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Anti-kyphosis smart bag detection of overweight bag load and improper spinal posture in army members when using work bags

Agung Hirawan*
Indonesia Defense University,
INDONESIA

Muhammad Rey Renoult
The Indonesian Navy,
INDONESIA

Diyan Parwatiningtyas
Indonesia Defense University,
INDONESIA

Iqbal Ahmad Dahlan
Indonesia Defense University,
INDONESIA

Adhi Kusumadjati
Indonesia Defense University,
INDONESIA

Jofim Yordaniel Napitupulu
The Indonesian Airforce,
INDONESIA

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Abstract

Heavy field equipment owned by soldiers such as backpacks unknowingly makes soldiers move with the wrong body posture when in the field. Carrying a bag with a heavy load and the wrong posture (slouching), can cause abnormalities in the spine, such as slouching (kyphosis). Therefore, a posture therapy is needed with the method of habituation using a work bag with a load not exceeding 15% of the user's body weight and using it with the correct posture. This therapy / habituation is of course carried out outside of field training hours that do not ignore the use of heavy loads, for example in the office or anywhere else when carrying a bag. Seeing this, researchers are trying to create and develop an anti-kyphosis smart bag that can prevent and treat spinal deformities. After making the system, this smart bag was then tested quantitatively with the aim of seeing the qualification of the system's ability to detect excess bag weight, if the weight of the bag exceeds 15% of the user's body weight and the ability of the system to detect improper posture seen from the sensitivity level of the load cell sensor based on its placement position in the back area. The test was conducted on three respondents who were selected based on their height, namely 170 cm, 175 cm, and 182cm. The system calibration results show that the system works accurately, with a measuring error of 0% and effective sensor placement between the thoracic kyphosis and lumbar lordosis areas of the back, with the ability to detect a bend angle of at least 24.7°. Seeing the effectiveness of this anti-kyphosis smart bag, it is hoped that it can be a smart solution for TNI members in maintaining spinal posture to avoid kyphosis due to the habit of carrying excessive loads with the wrong body posture.

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INTRODUCTION

The Indonesian National Army (TNI) is the main component of guarding the sovereignty and territorial integrity of Indonesia (Hanafi et al., 2019). A soldier is required to have strong mental and physical health in order to carry out his duties properly (Levine et al., 2016). Physical health is the most important substance for a soldier, because almost every activity uses physical strength (Schilz & Sammito, 2021). Physical strength is certainly fostered through physical development activities, such as running, push up, sit ups, pull up, and various other types of sports (Oja & Piksööt, 2023). In

***Corresponding Author:**
Agung Hirawan, Indonesia Defense University, Indonesia, Email: agungkir08@gmail.com

addition, a healthy and regular lifestyle is also the key to physical fitness (Widyasari & Turnip, 2019). However, there are some habits that are considered trivial that can actually lead to disease and aesthetic damage to the soldier's physique, namely the habit of sitting and standing with the wrong posture (Kett et al., 2021). In addition, if you are using a work bag with excess weight and the wrong posture. This can cause damage to the spine which leads to the onset of kyphosis disease (Suri Shojaei, & Bazrgari, 2020; Heller et al., 2019).

Kyphosis is a disease of the spine characterized by hunchback, where the posture will lean forward abnormally (Xuanchen, 2022; Lou et al., 2012). Symptoms of damage to the spine are characterized by back pain and neck and shoulder pain when carrying bags (Li, Zhang, & Shen, 2020). Currently as many as 619 million adults worldwide complain of these symptoms (Castro et al., 2024). So seeing these problems, a backpack has been developed that can measure the excess weight of the bag, including research conducted by Putri & Wildian in 2020 which analyzed the comparison of the weight of the bag with the user's body weight inputted in the system, with the bag weight limit being 15% of the user's body weight (Rashid et al., 2021; Putri & Wildian, 2020). In addition, similar research was also conducted by Oktari in 2020 who developed a children's bag that can detect bag overload. However, from this research, the problem of improper posture has not been solved, because the bag can only measure the weight of the bag and cannot detect improper spinal posture (Oktari, 2020). Therefore, researchers try to create and develop the capabilities of backpacks in previous studies. In this research, the bag is designed to be able to detect the excess weight of luggage and can detect improper spinal posture, which is characterized by vibration on the vibration module, LED lights, and display from the LCD so that users can see and feel the sign. Thus, users can carry luggage comfortably and safely from spinal disease (kyphosis). In addition, this bag can be a medical bag that can help recovery and therapy for users who already have kyphosis so that they can get used to doing activities with correct posture.

