



## **A Review on Current Mechanical and Electronic Design Aspects and Future Prospects of Smart Canes for Individuals with Lower Limb Difficulties**

**PAROMA AREFIN<sup>1\*</sup>, MD SHEHAN HABIB<sup>2</sup>,  
AISHAWARYA AREFIN<sup>3</sup> and MD SAIDUL AREFIN<sup>3</sup>**

<sup>1</sup>Bangladesh Council for Scientific and Industrial Research (BCSIR), Rajshahi, Bangladesh.

<sup>2</sup>Bangladesh Council for Scientific and Industrial Research (BCSIR), Chittagong, Bangladesh.

<sup>3</sup>Institute of Nutrition and Food Science, University of Dhaka, Dhaka, Bangladesh.

### **Abstract**

Smart canes are one of the mobility assistive devices to facilitate the freedom of movement and help people with mobility problems to move around and perform daily chores, which are not possible usually. But they are available in different design options to offer specific advantages. In this review paper, we have addressed different mechanical and electronic designs of assistive devices proposed and developed by various researchers. The aim of our study was to sort out different mechanisms of actions used by them. With the discussion and comparison of their mode of functions, we have found a direction to potential future improvements, development, and variations to fulfill individualized and customized requirements.



### **Article History**

Received: 01 April 2020

Accepted: 27 April 2020

### **Keywords:**

Design;  
Disability;  
Mechanical and  
Electronic Aspects;  
Smart Canes.

### **Introduction**

Mobility assistive devices are designed to recover the mobility problems to improve the ability to move with an aim to help people enjoy independent movement.<sup>1-5</sup> Patients who use mobility aids usually have more confidence and feelings of protection, thus they have increased activity levels than the people who do not use these.<sup>3-7</sup> Mobility aids can be of different types. But smart canes are the most

popular ones as they are handy and easy to use. Canes redistribute weight from a poor or painful lower extremity and thus improve flexibility by raising the support base, and provide an improved balance.<sup>8</sup> There are several cane designs on the market that have specific features for different target users. Canes are available primarily in three different forms. They are regular canes, canes offset, and quad-canes.<sup>8,9,10,11</sup>

**CONTACT** Paroma Arefin ✉ paroma.arefin@gmail.com 📍 Bangladesh Council for Scientific and Industrial Research (BCSIR), Rajshahi, Bangladesh.



© 2020 The Author(s). Published by Oriental Scientific Publishing Company

This is an Open Access article licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

Doi: <http://dx.doi.org/10.13005/msri/170105>

### **Mechanical Aspects of Design of Walking Canes**

The Smart Cane is capable of sensing movement, position, orientation, and force. It helps the Smart Cane to have all the important features and actions associated with using a cane. The main objective of Smart Cane architecture concept is to provide the cane user with continuous input guidance about the current state of cane use. As a result, the Smart Cane also needs to provide a communication system for the user of the cane and give the appropriate feedback. There are four main components of a walking cane: a base, shaft, collar, and a handle.<sup>1</sup> The cane base is the part of the cane that interacts with the surface on which the user walks. Because of this continuous friction, the cane usually places a ferrule over each contact point, or tip, to improve its resilience and provide a more slip-resistant base with the ground. A collar goes between the handle and shaft of the cane, which is intended for strengthening.<sup>8,9,10</sup>

