Control Design of Automatic Inflatable Vest for Deep Pressure Therapy

Farhan Ali Husaini[a,b], **Mohamad Izzur Maula**[a,b], **Muhammad Imam Ammarullah**[c], **Ilham Yustar Afif** [d], **M Danny Pratama Lamura**[a,b], **Tri Indah Winarni**[b,e]*, **J. Jamari**[a,b]*
[a]Department of Mechanical Engineering, Universitas Diponegoro
Semarang 50275, Central Java, Indonesia
[b]Undip Biomechanics Engineering & Research Centre (UBM-ERC), Universitas Diponegoro
Semarang 50275, Central Java, Indonesia
[c]Department of Mechanics and Aerospace Engineering, College of Engineering, Southern University of Science and Technology
Shenzhen 518055, Guangdong, China
[d]Department of Mechanical Engineering, Universitas Muhammadiyah
Semarang 50273, Central Java, Indonesia
[e]Department of Anatomy, Faculty of Medicine, Universitas Diponegoro
Semarang 50275, Central Java, Indonesia
*E-mail: j.jamari@gmail.com; triwinarni@lecturer.undip.ac.id

Abstract

This research focuses on enhancing the control system of the commercial inflatable vest to optimize pressure regulation for deep pressure therapy (DPT) in children with autism spectrum disorder (ASD). The main goal is to provide a safe and reliable DPT experience with calming effects. The proposed control system incorporates a feedback loop mechanism to maintain the desired pressure level and includes safety features to prevent overinflation. The study dis-cusses the development of the pressure control system, covering both hardware and software components. Experimental results demonstrate the system's effectiveness in maintaining the target pressure with the average error is 1.531%. This study has successfully advanced deep pressure therapy devices, emphasizing the significance of automatic pressure control that meets the criteria for medical gas pressure (error no greater than 5%) and incorporates safety features as a therapy device.

Kata kunci: control system; inflatable vest; deep pressure therapy

Abstrak

Penelitian ini berfokus pada peningkatan sistem kontrol rompi mengembang (*inflatable*) untuk mengoptimalkan pengaturan tekanan udara untuk terapi *deep pressure* (DPT) pada anak dengan *autism spectrum disorder* (ASD). Tujuan utama penelitian ini adalah merancang alat DPT yang aman dan andal dan mampu memberikan efek ketenangan. Sistem kontrol yang diusulkan menggabungkan mekanisme *feedback loop* untuk menyesuaikan tekanan udara dengan yang diinginkan dengan fitur keselamatan untuk mencegah inflasi yang berlebihan. Penelitian ini membahas tentang pengembangan sistem kendali tekanan udara yang mencakup komponen perangkat keras dan perangkat lunak. Hasil eksperimen menunjukkan efektivitas sistem kendali dalam menyesuaikan tekanan udara dengan target tekanan udara memiliki error rata-rata sebesar 1,531%. Penelitian ini telah berhasil mengembangkan perangkat DPT yang kriteria *medical gas pressure* (error tidak melibihi 5%) dengan fitur keselamatan pada perangkat DPT.

Kata kunci: sistem kendali; rompi mengembang; terapi *deep pressure*

1. Introduction

Deep pressure therapy (DPT) involves the application of targeted and deep pressure to induce a calming effect and reduce anxiety-related physical activities. DPT is commonly used to alleviate stress and improve school performance in children with autism spectrum disorder (ASD) [1].

Several DPT devices have been developed, including non-wearable devices such as the Squeeze Machine [2], Hug'm Apparatus [3], Portable Autism Hugging Machine Chair (AHMPS) [4], and weighted blankets, as well as wearable devices like Compression Clothing, T-Jacket [5], and weighted vests [6]. Studies on the effects of DPT have shown varying results, with some reporting positive effects [5], [7]–[12], others reporting no significant effects [3], [13]–[16], and many yielding inconclusive results [17]–[20]. These inconsistencies can be attributed to factors such as the lack of standardized protocols regarding pressure load and intervention duration. Therefore, there is a need for a DPT device that can automatically control the magnitude and duration of applied pressure.

Inflatable vests are among the devices used for deep pressure therapy, providing controlled pressure similar to a comforting hug. However, most commercially available inflatable vests, such as Snug vest, Vayu vest, and Squease vest, still rely on manual control, limiting the regulation of pressure.