METHOD

The method used in this research is a quantitative method to see the effectiveness of the system. This anti-kyphosis smart bag is a backpack that uses a weight sensor (load cell) to detect the weight of the luggage and the angle of curvature of the spine through the compressive force of the bag to the back (Davis et al., 2010). This bag is designed in such a way as to prioritize effectiveness and quality so as not to reduce user comfort. The following system design is shown in Figure 1 below.

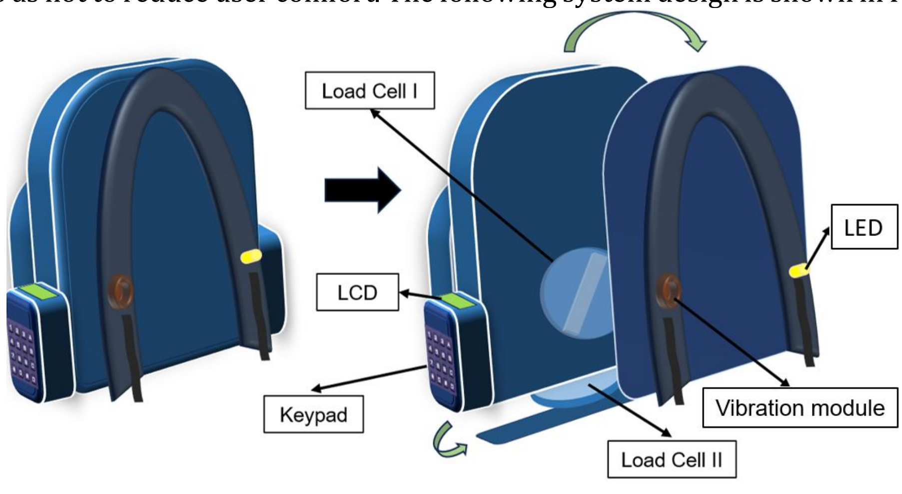


Figure 1. Anti-kyphosis smart bag design

Based on the system design drawing in Figure 1, this bag consists of several components, such as two load cells that function as weight sensors, keypad as a user weight input system, actuators in the form of LED, LCD, vibration modules as output indicators, and Arduino Uno as a microcontroller. All of these components are integrated with each other to execute any weight or compressive force input given. The following are the work steps of the system, can be seen in Figure 2.