### **Designing Materials**

The aluminum canes are most preferable among other materials. They are designed in a way so that the user to change the height to match their body. The shaft shape can vary according to the form of cane being used. Grips come in all sizes and shapes. The optimal type of handle for use can differ depending on whether the user is using the system to support their weight or to help maintain their balance. Ferrules used in walking canes nowadays are typically made of rubber, just a few inches thick, and used to increase the device's stability and enhance the contact grip between it and the ground. The cane shaft is the part that connects the ferrule to the handle and is usually either made of wood or aluminum, with emphasis on a lightweight design. The handle material can vary considerably, from wood to ABS plastic, depending on the personal preferences and support requirements of the user. With the development of manufacturing technologies, more customizable ergonomic and customized canes have now become readily available to minimize discomfort and maximize comfort as much as possible. Aluminum canes are typically of adjustable length. Therefore perfect fitting before purchase is often feasible. Aluminum cane can be designed as a "folding" cane that can fall for compact storage while traveling. Compared to

aluminum canes wooden canes are lightweight and inexpensive. Aluminum is commonly used because it is light and robust. But it is essential to consider the use of magnesium, which is lighter and more durable and never used it before. The width, thickness, and height of the cane should be modified as little as necessary due to the introduction of components to the tool.<sup>11-15</sup>

### **Load Bearing Capacity**

People with mobility problems and incapable to completely support their weight due to pain or balancing limitations have to use canes.<sup>7</sup> Load bearing capacity is an important feature in the designing of a smart cane.<sup>16-18</sup>

The Smart Cane Device assists in evaluating recovery progress by assessing if the correct weight-bearing is applied to the cane.<sup>12</sup> Its preset force feature allows the weight-bearing percentage to be changed on the cane for optimum rehabilitation. These systems are designed in a way so that it can sense weight-bearing and measure the cane load automatically. This typically ranges from 20 – 25 percent of the bodyweight of the patient.<sup>15-17</sup> It controls the force applied, and issues a warning when the required amount of weight has not been achieved. This alarm will inform the consumer that the force being applied will either increase or decrease. The system will also keep a record of the measurements of force and the length of their interaction during each phase. In his research, Klenerman<sup>15</sup> found a significant linear relationship between measurement and average force applied. A study by Routson<sup>4,19</sup> showed that biofeedback was successful in boosting significant cane loads.

### **Weight of Walking Canes**

The Smart Cane Device measures weight-bearing applied to the cane. Smart canes are fitted with devices capable of reliably calculating weight and the cane load.<sup>20,21,22</sup> The weight of walking canes should be less for this purpose. It should be heavy enough to carry the user's weight and, at the same time, be as light as possible to be user friendly. The popularity of the walking sticks available in the market indicates that the weight of walking canes is one of the most influencing factors while choosing for use.<sup>22-24</sup>

### **Ergonomics Handle Design**

Canes providing ergonomic handle design are walking sticks with handles that provide the user with more significant support and decrease the risk of wrist injury. Ergonomic canes are specifically designed to provide comfort, style, and durability. The handles are comfortable to hold and reduce the stress on the wrist, making them suitable for users of cane.<sup>25-27</sup>

### **Handle**

The handle of ergonomic walking canes is built to suit the user's hand comfortably in the palm. In this way, the body's weight is uniformly distributed around the entire side, making walking with a cane less painful for people living with arthritis. Ergonomic canes are built for right and left-handed individuals.<sup>12,28</sup> There are a variety of styles of handles and grips, and patients with some mobility disabilities can choose them according to their own requirements. Carpal tunnel syndrome has been identified with the most frequently used umbrella shape handle, but is less common with foam-padded horizontal palm grips.<sup>3</sup> Patients needing wrist support or trying to reduce wrist discomfort can benefit from an ergonomic handle that is used like one is shaking hands with the handles. When walking with a cane, it is typically carried on the same side by the arm as the stronger leg of the patient.<sup>12,14,29</sup>

### **Elbow Flexion & Length**

There are various ways to fit a cane but most physiotherapists are using elbow flexion as a reference. Ideally, while carrying the cane about 15 cm from the lateral border of the toes there should be 20° to 30° ranges of flexion in the elbow.<sup>30</sup> This amount of flexion enables active elbow movement when walking.<sup>12,14,31</sup> When the patient's arm is hanging by their side, the length of the cane will be about the distance from the ground to the greater trochanter or wrist crease. The cane tip is mounted on the ground, approximately 6 inches apart from the adjacent toes. An appropriate length for cane is the length from the ground to the crease of the wrist during the user's arm is hanging comfortably at his/her side.<sup>13,15,18,31</sup>