The Squease Vest has been improved by researcher Maes J who added sensors, for heart rate and respiration rate to keep track of the users condition [21]. They also integrated a microcontroller to process data from these sensors and an air pump was used to inflate the vest. However there is an air pressure sensor in the control system, which means it cannot adjust the air pressure provided automatically.

This paper focuses on enhancing the Squease vest to create a dependable and safe deep pressure therapy experience. The proposed control system ensures that the pressure is optimized for user comfort and safety. It uses a feedback control loop to maintain the desired pressure level and incorporates safety measures to prevent, over inflation.

2. Materials and Methods

2.1 Design and Construction

The design and construction consist of two main components: hardware and software. The hardware encompasses a series of electronic and pneumatic components for the air pressure control system. Meanwhile, the software involves serial communication and interface for the air pressure control system.

2.1.1 Hardware System of the Pressure Control System

The hardware system of the pressure control system consists of electronic and pneumatic components, as shown in Figure 1, where (1) is the inflatable vest, (2) is the control box, (3) is the microcontroller, (4) is the relay modules, (5) is the pressure sensor, (6) is the air compressor, (7) is the control valve, (8) is the toggle switch, (9) is the battery, (10) is the solenoid valve, and (11) is the transceiver module.

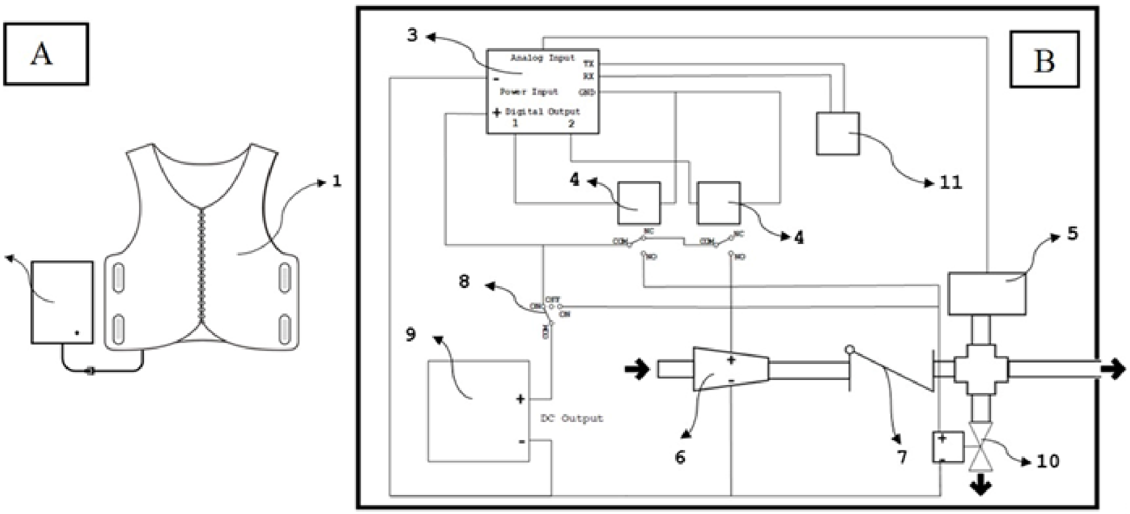


Figure 1. Hardware system of the pressure control system. (A) inflatable vest with pressure control box; (B) the components of the pressure control system are located within the control box

The microcontroller plays a vital role in the pressure control system, as it is responsible for reading the data from the pressure sensor, receiving the desired set point data, and facilitating communication between the computer and the system via the transceiver module. It effectively regulates the flow of DC current from the battery to either the solenoid valve or the air compressor through the relay module. When the pressure falls below the set point, the microcontroller triggers the activation of the air compressor, resulting in the inflation of the vest and the closure of the solenoid valve. Conversely, if the pressure exceeds the set point, the microcontroller deactivates the air compressor and opens the solenoid valve, allowing air to be released from the vest. Once the pressure reaches the desired set point, the relay module discontinues the current flow, effectively trapping the air inside the vest. To prevent air leakage, the air compressor is connected to a check valve. Additionally, the MPX5100DP sensor undergoes calibration using a low-pressure gauge to ensure precise pressure measurements. This calibration process involves recording the analog readings of the sensor at 0 kPa and 20 kPa, which correspond to values of 44 and 223, respectively, when utilizing the analogRead function. Utilizing the recorded data, an interpolation equation is derived to accurately convert the analog readings into corresponding pressure values. By employing this interpolation equation, the sensor readings can be effectively converted into accurate pressure values within the 0 to 20 kPa range. The working principle of the control system can be explained through a flowchart, depicted in Figure 2. The flowchart illustrates the step-by-step process of the control system's operation, showcasing the sequence of actions taken to adjust and regulate the air pressure in the inflatable vest.