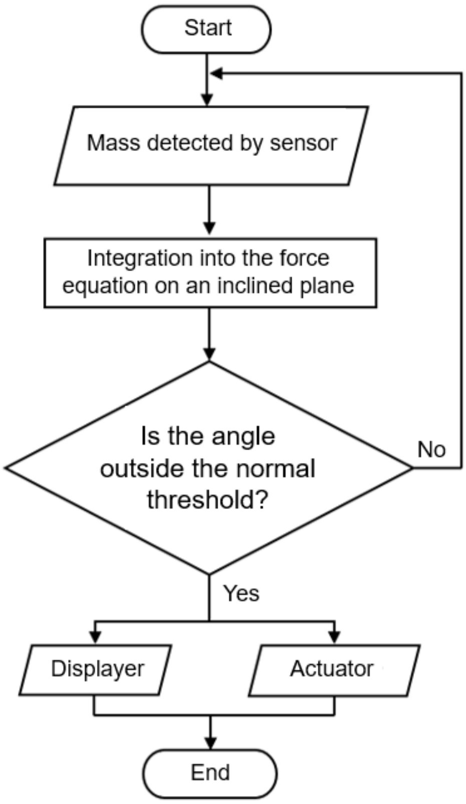
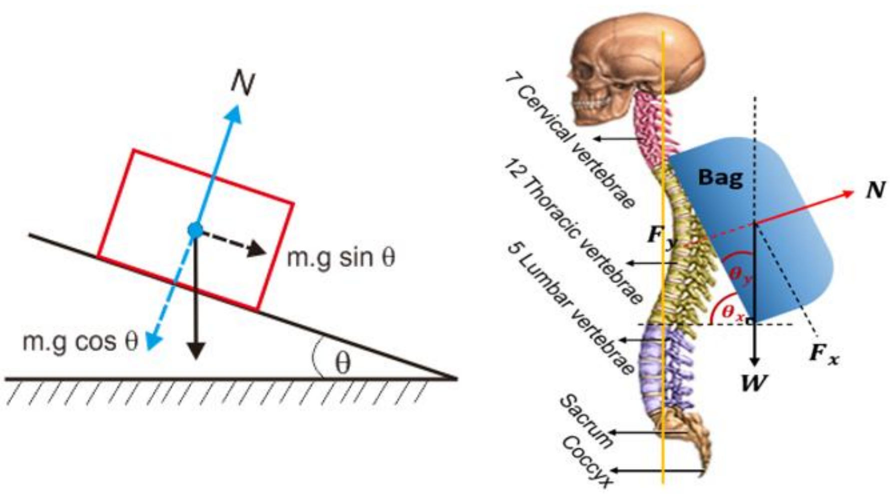


Figure 2. System workflow

In general, the working principle of this anti-kyphosis smart bag is to utilize the weight of the luggage and the compressive force of the bag towards the user's back. Initially, the horizontal weight sensor (load cell II in Figure 1) will detect the mass of the object inserted into the bag. The mass will be compared to the user's weight limit, which is 15% of the user's body weight. The vertical weight sensor (load cell I in Figure 1) will detect the pressure of the bag from the y-axis direction to the back (Figure 3).



(a) (b)

Figure 3. (a) Force on an inclined plane (b) Working principle of the smart bag

The angle of curvature of the spine (kyphosis) can be determined by applying the principle of force on an inclined plane, following the equation (Ha & Kim, 2020).

$$F_y = M.g = W.\cos\theta_x \quad (1)$$
$$M.g = m.g.\cos\theta_x \quad (2)$$

$$\theta_x = \cos^{-1}\frac{M.g}{m.g} \tag{3}$$

where (F_y) is the force acting on the y-axis; $(M.g)$ is the measured weight of the weight sensor when the bag is worn; and $(m.g)$ is the actual weight of the load.

θ_x in Figure 3 is the angle of inclination of the object with respect to the x-axis, while in this case the angle of curvature of the spine (θ_y) is viewed with respect to the vertical y-axis. Therefore, θ_y can be determined using equation (4) as follows.

$$\theta_y = 90° - \theta_x \tag{4}$$

Based on research conducted by Devlin in 2011 (Delvin, 2011) that the normal spine has a curvature angle of thoracic kyphosis and lumbar lordosis each with a vulnerability of 20° to 40°. In this study, a minimum angle of 20 ° was chosen as the normal angle of curvature of the spine. Thus, the spinal kyphosis angle (θ) can be determined by subtracting the value of the spinal curvature angle in the y-axis from the normal spinal curvature limit angle, as in equation (5).

$$\theta = \theta_y + 20° \tag{5}$$

To determine the effectiveness of this system, two types of tests were conducted. The first test is to test the sensitivity of the sensor when measuring the weight of the bag and the percentage of 15% of the user's body weight by comparing experimental results and theory (calibration). The system will automatically calculate the percentage of bag weight and provide information if the weight exceeds 15% of the user's body weight. As for the theoretical mechanism of calculating the percentage of weight of 15% of the user's body weight, using equation 6 as follows.

$$W_{15\%} = \frac{15}{100} \times w_1 \tag{6}$$

The next test is the determination of the kyphosis angle on sensor sensitivity on variables of height difference, sensor placement, and user bag weight. The user's height was randomly selected as 170 cm, 175 cm, and 182 cm with the sensor placement position aligned with three spinal regions, namely thoracic kyphosis, between kyphosis and lordosis, and lumbar lordosis. The weight of the bag was also randomly selected as 2 kg, 4 kg, and 6 kg. After analysis, to obtain a normal angle of curvature within the weight range, the minimum weight limit that can be detected by the load cell sensor must be determined, and the one that meets is 0.5 Kg.

