart of alarm “interrupt” system.

In this research we spent around US$340 for developing the smart bed while the bolster is US$48. The bolster is more expensive due to the battery selection since the heat should be transferred equally to the bolster surface for hours. Nevertheless, this battery selection can be changed if the affordable battery technology is provided in the future.

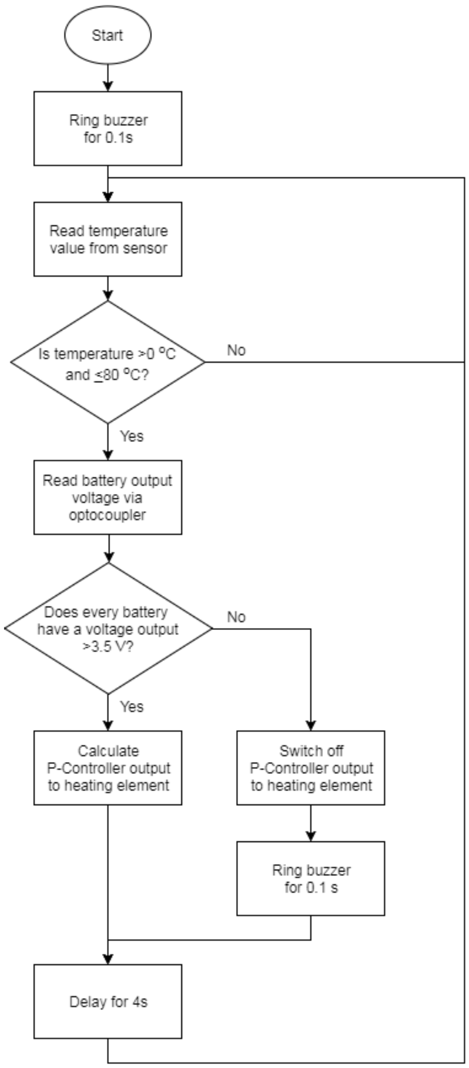

Fig. 7. Flowchart of warm bolster.

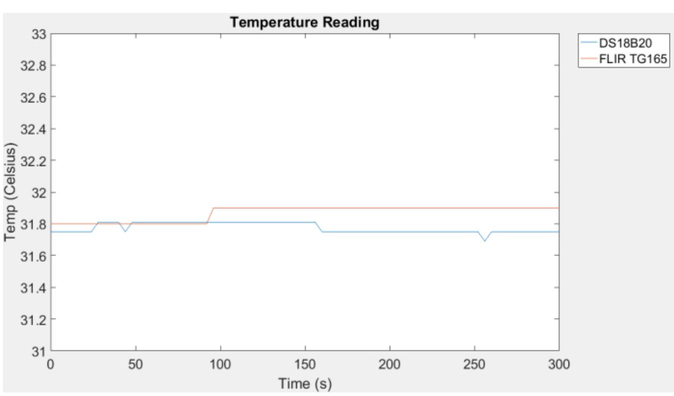

Fig. 8. Graph of comparison of temperature measurement between DS18B20 and FLIR TG165 when the bolster already warms up.

Fig. 9. The smart bed system and warm bolster. The battery module is put inside the bolster as shown in the left side while the other modules are on the black table.

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