### **Position of Sensors**

Smart canes track the weight-bearing of users while walking with the help of sensors providing

individualized information about their progress. Sensors can be placed in different positions in the smart walking stick. In either place, either left, right or front, the sensor can be positioned. Mostly, the sensors are either located on the handgrip,<sup>12,32</sup> tip or shaft<sup>33,34</sup> of the smart canes. Significant cane modifications may include putting sensors on the handgrip or tip. Both changes must be ergonomic, as both positions influence how users support their weight. The shaft provides more space for the electronics to be mounted. This can entail changes in the center force and weight of the cane. The embedded pressure sensors may be mounted in the tip of a normal cane at two separate depths, so they do not impact the ergonomics of the cane. Unfortunately, an extensive validation process is expected when granting ergonomics. Au *et al.*, recommended a cane fitted with a three-axis accelerometer, a gyroscope with three axes, and two pressure sensors. They used the accelerometers and gyroscopes to measure the positions of the cane and its accelerations. In its configuration, one pressure sensor was set on the distal tip of the cane, and the load force was acquired, and the another one was added to the gripping force of the handle display.<sup>35-37</sup>

Wearable sensors, such as sole pressure sensors and/or inertial sensors,<sup>34-38</sup> can be used to test gait during everyday living activities. But some designs may not give the desired level of comfort or ease of handling, so people are demotivated to use those.

### **Base of Walking Canes**

The base of the cane is a structure between the ferrule and the shaft, constructed to accommodate the electronic components that are not found in the handle. While its primary purpose is to house the load cell, it also contains the device-driven batteries and connectors that allow communication between the sensors in the lower half of the cane and the handle microcontroller. For usage, housing had to be added to the load cell, which could both secure it and prevent it from moving when using the cane.<sup>4,39</sup>

### **Electronic Aspects of Design of Walking Canes**

The Smart Cane was originally aimed at to lowering the fall risk related to cane use. It provides automated information about the position and applied forces with the help of sensor.<sup>38</sup> The design of SmartCane

was based on the accurate integration of processor, software, and sensors. It can reduce the hazards of fall by continuous monitoring by<sup>-1-8,40-42</sup>

- Identifying cane using styles
- Continuous updating the user about cane orientation, and
- Guiding user to use cane properly

The Smart Cane comprises a regular cane, sensors, and data acquisition settings. The integrated Bluetooth system lets the system to relay data wirelessly to either data analyzer or to a distant place so that it can give the necessary information to medical entity. This data can be stored and further investigated.<sup>22-27</sup> The Smart Cane entrenches regular cane with sensors, and a smartphone and a microcontroller,. It tracks the movement of users walking to conduct gait analysis. In a smart cane, the input voltage should be between 9V and 12V DC, and the current must be rated for a minimum of 250mA current output, although something more like 500mA or 1A output is better.

#### Types of Sensors

Smart Cane can get into all movement and force related data through various sensors. Sensors are introduced to detect a possible obstruction in the user's way. To measure contact forces, Perez<sup>10</sup> used a force sensor along with processing units and it could serve therapeutic purposes. Systems with embedded sensors were proposed to expand the monitoring to everyday living activities. Embedded sensors can be used for monitoring purposes. Trujillo-León A<sup>18</sup> proposed a tactile sensor for tracking cane use in his research. The suggested handle could be a solid and cost-effective alternative for tracking the condition of users in the context of robotic mobility aids. The six-axis force sensor would be replaced by a charged cell to allow embedded processing on the cane and to avoid using wired data transmission.