The correct posture when carrying a backpack is not slouching. However, an upright posture for a long duration of time will also cause pain and strain on the back muscles, so there needs to be a certain limit of compressive force that becomes the limit of detection of the loadcell sensor, because the minimum compressive force of the load to the sensor occurs when the position is too upright, while the maximum compressive force is when the bag user is slouching. The minimum normal angle of curvature of the spine is 20°. However, the respondents (users) complained that their posture was too upright, so an angle of curvature between 25°-35° was taken and considered good enough by the respondents. To obtain such an angle, through the load cell sensor, the coding of the load cell sensor must calculate how much the bag presses on the back. From experiments and mathematical calculations through equation 3, it was found that 0.5 Kg is the limit of whether or not the load cell sensor works. That is, if the pressing force exerted by the bag on the back is below 0.5 Kg, the system will not issue a warning output indicating that the kyphosis curvature angle at that time is still below 25° (still in a safe posture). However, if the compressive force is more than 0.5 Kg then mathematically and experimentally, the user is in a hunched posture (angle more than 35°) where the bag will provide output in the form of an illuminated LED, vibration, and warning through the LCD screen.

The measurement error in the system can be calculated using equation (7) as follows (Maharani, 2020).

$$E = \left|\frac{x - x_0}{x_0}\right| \times 100\% \tag{7}$$

with E being the percentage of measurement error; x being the experimental result; and x_0 being the theoretical calculation result.

RESULTS AND DISCUSSION

Sensor sensitivity test (calibration)

A keypad for user weight input is integrated with the entire system. Two load cell sensors each function to detect the weight of the bag and determine the angle of the spinal curve through the amount of force pressing the bag to the back. As output, the user can obtain information through LED, vibration module and LCD display. If the LED lights up and the vibration module works, it indicates that the weight of the items in the bag exceeds the normal limit and the spine curvature angle (kyphosis) exceeds 20°. All systems are connected by Arduino Uno as a microcontroller. The systems toocircuit can be seen in Figure 4 as follows.

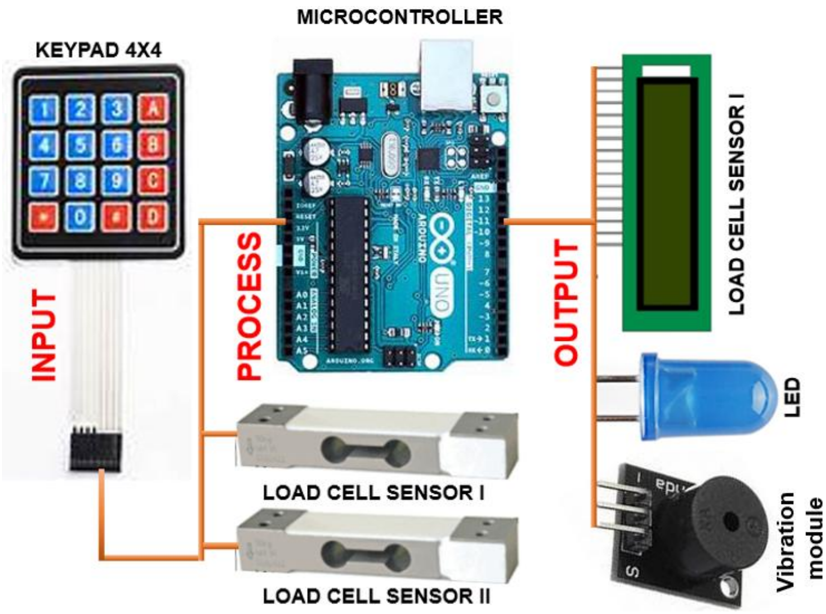


Figure 4. Systems circuit

After the calibration process, the results are shown in Table 1 as follows.

