# Indoor Human Following Assistive Robot with Fall Detection Capability for the Elderly and the Differently Abled.

SL Seneviratne[1#], BCJ De Zoysa[1], AMSE Senaratne[1], EC Padmarisi[1] and PSH Pallemulla[1]
[1]*Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka*
[#]<seneviratnesl@kdu.ac.lk>

***Abstract*— *The number of falls among the elderly people increase each year and the lack of appropriate care and support leads to serious injuries that could also cost lives. Therefore, the elderly and the differently abled people require constant monitoring. It is too costly to hire a caretaker or move the person to a nursing home or to an elder care home. To minimize the risks faced by the person due to falls, to remind the person of their medication, to contact the guardian, if necessary, to alert the guardian when a fall is detected, and to provide company to the person, a robot is developed and implemented. The main objective of the project is to identify the primary and secondary activities of daily living that require assistance for the elderly and the differently abled, to implement human detection, tracking, and fall detection in the robot. Secondly, to design a robot that will assist the elderly and the differently abled in fulfilling a subset of activities of daily living, to optimize the robot for domestic purposes through software validation and verification, and finally to fabricate the designed robot. Human Detection, Following, and Fall Detection algorithms are implemented using Python with a Raspberry Pi 4 for processing. Pose estimation will be used to detect the human, build the logic for human following, and fall detection as well. The robot follows the elderly person from behind and detects any falls.*

***Keywords*— human-following, fall-detection, indoor.**

## I. INTRODUCTION

Falls are a significant problem for the elderly and those with special needs. The World Health Organization (WHO) reports that between 28% and 35% of those over 65 fall each year(Chin *et al.*, 2020) and the number keeps rising as the population ages. For people 65 years of age and older, falls are now the leading cause of death (*Guardian Camera AI*, 2020). The elderly and those with disabilities now require specialized medical care, which is an economic burden due to the rise in fall incidents. Serious injuries and even death might result from inadequate assistance and treatment.

An AARP (American Association of Retired Persons) survey (Tabbakha, Tan and Ooi, 2017) claims that approximately 90% of seniors over 65 want to live at home even though they require ongoing medical care or daily help. Seniors' emotional health benefits from continuing to live at home or in a familiar neighborhood. However, because of present-day circumstances, the elderly who should be receiving aid to live are always living alone because their guardians are out at work.

Transferring the elderly person to a nursing home or elder care facility where social activities, health monitoring, and medication management are well-cared for, can readily alleviate this issue. However, it is too expensive for the majority of people, and it becomes even more challenging when older individuals refuse to leave their homes. As a result, the guardians who are away from home are worried about leaving the elderly at home alone(Tabbakha, Tan and Ooi, 2017).

We have designed and built a robot to help the elderly and the differently abled to detect any falls while following the person and immediately notify the guardian in order to reduce the risks of falls faced by the elderly. The robot will also remind the person to take their medication, help the person with very simple tasks such as providing them with water, and to lessen the worries of the guardian.

For this use, a number of gadgets with a wide range of features and technological approaches have been developed. However, none of the robots have an assistive companion feature that helps the elderly and persons with disabilities with simple chores like reminding them to take their medication. As a result, we hope that our design will give the community a better choice while also adding variation to the existing ones.

## II. LITERATURE REVIEW

Human following is said to be an aggregation of various research on relations between human and the robot (Itoh *et al.*, 2006). The robots being developed these days are made autonomous by the use of various sensors such that it takes its own decisions and does not rely on human intervention. In order to create a robot that is capable of following a person, there are two fundamental robotic tasks that must be accomplished:

(1) person tracking and localization – the robot must be able to identify the target person in the environment.
(2) robot navigation – the robot must be able to follow the person appropriately (Honig *et al.*, no date).

According to (Pannurat, Thiemjarus and Nantajeewarawat, 2017), a fall is defined as “an event which results in a person coming to rest unintentionally on the ground or other lower level, not as a result of a major intrinsic event (such as a stroke) or overwhelming hazard". It is mentioned in the paper (Yang, Ren and Zhang, 2016) that a fall usually takes place within 0.45s and 0.85s, and also the posture and shape of the person changes during a fall. These changes are especially important when detecting a fall.

A vast number of recently developed fall detection systems operate based on a general framework, (Koshmak, Loutfi and Linden, 2016), that is,

(1) Data acquisition.
(2) Data processing/feature extraction.
(3) Fall detection.
(4) Caregiver Notification.

A fall detection system can be classified into two categories: context-aware systems and wearable devices. Context-aware systems use devices such as cameras, floor sensors, infrared sensors, microphones, Passive Infrared (PIR) sensors, and pressure sensors to detect falls. Their advantage is that a person is not required to wear any special equipment. Wearable device-based approaches rely on clothing with embedded sensors to detect the motion and location of the person.

Vision-based systems can conduct inactivity detection and analyze the body shape changes or 3D head motion. They provide an unobtrusive way to monitor the person, and several studies have shown that vision-based systems have a relatively low rate of resulting in positive false alarms (Koshmak, Loutfi and Linden, 2016).

(El-Bendary *et al.*, 2013) mentions about research done on camera-based fall detection systems. They detected falls based on analyzing the aspect ratio of the moving object's bounding box. This method is said to be very inaccurate, depending on the relative position of the camera and person. (Shoaib et al.)