Chamorro-Moriana *et al.*,<sup>43</sup> suggested the creation of a different device that can be used to regulate and increase the precision of the loads so that the lower portion of the body can be unburdened. They proposed GCH System 2.0, a force sensor based system. They confirmed the accuracy and

precision of the instrument by different studies. The method, designed to determine the loads applied by users during assisted gait on crutches, could provide accurate and reliable load measurements. Gill proposed a design of a Multi-sensor embedded IoT-enabled mobility device for appropriate gait monitoring.<sup>44</sup>

#### Transmitter Unit and Receiver Unit and their Embedded Systems

The smart cane uses load- and measuring sensors. The cane transmits the meaning to transmitters until it's got. It encodes the providing post. The information is then transmitted as encoded to the receiving unit and is decoded by the receiving unit. The receiver provides the user with signals by decoding.<sup>22-32</sup> Au *et al.*,<sup>38</sup> proposed a cane that included an integrated MircoLeap processing unit. It gathered sensor data. So it acted as a transmitter device, and it emitted an audio alarm to provide user input. And it functioned as a receiver unit. Rangeetha<sup>45</sup> suggested a smart cane for people with visual impairments. In styling. The transmitter was attached to the bus, and the receiver was connected to the walking stick. There were 4 channels for the transmitter and the receiver. Radiofrequency receiver received transmitter signal.

#### Feedback Processing Methods

Smart canes are popular primarily because they provide support and reduce load over a feebler leg. Besides, a smart cane can assist the propulsion and braking portions of the gait as well as the somatosensory information.<sup>1-10</sup> Smart canes use such feedback as tone, vibration, lights, etc. Other biofeedback devices are also available, which use foot plantar pressure rather than an instrumented cane.<sup>15,18,29,34</sup> Canes receive direct input, both auditory and proprioceptive. The body position-related sensory input assist compensate for sensorimotor damages influencing stability and reduce the threat of falling.<sup>12,14,20,36</sup> Initial findings from a study on the influences of greater somatosensory feedback on the level and slope walking in post-stroke individuals point to beneficial effects, including improved gait rhythm and speed, reduced step distance, and enhanced center of mass control. Mercado *et al.*,<sup>17</sup> developed a system using a quad cane that provided auditory feedback based on the

user's application of force to the handle. An easy and instinctive over-the-counter solution is required, which can encourage the appropriate use and loading of long-term cane. Even with instruction, it can be challenging to consistently load a system with enough body weight in the long run. Patients often use knee pain to determine the level of cane assistance. Pain is variable according to different individual and does not correspond with loading of joint, so it is an undesirable input signal to direct exact loading of canes.<sup>10,14,34-40</sup> In their study, Routson<sup>19</sup> examined the effectiveness of a smart cane with vibrotactile feedback aimed at facilitating increased cane loading. These findings show that the vibrotactile biofeedback of the smart cane helped patients to obtain cane loading of 15 percent BW or more than that of verbal training only. Conventional cane loading was higher after using the smart cane than the naïve and verbal instruction conditions, which demonstrated a potential smart cane training impact. Improved loading of cane over the long term will decrease joint pain and enhance functionality. The smart cane could help users add ample load to the walking cane.

Biofeedback is a non-invasive method of measuring physiological functions where the most subtle changes in body functions are calculated by specific instruments. Biofeedback canes are also very helpful for people suffering from strokes and other disabilities.<sup>46</sup> The load application process is entirely under patient supervision and is a training feature to an unknown degree. The physician and therapist have considerable difficulty in deciding whether proper forces are being applied, and can typically track only one static sample of a bathroom scale of the cane load. The Biofeedback cane device allows for adjustment of the audio alarm based on cane load. The device also records the pressure on the cane for every step. This knowledge may prove useful in additional studies.