Table 1. Sensor calibration results on 15% user weight measurement

User's weight (w_1) Kg	Bag weight (Kg)	Results		E (%)
		$W_{15\%}$ (Kg) theoretics	$W_{15\%}$ (Kg) experiment	
35	5,65	5,25	5,25	0
40		6,00	6,00	0
41		6,15	6,15	0
37		5,55	5,55	0
38		5,70	5,70	0
42		6,30	6,30	0
36		5,40	5,40	0
39		5,85	5,85	0
31		4,65	4,65	0
34		5,10	5,10	0
Average error				0%

In system calibration, there are 10 user weight data that are determined randomly. The weight data is not actually a soldier's weight data, because in this test the bag does not need to be worn because there is no influence if the bag is worn or not. This is because when calculating 15% of the user's body weight and comparing it to the weight of the bag, only one load cell sensor is used at the bottom of the bag (can be seen in Figure 1, load cell II), which means the bag can still function without needing to wear it. This is different from the working principle of the load cell sensor I in Figure 1, whose performance is influenced by the slope of the user's spine, so it can only work when the bag is being worn. The choice of body weight ranging from 31 kg to 42 kg only depends on the capacity of the load cell sensor (under 10 kg) and the strength of the bag. The weight data is then input using the keypad.

The data in Table 1 is the result of system calibration, with the aim of seeing the performance and accuracy of the system. Based on the data in table 1, the results show that the system accuracy is very good, which indicates that the system is working optimally. The bag can detect the weight of the user's luggage with a measurement error percentage of 0%. In addition to the measurement accuracy of the sensors, tests were also conducted on the accuracy of the actuators used as output markers in the system. The actuators are LEDs and vibration modules. The following test results can be seen in Table 2.

Table 2. Actuator test

User's weight (w_1) Kg	Bag weight (Kg)	Results $W_{15\%}$ (Kg) experiment	Systems view	
			LED	Vibration module
35	5,65	5,25	Y	Y
40		6,00	X	X
41		6,15	X	X
37		5,55	Y	Y
38		5,70	X	X
42		6,30	X	X
36		5,40	Y	Y
39		5,85	X	X
31		4,65	Y	Y
34		5,10	Y	Y

Y: Working
X: Not working

Based on the test results in Table 2, the results show that all actuators work optimally. The actuator works according to the principle that has been set in the system code, where the actuator can only function if the weight of the bag used exceeds the calculation of 15% of the user's body weight. Conversely, if the weight of the bag is smaller than 15% of the user's body weight, the actuator will not work.

Spinal curvature angle measurement

From a medical perspective, body weight greatly influences the curvature of the spine. The heavier the body weight, the greater the burden on the bones in supporting muscle and fat, so the risk of kyphosis will be greater (Han et al., 2013). However, in this test there was no review of the relationship between height and user weight. The effectiveness of the system is only reviewed based on the user's height, the weight of the bag used, and the effective position of the sensor when used. This is due to the limitations of researchers and systems that have not been able to elaborate a system so that it can link these two variables. Additionally, there is a load cell sensor system that points towards the back (can be seen in Figure 1, load cell I) where the load cell can only detect the pressing force of the bag from the Y axis direction (figure 3) and cannot detect the user's body weight. The test results can be seen in tables 3, 4 and 5 as follows.

Table 3. The effect of the position of the load cell sensor and the variation of the user's height on the sensitivity of the sensor on a bag weighing 2 kg

User's height (Cm)	Sensor location	F_y (N)	θ	Systems output			
				LED		Vibration module	
				Upright position	Bent position	Upright position	Bent position
175	Thoracic kyphosis	4,3	32,4°	X	Y	X	Y
	Between kyphosis and lordosis	5,8	36,8°	X	Y	X	Y
	Lumbar lordosis	5,1	34,7°	X	Y	X	Y
182	Thoracic kyphosis	6,7	39,5°	X	Y	X	Y
	Between kyphosis and lordosis	7,7	43,5°	X	Y	X	Y
	Lumbar lordosis	5,9	37,1°	X	Y	X	Y
170	Thoracic kyphosis	4,9	34,1°	X	Y	X	Y
	Between kyphosis and lordosis	7,5	42,0°	X	Y	X	Y
	Lumbar lordosis	5,5	35,9°	X	Y	X	Y