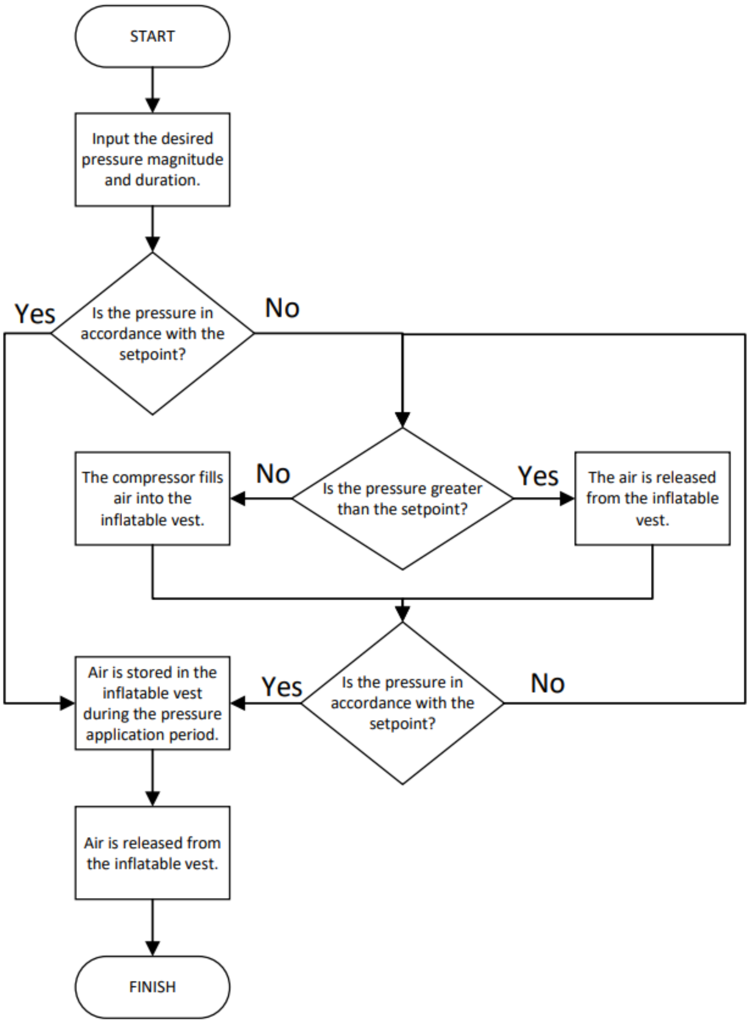


Figure 2. Flowchart of the pressure control system's working principle

2.1.2 Software System of the Pressure Control System

To establish control over the Arduino, the HC-05 Bluetooth module is utilized for Bluetooth serial communication between the computer and the Arduino. The serial communication between PC, Arduino, and electronic devices can be observed in Figure 3.