### **Power Management**

Power management is an essential aspect of these types of smart canes with minimal computing capabilities. There are several battery life optimization techniques that are reactive, static. In this way, a power-saving mode is constantly enabled when battery storage capacity is below a specific level. Another approach is that the

power saving mode consists of changing device parameters, e.g., increasing the rate of sampling or decreasing precision. Though it is simple and always in power-saving mode, can adversely affect the user experience of the excellence delivered, like the accuracy of calculating device parameters taking into account user health conditions. Ayala *et al.*, suggested a reasonable alternative to consider QoS targets involving specific device properties such as relative error or sampling accuracy. The reconfiguration is activated in this device to preserve a specific QoS. Dynamic Software Product Lines are good tactics to adapt handling mobile device system by developing software. It can adapt to variations by linking the variance factors that can alter during system execution due to an occurrence like little battery level.<sup>42,45</sup>

A significant issue is energy conservation in outdoor mobile devices, which is more applicable in smart canes. There is a major problem in the IoT about the power supply. There are issues to be considered about the expense of the battery, the care for recycling and about the large maintenance scale. The use of energy harvesting offers one of the great solutions. Technologies for energy gathering use power generation substances like solar cells that are suitable to these systems. A harvesting method can, therefore, be useful for controlling the sensors. Again its use in Smart Cane may necessitate a detailed ergonomic study to explore a range of substitutes.<sup>47</sup> Smart wearables offer a prodigious chance to track and assess health problem in a non-intrusive manner during everyday activities, such as walking. Assistive devices are battery-based, and battery type and size are dictated by the power requirements of the user. Users, of course, need more user-friendly, handy, and lighter devices with extended battery life. An worthy approach is to incorporate a mechanism of user adaptation that will reconfigure the machine over its everyday usage, to consume less power.<sup>47,48</sup>

### **Discussion**

In this review study, we have discussed the proposed or currently available technologies to develop smart canes. We have noticed that to meet the requirements; standard canes have given its place to smart canes. In these types of canes, different kinds of sensors and feedback processing

methods are used. The individuals with lower limb problems, and the elderly have different personalized limitations of movement. The available and proposed set of mechanisms can lead to the development of customized smart canes. Even if a person gives his/her list of necessities, companies can quote for a model embedding the required mechanisms. Future studies are possible to develop more compact designs with the proper combination of sensor and feedback processing units, yet more economical.

### Conclusion

Smart canes are boon for elderly and disable people. We have discussed and found different mechanical and electronic dimensions of smart canes that signify various action of mechanisms. The advancement in smart cane technologies can be individually used for future improvements, possible development, and variations. Our study can help to get possible options of modifications to develop the best cane. There is still research gaps to develop more compact and inexpensive canes with all facilities as it is a daily necessity in the life of individuals with lower limb injury problems.

### Highlights

- Different mechanical design modification is possible to obtain personalized canes
- Electronic aspects can be modified to get desired properties of smart canes

### Acknowledgements

- Paroma Arefin: Conceptualization, Resources, Writing - Original Draft
- Md Shehan Habib: Methodology, Validation, Resources, Writing - Original Draft
- Aishwaryia Arefin: Investigation, Writing - Original Draft
- Md Saidul Arefin: Writing - Review & Editing, Supervision

### Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Conflict of Interest

The authors do not have any conflict of interest.