Y: Working
X: Not working

Table 4. The effect of the position of the load cell sensor and the variation of the user's height on the sensitivity of the sensor on a bag weighing 4 kg

User's height (cm)	Sensor location	F_y (N)	θ	Systems output			
				LED		Vibration module	
				Upright position	Bent position	Upright position	Bent position
175	Thoracic kyphosis	5,5	27,9°	X	Y	X	Y
	Between kyphosis and lordosis	5,7	28,1°	X	Y	X	Y
	Lumbar lordosis	5,4	27,7°	X	Y	X	Y
182	Thoracic kyphosis	5,0	27,1°	X	Y	X	Y
	Between kyphosis and lordosis	5,7	28,2°	X	Y	X	Y
	Lumbar lordosis	5,3	27,6°	X	Y	X	Y
170	Thoracic kyphosis	5,6	28,0°	X	Y	X	Y
	Between kyphosis and lordosis	6,7	29,6°	X	Y	X	Y
	Lumbar lordosis	6,3	29,0°	X	Y	X	Y

Y: Working
X: Not working

Table 5. The effect of the position of the load cell sensor and the variation of the user's height on the sensitivity of the sensor on a bag weighing 6 kg

User's height (cm)	Sensor location	F_y (N)	θ	Systems output			
				LED		Vibration module	
				Upright position	Bent position	Upright position	Bent position
175	Thoracic kyphosis	6,4	26,1°	X	Y	X	Y
	Between kyphosis and lordosis	7,0	26,7°	X	Y	X	Y
	Lumbar lordosis	7,0	26,7°	X	Y	X	Y
182	Thoracic kyphosis	6,3	24,4°	X	Y	X	Y
	Between kyphosis and lordosis	8,2	27,8°	X	Y	X	Y
	Lumbar lordosis	7,3	26,9°	X	Y	X	Y
170	Thoracic kyphosis	7,5	27,1°	X	Y	X	Y
	Between kyphosis and lordosis	8,0	27,6°	X	Y	X	Y
	Lumbar lordosis	6,3	24,4°	X	Y	X	Y

Y: Working
X: Not working

Based on Tables 3, 4, and 5, the placement of the load cell sensor can be adjusted according to the level of sensitivity. From the experiments conducted, the most effective position for the load cell sensor is between thoracic kyphosis and lumbar lordosis. This is characterized by the magnitude of the spinal curvature angle detected, which indicates the sensitivity of the sensor is getting better. Although in experiment 1 in table 5 the compressive force of the bag load detected by the sensor in lumbar lordosis and between thoracic kyphosis and lumbar lordosis is the same (7.0 N), overall, from all experiments it is more dominantly effective if placed between kyphosis and lumbar lordosis because the compressive force of the bag is stronger/larger than the compressive force of the bag in other positions. The similarity of values and variations in data are generally caused by different human postures and are still considered normal if they do not exceed the tolerance limit for the angle of curvature. For more details, an illustration of the position of the sensor on the bone can be seen in Figure 5 as follows.

In the three tests conducted, there were differences in the detected angles, which were influenced by the weight of the bag used. At a bag weight of 2 kg, the minimum angle detected was 32.4°. At a bag weight of 4 kg, the minimum angle detected was 27.1°. While at a bag weight of 6 kg, the minimum angle detected was 24.4°. From these data, it is evident that the heavier the bag used, the greater the compressive force of the bag weight to the load cell sensor. The relationship between the weight of the bag and the amount of force and the relationship between the force and the amount of angle can be seen in the graph in Figure 6 below.

The greater the force generated, the smaller the angle of curvature of the user's spine will be detected, because the bag will be more sensitive in detecting the size of the angle formed due to the size of the weight of the bag load. This is in accordance with the theory of equation 3, namely, the amount of force is inversely proportional to the amount of angle. Thus, the heavier the bag used, the more sensitive the system will be in detecting the angle of curvature, so that the user will always be in an ideal posture, with a vulnerable spinal curvature angle of 25° to 35°.