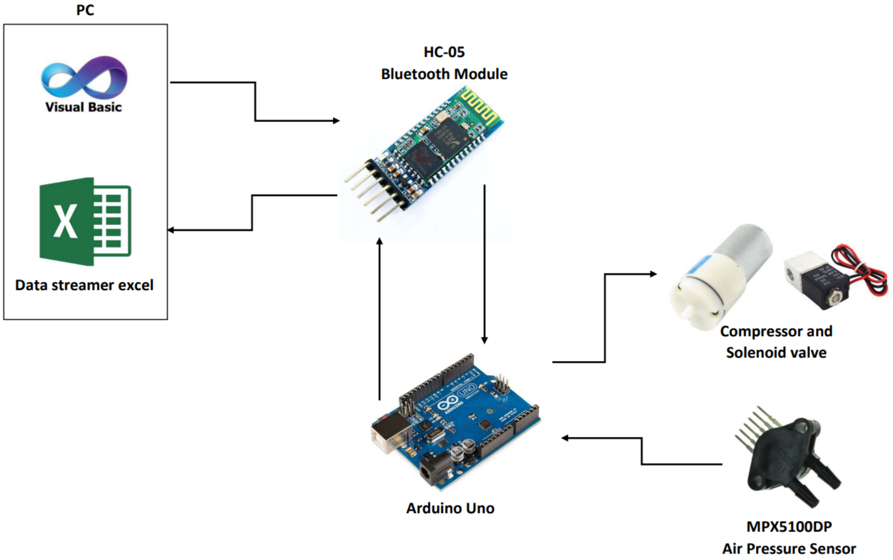
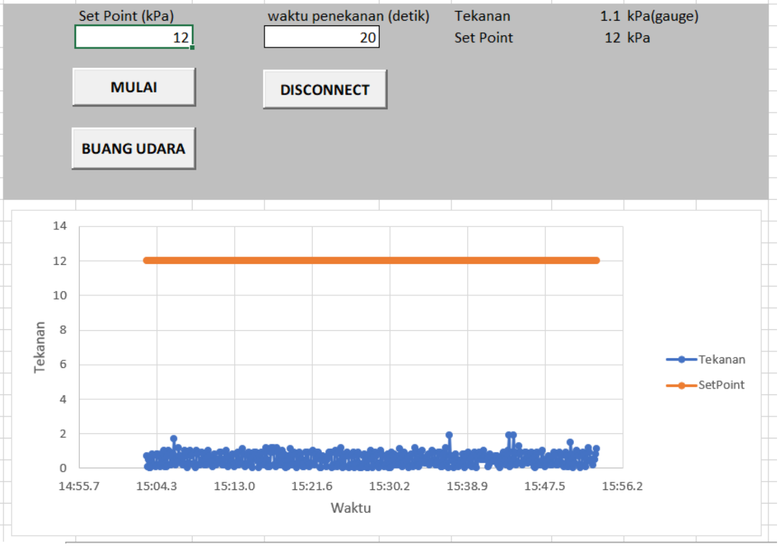


Figure 3. The serial communication of the control system

The control systems interface is created using Visual Basic and Excel data streamer allowing the operator to enter the desired pressure setpoint and duration. To initiate the execution of input commands the operator simply needs to press the "START" button while the "BUANG UDARA" button is responsible, for letting out the air. The operator can terminate the connection between the computer and the Arduino by utilizing the "CONNECT/DISCONNECT" button. Figure 4 illustrates the interface of the control system.



Set Point (kPa): 12

waktu penekanan (detik): 20

Tekanan 1.1 kPa(gauge)

Set Point 12 kPa

Figure 4. Interface of the control system

2.1.2 Inflatabel Vest

The Squease inflatable vest, created by Squeasewear Ltd. is chosen, due to its practicality and comfort. It is specifically designed to be lightweight and easy to carry around making it a convenient option for those seeking pressure therapy. The vest is made using breathable materials ensuring an experience when worn. Its adjustable design allows for a fit ensuring distribution of pressure. Overall the Squease inflatable vest provides an comfortable solution for individuals who require pressure stimulation. You can find an illus-tration of the installation process for the pressure control system on the Squease vest, in Figure 5.

Figure 5. Installation of the pressure control system onto the Squease inflatable vest

2.2 Pressure Control System Performance Testing

The performance testing of the pressure control system was conducted by observing the system's response to changes in the setting point. The setting point was varied from 0 to 5 kPa, 5 to 10 kPa, 10 to 15 kPa, 15 to 20 kPa, and 20 to 25 kPa. The experiment yielded valuable data on the system's response speed and error. The re-sponse speed of the control system was determined by dividing the change in the setting point value by the time taken for the pressure to adjust to the new setting point.