### References

1. Requejo PS, Furumasu J, Mulroy SJ. Evidence-Based Strategies for Preserving Mobility for Elderly and Aging Manual Wheelchair Users. *Top Geriatr Rehabil.* 2015 Jan-Mar;31(1):26-41. doi: 10.1097/TGR.0000000000000042. PMID: 26366040; PMCID: PMC4562294.
2. Bruun G. Mobility aids, proposal for research and development. In *Development of Electronic Aids for the Visually Impaired*; Emiliani, P.L., Ed.; Springer: Dordrecht, The Netherlands, 1986;265–273.
3. Bateni H, Maki BE. Assistive devices for balance and mobility: Benefits, demands, and adverse consequences. *Arch. Phys. Med. Rehabil.* 2005;86:134–145.
4. Faruqui SR, Jaebon T. Ambulatory assistive devices in orthopaedics: Uses and modifications. *J. Am. Acad. Orthop. Surg.* 2010;18: 41–50.
5. Salminen AL, Brandt A, Samuelsson K, Toytari O, Malmivaara A, Mobility devices to promote activity and participation: A systematic review. *J. Rehabil. Med.* 2009;41: 697–706.
6. Matalenas LA, Hu T, Veeramachaneni V, Muth J. A Cane for More than Walking. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* SAGE Publications. 2016 Sep;60(1):1063–7. Available from: <http://dx.doi.org/10.1177/154193121360124>
7. Iezzoni LI, McCarthy EP, Davis RB, Siebens H. Mobility difficulties are not only a problem of old age. *J Gen Intern Med.* 2001 Apr;16(4):235-43. doi: 10.1046/j.1525-1497.2001.016004235.x. PMID: 11318924; PMCID: PMC1495195.
8. Au L, Jordan B, Wu W, Batalin M, Kaiser WJ. Design of Wireless Health Platforms. In: Bonfiglio A., De Rossi D. (eds) *Wearable Monitoring Systems.* Springer, Boston, MA. 2011.
9. Boyles RW. Mechanical Design of an Instrumented Cane for Gait Prediction by

- Physical Therapist. M.S. thesis, Dept. Mech. Eng., Vanderbilt Univ., Nashville. 2015.
10. Perez C, Fung J. An Instrumented Cane Devised for Gait Rehabilitation and Research. *Journal of Physical Therapy Education* [Internet]. Ovid Technologies (Wolters Kluwer Health). 2011;25(1):36–41. Available from: <http://dx.doi.org/10.1097/00001416-201110000-00007>
  11. Lam R. Practice tips: choosing the correct walking aid for patients. *Can Fam Physician*. 2007; 53.
  12. Kaye HS, Kang T, LaPlante MP. Mobility device use in the United States. Disability statistics report no. 14. Washington, DC: National Institute on Disability and Rehabilitation Research, U.S. Department of Education. 2000.
  13. Dang D, Suh Y. Walking Distance Estimation Using Walking Canes with Inertial Sensors. *Sensors*. MDPI AG. 2018 Jan 15;18(1):230. Available from: <http://dx.doi.org/10.3390/s18010230>
  14. Vonn WY, Yang S. Cane Design: A Preliminary Research Concerning on Cane and Elderly Users. *International Journal of Social Science and Humanity*. *EJournal Publishing*. 2018 Jan;31–6. Available from: <http://dx.doi.org/10.18178/ijssh.2018.v8.929>