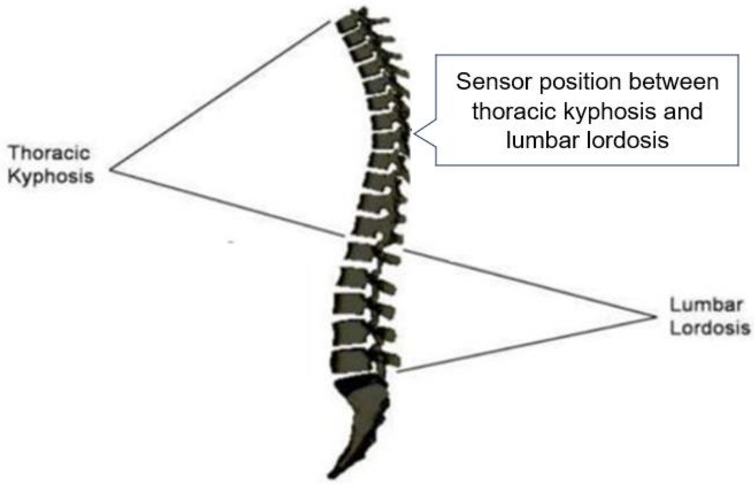


Figure 5. Illustration of effective placement of the load cell sensor on the back

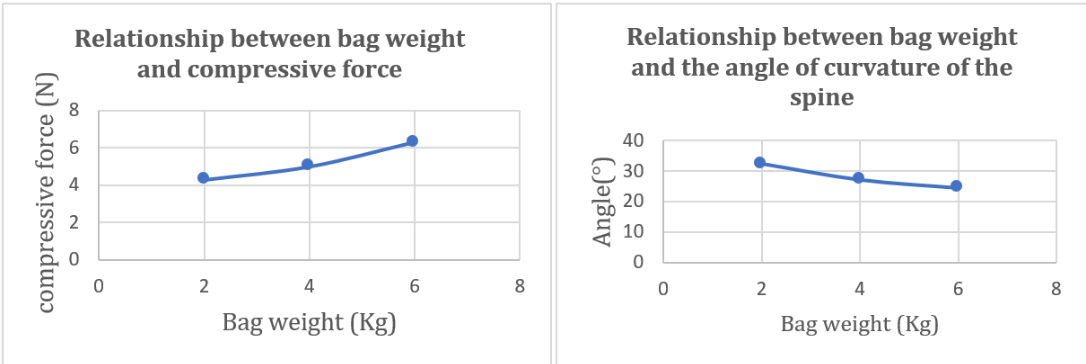


Figure 6. (a) Relationship between bag weight and compressive force (b) Relationship between bag weight and the angle of curvature of the spine

CONCLUSION

An anti-kyphosis smart bag has been created and developed that can detect excess bag weight and incorrect posture when using the bag. The test results show that the system can detect the weight of the bag and its comparison with 15% of the user's body weight with a calibration error of 0% with actuators in the form of LEDs, LCD displays and vibration modules which function if the weight of the bag used exceeds the limit of 15% of the user's body weight.. This smart bag uses a load cell sensor as a compressive force detector, whose effective placement position is between kyphosis and lordosis in the spine. This is because in that position the sensor is at its most sensitive point. The range of bone curvature angles that can be detected is between 24.4° to 39.5°. The heavier the bag used, the smaller the bending angle tolerance limit will be, so that the user will always be in the correct posture even though using a heavy bag.

With the effectiveness of this bag, it is hoped that it can be a smart solution for TNI members in the future in maintaining spinal posture to avoid kyphosis. As a suggestion, further research regarding anti-kyphosis smart bags uses sensors that have a high level of sensitivity and are able to connect to the internet, so that bad habits regarding the user's body posture can be monitored via gadget, as a cure or therapy. steps especially for those who already suffer from kyphosis.

AUTHOR CONTRIBUTIONS

Each author of this article played an important role in the process of method conceptualization, simulation, and article writing.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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