3. Result and Discussion

3.1 Weight and Dimensions

The findings, from the development and building of the control system have been. Organized in Table 1. This table displays the measurements of the system derived from the SolidWorks model as the weight associated with the control system. The information presented in Table 1 allows for an evaluation of the characteristics of the control system assisting in additional analysis and potential enhancements, down the line

Table 1. The dimensions and weight of the inflatable vest pressure control system

No.	Specification	Value	Unit
1.	Length	17.1	cm
2.	Width	14.1	cm
3.	Height	5.2	Cm
4.	Weight	0.65	kg

3.2 Control System Performance

In the study assessing the effectiveness of the control system, the experimental results were meticulously analyzed and represented in a pressure versus time graph, as depicted in Figure 6. This graph is important for understanding how well the control system performed throughout the experiment. In the section we will discuss the findings and implications of analyzing this graph, which will give us a better understanding of how effective the control system was, in this particular context.

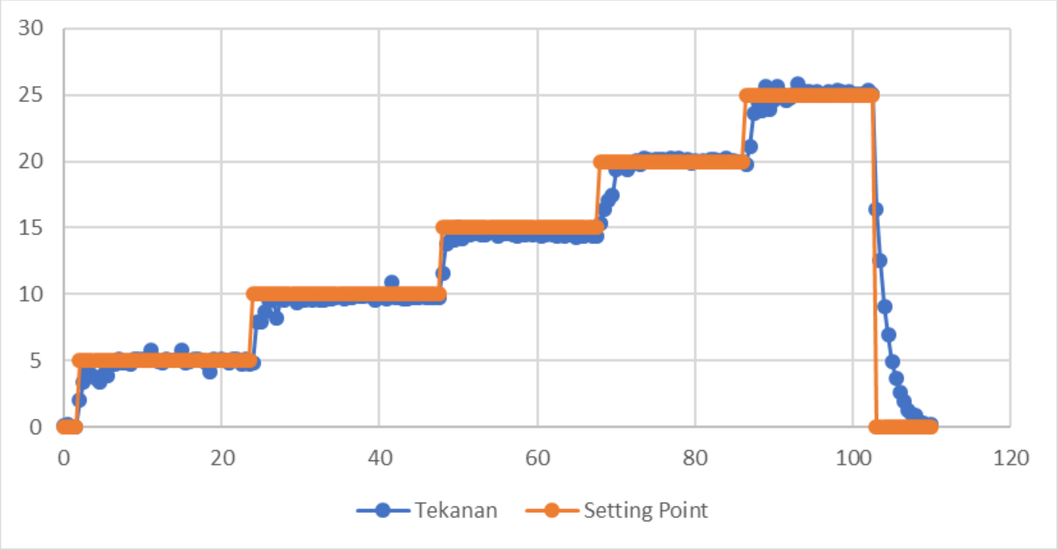


Figure 6. Graph of the control system testing results in response to setpoint changes

The graph illustrates the pressure adjustment capability of the control system at different setpoints: 5 kPa, 10 kPa, 15 kPa, and 20 kPa. The time required for pressure adjustment in response to setpoint changes is as follows: 7 seconds for 0 to 5 kPa, 3.5 seconds for 5 to 10 kPa, 2.5 seconds for 10 to 15 kPa, 5.5 seconds for 15 to 20 kPa, and 7.5 seconds for 20 to 25 kPa. Additionally, the average response speed of the control system is determined to be 0.96 kPa/s. The average error in pressure adjustment is 0.216 kPa, with a maximum error of 0.6 kPa. The results of the difference in setting point and measured pressure can be seen in Table 2.

Table 2. Results of the Difference Testing Error at Each Pressure

No.	Setting Point (kPa)	Measured Pressure (kPa)	Error (kPa)	Error (%)
1.	5	5.010	0.0103	0.206
2.	10	9.698	0.3025	3.025
3.	15	14.538	0.4617	3.078
4.	20	20.124	0.124	0.62
5.	25	25.182	0.1823	0.729
	Average		0.216	1.531

3.3 Discussion

Based on the performance testing results, the control system demonstrated that the error values obtained fall within the criteria for a medical gas pressure, which mandates an error no greater than 5% [22]. Additionally, the control system is equipped with a safety feature in the form of a toggle switch connected directly to the solenoid valve. This allows for the immediate release of air (bypassing the control system) in the event of any malfunction, ensuring user safety and control during unexpected situations.