  15. Klenerman L, Hutton WC. A Quantitative Investigation of The Forces Applied to Walking-Sticks and Crutches. *Rheumatology*. 1973;12(3):152–158.
  16. Ballesteros J, Tudela A, Caro-Romero JR, Urdiales C. Weight-Bearing Estimation for Cane Users by Using Onboard Sensors. *Sensors (Basel)*. 2019 Jan 26;19(3):509. doi: 10.3390/s19030509. PMID: 30691145; PMCID: PMC6387159.
  17. Mercado J, Chu G, Imperial EJ, Monje KG, Pabustan RM, Silverio A. Smart cane: Instrumentation of a quad cane with audio-feedback monitoring system for partial weight-bearing support; Proceedings of the 2014 *IEEE International Symposium on Bioelectronics and Bioinformatics (ISBB)*; Chung Li, Taiwan. 11–14. 2014 April;1–4.
  18. Trujillo-León A, Ady R, Vidal-Verdú F, & Bachta W. A tactile handle for cane use monitoring. 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). 2015;3586-3589.
  19. Routson RL, Bailey M, Pumford I, Czerniecki JM, Aubin PM. A smart cane with vibrotactile biofeedback improves cane loading for people with knee osteoarthritis. *Conf Proc IEEE Eng Med Biol Soc*. 2016 Aug;3370-3373. doi:10.1109/embc.2016.7591450. PMID: 28269026.
  20. Wikipedia Contributors. Mobility Aid. Wikipedia, The Free Encyclopedia. Available online: [https://en.wikipedia.org/w/index.php?title=Mobility\\_aid&oldid=790371055](https://en.wikipedia.org/w/index.php?title=Mobility_aid&oldid=790371055) (accessed on 20 November 2017).
  21. O'Sullivan SB, Schmitz TJ. Assistive devices and gait patterns. In: SchneeM, editor. *Physical rehabilitation: assessment and treatment*. 4<sup>th</sup> ed. Philadelphia, PA: FA Davis Company. 2001;425-34.
  22. Alexander NB. Gait disorders in older adults. *J Am Geriatr Soc*. 1996;44(4):434–451.
  23. Faruqui SR, Jaeblon T. Ambulatory assistive devices in orthopaedics: uses and modifications. *J Am Acad Orthop Surg*. 2010;18(1):41–50
  24. Liu HH. Assessment of rolling walkers used by older adults in senior-living communities. *Geriatr Gerontol Int*. 2009;9(2):124–130.
  25. Sudarsky L. Geriatrics: gait disorders in the elderly. *N Engl J Med* 1990;322(20):1441-6
  26. Van Hook FW, Demonbreun D, Weiss BD. Ambulatory devices for chronic gait disorders in the elderly. *Am Fam Physician*. 2003;67(8):1717-24.
  27. Joyce BM, Kirby RL. Canes, crutches and walkers. *Am Fam Physician*. 1991;43(2):535-42.
  28. Studenski SA, Brown CJ, Duncan PW. Mobility aids. In: American Geriatrics Society. *Review syllabus: a core curriculum in geriatric medicine*. 6<sup>th</sup> ed. New York, NY: American Geriatrics Society. 2006;117-8.
  29. Laufer Y, Dickstein R, Chefez, Y, Marcovitz E. The effect of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation. *Journal of Rehabilitation Research and Development*. 2001 Jan/Feb;38(1):69 – 78.
  30. Cameron R. Hernandez, MD, Mount Sinai School of Medicine. ElderCare A Resource for Interprofessional Providers. Choosing