Compared to the modified Squease Vest™ control system conducted by Maes J [21], the current control system has shown advancements in controlling the magnitude and duration of the applied pressure. However, it has not been integrated with physiological sensors to create a closed-loop system. The absence of standardized protocols for physiological conditions, such as required treatment and pressure levels [23], hinders the implementation of a closed-loop system. Therefore, further research is necessary to obtain these variables. By incorporating physiological sensors from external sources, this control system can facilitate research on the impact of pressure magnitude on reducing anxiety or stress.

Although the current control system effectively regulates the air pressure inside the vest, it does not directly measure the pressure experienced by the body, which is essential for providing the desired deep pressure effect. Hence, additional studies are needed to explore the correlation between the applied pressure and the touch pressure received by the user's body.

The current control system marks a notable advancement in pressure regulation; however, there is still potential for further improvement by exploring the concept of a closed-loop system and investigating the influence of touch pressure on the user's experience. This research serves as a foundational step for future studies delving into the effects of varying pressure magnitudes on anxiety or stress changes using external physiological sensors.

Despite the control system's smaller size compared to some deep pressure therapy devices [2], [24], it is not yet fully portable. To address this, upcoming iterations will prioritize two key aspects. Firstly, there will be a focus on downsizing the hardware components used in the system to create a more portable and less obtrusive vest. Secondly, the inclusion of a DC motor driver module for the air compressor is planned. This module will enable control using a Proportional-Integral-Derivative (PID) algorithm, aiming to minimize overshooting when adjusting the pressure to the desired setpoint. Integrating the PID controller will result in a more accurate and stable response in controlling the air pressure within the vest. These enhancements are expected to offer a superior user experience, featuring a more compact design and precise pressure control in the inflatable vest.

4. Conclusion

The control system of the inflatable vest effectively adjusts the air pressure according to the setpoint with an average response time of 1 second per kilopascal (s/kPa). The system exhibits an average pressure adjustment error of 0.39 kPa, with a maximum error of 1.1 kPa. The system's performance meets medical gas pressure criteria, with errors below 5%, making it suitable for precise medical applications.

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References

[1] L. Bestbier and T. I. Williams, “The immediate effects of deep pressure on young people with autism and severe intellectual difficulties: Demonstrating individual differences,” *Occup. Ther. Int.*, vol. 2017, no. 1, 2017, doi: 10.1155/2017/7534972.

[2] T. Grandin, “My experiences as an autistic child and review of selected literature,” *J. Orthomol. psychiatry*, vol. 13, no. 3, pp. 144–174, 1984.

[3] K. E. Krauss, “The Effects of Deep Pressure Touch on Anxiety,” *Am. J. Occup. Ther.*, vol. 41, no. 6, pp. 366–373, Jun. 1987, doi: 10.5014/ajot.41.6.366.

[4] I. Y. Afif, M. I. Maula, M. B. Aliyafi, A. L. Aji, T. I. Winarni, and J. Jamari, “Design of Hug Machine Portable Seat for Autistic Children in Public Transport Application,” in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1096, no. 1, p. 12034.

[5] K. K. Poon, I. Chew, A. Tan, and J. Teh, “The effectiveness of the t. jacket for children with autism spectrum disorders,” *J. Appl. Res. Intellect. Disabilties*, vol. 27, no. 4, p. 384, 2014.

[6] C. J. Taylor, A. D. Spriggs, M. J. Ault, S. Flanagan, and E. C. Sartini, “A systematic review of weighted vests with individuals with autism spectrum disorder,” *Res. Autism Spectr. Disord.*, vol. 37, pp. 49–60, 2017.

[7] H.-Y. Chen, H. Yang, L.-F. Meng, P.-Y. S. Chan, C.-Y. Yang, and H.-M. Chen, “Effect of deep pressure input on parasympathetic system in patients with wisdom tooth surgery,” *J. Formos. Med. Assoc.*, vol. 115, no. 10, pp. 853–859, 2016.

[8] T. Chi and M. Chen, “A frequency hopping method for spatial RFID/WiFi/Bluetooth scheduling in agricultural IoT,” *Wirel. Networks*, vol. 25, no. 2, pp. 805–817, 2019, doi: 10.1007/s11276-017-1593-z.