- the Correct Walker. Arizona Center on Aging. February 2018.
31. Kumar K., Champaty B., Uvanesh K., Chachan R., Pal K., Anis A. Development of an ultrasonic cane as a navigation aid for the blind people; Proceedings of the 2014 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT); Kanyakumari, India. 2014 10–11 July; 475–479.
  32. American Geriatrics Society. Health in Aging. Choosing the right cane or walker. [http://www.healthinaging.org/files/documents/tipsheets/canes\\_walkers.pdf](http://www.healthinaging.org/files/documents/tipsheets/canes_walkers.pdf).
  33. Silva J. How to use a cane. (Video from Caregivers Training.com). <http://www.youtube.com/watch?v=fRn8ZZJMzno> March 2013 (updated May 2015) Elder Care A Resource for Interprofessional Providers Canes Cameron R. Hernandez, MD, Mount Sinai School of Medicine Tracy Carroll, PT, CHT, MPH, College of Medicine, University of Arizona Barry D. Weiss, MD, College of Medicine, University of Arizona
  34. Ostaszewski M, Pauk J. Estimation of ground reaction forces and joint moments on the basis on plantar pressure insoles and wearable sensors for joint angle measurement. *Technol. Health Care*. 2018;26:605–612. doi: 10.3233/THC-182507.
  35. Carcreff L, Gerber CN, Paraschiv-Ionescu A, De Coulon G, Newman CJ, Armand S, Aminian K. What is the Best Configuration of Wearable Sensors to Measure Spatiotemporal Gait Parameters in Children with Cerebral Palsy? *Sensors*. 2018;18:394. doi: 10.3390/s18020394.
  36. Hesse S, Bertelt C, Jahnke M, Schaffrin A, Baake P, Malezic M, Mauritz K. Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. *Stroke*. 1995;26:976–981. doi: 10.1161/01.STR.26.6.976.
  37. Ferrari A, Rocchi L, van den Noort J, Harlaar J. Converging Clinical and Engineering Research on Neurorehabilitation. Springer; Berlin/Heidelberg, Germany. Toward the Use of Wearable Inertial Sensors to Train Gait in Subjects with Movement Disorders. 2013;937–940.
  38. Au L, Jordan B, Wu W, Batalin M, Kaiser WJ. Design of Wireless Health Platforms. In: Bonfiglio A., De Rossi D. (eds) *Wearable Monitoring Systems*. Springer, Boston, MA. 2011
  39. Leemets, Kaur & Terasmaa, Tonis & Jaakson, Paul & Kume, Alar & Tamm, Tarmo. (2015). Development of A Smart Insole System for Gait and Performance Monitoring. 10.2991/icmsa-15.2015.130.
  40. Van Ginckel A, Hinman RS, Wrigley TV, Hunter DJ, Marshall CJ, Duryea J, *et al.*, Effect of cane use on bone marrow lesion volume in people with medial tibiofemoral knee osteoarthritis: randomized clinical trial. *Osteoarthritis and Cartilage*. Elsevier BV. 2019 Sep;27(9):1324–38. Available from: <http://dx.doi.org/10.1016/j.joca.2019.05.004>.
  41. Afzal MR, Pyo S, Oh M-K, Park YS, Lee B-C, Yoon J. Haptic based gait rehabilitation system for stroke patients. 2016 *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* [Internet]. IEEE. 2016 Oct. Available from: <http://dx.doi.org/10.1109/iros.2016.7759494>.
  42. Dabir A, Solkar R, Kumbhar M, Narayanan G. GPS and IOT Equipped Smart Walking Stick. International Conference on Communication and Signal Processing (ICCSP) [Internet]. IEEE. 2018 Apr. Available from: <http://dx.doi.org/10.1109/iccsp.2018.8524472>.
  43. Chamorro-Moriana G, Sevillano JL, Ridao-Fernández C. A Compact Forearm Crutch Based on Force Sensors for Aided Gait: Reliability and Validity. *Sensors (Basel)*. 2016 Jun 21;16(6):925. doi: 10.3390/s16060925. PMID: 27338396; PMCID: PMC4934350.
  44. Gill, Satinder & Seth, Nitin & Scheme, Erik. A Multi-Sensor Matched Filter Approach to Robust Segmentation of Assisted Gait. *Sensors*. 2018. 18.2970. 10.3390/s18092970.
  45. Rangeetha S, Rilvanafathima B, Sanjana R, Nivetharajam S. Arduino Based Smart Walking Stick For Visually Impaired to Identify Bus Route, *International Journal of Engineering Research & Technology (Ijert)*. 2016 April;5(4), Issue 04. <http://Dx.doi.org/10.17577/Ijertv5is040504>.



46. Moran PT, Harris GF, Acharya K, Zhu H, Wertsch JJ. A biofeedback cane system: instrumentation and subject application results. *IEEE transactions on Rehabilitation Engineering*. 1995 Mar;3(1):132-138.
47. Ayala I, Ballesteros J, Caro-Romero JR, Amor M, Fuentes L. Self-Adaptation of mHealth Devices: The Case of the Smart Cane Platform. Proceedings [Internet]. MDPI AG. 2019 Nov 20;31(1):23. Available from: <http://dx.doi.org/10.3390/proceedings2019031023>
48. Anastasi, Giuseppe & Conti, M & Passarella, Andrea. Power Management in Mobile and Pervasive Computing Systems. Handbook of Algorithms for Wireless Networking and Mobile Computing. 2005. 10.1201/9781420035094.ch24.