[9] S. M. Edelson, M. G. Edelson, D. C. R. Kerr, and T. Grandin, “Behavioral and physiological effects of deep pressure on children with autism: A pilot study evaluating the efficacy of Grandin’s Hug Machine,” *Am. J. Occup. Ther.*, vol. 53, no. 2, pp. 145–152, 1999.

[10] T. Grandin, “Calming effects of deep touch pressure in patients with autistic disorder, college students, and

animals," *J. Child Adolesc. Psychopharmacol.*, vol. 2, no. 1, pp. 63–72, 1992.
[11] N. L. VandenBerg, "The use of a weighted vest to increase on-task behavior in children with attention difficulties," *Am. J. Occup. Ther.*, vol. 55, no. 6, pp. 621–628, 2001.
[12] L. Zissermann, "The effects of deep pressure on self-stimulating behaviors in a child with autism and other disabilities," *Am. J. Occup. Ther.*, vol. 46, no. 6, pp. 547–551, 1992.
[13] S. L. Carter, "An empirical analysis of the effects of a possible sinus infection and weighted vest on functional analysis outcomes of self-injury exhibited by a child with autism.," *J. Early Intensive Behav. Interv.*, vol. 2, no. 4, p. 252, 2005.
[14] S. Hodgetts, J. Magill-Evans, and J. Misiaszek, "Effects of weighted vests on classroom behavior for children with autism and cognitive impairments," *Res. Autism Spectr. Disord.*, vol. 5, no. 1, pp. 495–505, 2011.
[15] B. Reichow, E. E. Barton, J. N. Sewell, L. Good, and M. Wolery, "Effects of weighted vests on the engagement of children with developmental delays and autism," *Focus Autism Other Dev. Disabl.*, vol. 25, no. 1, pp. 3–11, 2010.
[16] N. Watkins and E. Sparling, "The effectiveness of the Snug Vest on stereotypic behaviors in children diagnosed with an autism spectrum disorder," *Behav. Modif.*, vol. 38, no. 3, pp. 412–427, 2014.
[17] N. Bagatell, G. Mirigliani, C. Patterson, Y. Reyes, and L. Test, "Effectiveness of therapy ball chairs on classroom participation in children with autism spectrum disorders," *Am. J. Occup. Ther.*, vol. 64, no. 6, pp. 895–903, 2010.
[18] D. Fertel-Daly, G. Bedell, and J. Hinojosa, "Effects of a weighted vest on attention to task and self-stimulatory behaviors in preschoolers with pervasive developmental disorders," *Am. J. Occup. Ther.*, vol. 55, no. 6, pp. 629–640, 2001.
[19] S. Hodgetts, J. Magill-Evans, and J. E. Misiaszek, "Weighted vests, stereotyped behaviors and arousal in children with autism," *J. Autism Dev. Disord.*, vol. 41, no. 6, pp. 805–814, 2011.
[20] M. Losinski, K. Cook, S. Hirsch, and S. Sanders, "The Effects of Deep Pressure Therapies and Antecedent Exercise on Stereotypical Behaviors of Students With Autism Spectrum Disorders," *Behav. Disord.*, vol. 42, no. 4, pp. 196–208, Jul. 2017, doi: 10.1177/0198742917715873.
[21] J. E. Maes, "The design of a smart inflatable vest for children with sensory processing disorder," 2012.
[22] H. R. Fajrin, S. K. Afifah, and S. A. Wibowo, "Mixed Pressure Control Innovation of Oxygen and Air Pressure in Ventilator with Safety Valve," *J. Phys. Conf. Ser.*, vol. 1933, no. 1, 2021, doi: 10.1088/1742-6596/1933/1/012106.
[23] J. C. Duvall, N. Schleif, L. E. Dunne, and B. Holschuh, "Dynamic Compression Garments for Sensory Processing Disorder Treatment Using Integrated Active Materials," *J. Med. Device.*, vol. 13, no. 2, 2019.
[24] I. Y. Afif, M. I. Maula, M. B. Aliyafi, A. L. Aji, T. I. Winarni, and J. Jamari, "Design of Hug Machine Portable Seat for Autistic Children in Public Transport Application," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1096, no. 1, p. 012034, 2021, doi: 10.1088/1757-899x/1096/1/012034.