Computer vision-based fall detection systems hold a major advantage over wearable fall detection systems because the wearable devices can be a hindrance to daily activities of an elderly person. The acceptance of a wearable device by the elderly is very minimal (El-Bendary *et al.*, 2013) and wearables have their limitations for massive usage and monitoring (neuralet, 2022).

Computer vision-based fall detectors are categorized into two: analytical methods and machine learning methods. In analytical methods, initially certain types of features will be extracted from the vision/video data and afterwards these features will be analyzed for the determination of fall and non-fall activities.

Human Pose Estimation (HPE) is a way to identify and classify the joints in the human body. HPE captures a set of coordinates for each joint called a key point, which is useful in describing the pose of a person. The aim of HPE is to form a skeleton-like representation of a human body and then process it further for task-specific applications (*Human Pose Estimation: Deep Learning Approach [2022 Guide]*, 2021). "Fall" is a sudden change in the posture of a person's body, for instance, the posture of the body changing from standing (vertical) to a lying (horizontal) position. Therefore, pose estimation can be a very helpful technique to track and estimate the state of the body parts and use their changes to detect falls. (neuralet, 2022) has developed a fall detection system using Pose Estimation and Motion Detection.

One of the major goals when building an assistive robot is to develop a robot that allows the most natural interaction between the user and the robot. Elderly people are not familiar with, and they find it difficult to interact through means such as keyboards and computer screens, therefore, the communication between the person and the robot should be something that the elderly person is familiar with. Therefore, spoken interaction with the robot is absolutely essential (Roy *et al.*, 2000).

Another research done by the National Institutes of Health found out that 67% of the elderly who fall and fail to seek help within 72 hours are unlikely to survive. Therefore, only being able to detect the fall is hopeless, the guardian, a nurse or a doctor should be notified of the fall immediately. There are manual emergency buttons that are often employed; however, this method is not practical since the elderly person might be unconscious, or the button might be out of reach of the person. Another system that is mentioned in (Kalinga *et al.*, 2020) uses a GPS/GSM module to automatically send help requests to caregivers with the elder's location.

With the rapid increase in development of robots, lightweight construction and energy efficiency play a significant role as mobile, dynamic systems have to work self-sufficiently. Additionally, a robot should be energy efficient since the systems are working self-sufficient. The storage capacity is also limited. Weight reduction can be done by changing the design of the components, improved utilization of material by more exact knowledge of the loads, and by using composite materials which make a clear change in weight (Albers *et al.*, 2007).

Robot motion control enables a mobile robot to move through locomotion and steering. This controlled motion enables these complex tasks with whatever end effector is appropriate on the robot (Group, 2019). Locomotion is therefore fundamental for a robot's movement through the working environment. Some indoor robots are designed to move, run, or walk in order to complete the assignments specified to them. Robots can be equipped with legs, wheels, or wings. It is proven that wheeled robots are the most efficient (Niloy *et al.*, 2021).

## III. METHODOLOGY

The block diagram shown in Figure 1 includes the basic functions of the robot with a laptop for processing.

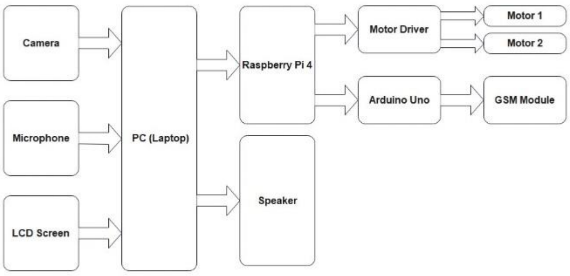


Figure 1: Block Diagram with Laptop for Processing

In this version of the robot, the laptop is used as the graphical processor. The objective of our project is to optimize the robot for domestic use. To fulfil this objective, we need to make sure that the robot is fabricated to be used by any person. The current version of the robot, with the laptop for processing is not optimized for domestic purposes. Therefore, another version of the robot with an NVIDIA Jetson Nano was proposed. Figure 2 shows the block diagram of the robot with an NVIDIA Jetson Nano for processing.

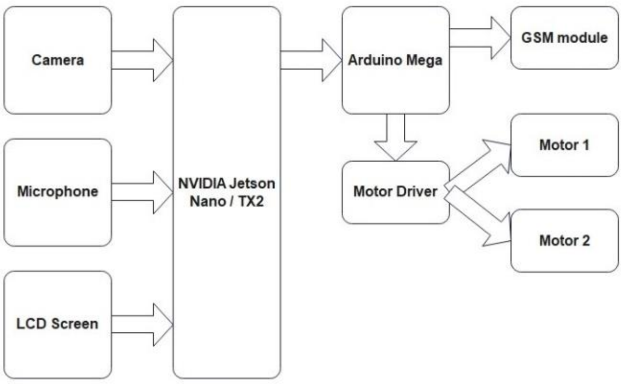


Figure 2: Block Diagram with an NVIDIA Jetson Nano for Processing

An NVIDIA Jetson Nano has a 128-core Maxwell GPU at 921 MHz (*Jetson Nano vs Raspberry Pi 4: The Differences | All3DP*, 2022). When in comparison to the Raspberry Pi 4, the Jetson Nano has a much more powerful GPU, therefore, the processing can be done with the Jetson Nano alone. The version of the robot with the Jetson Nano for processing will be subjected as future work and the version with the laptop will be tested to obtain reliable results for observations.

### A. *Human Following*

The logic implemented in our project for Human Following is a new concept which uses Pose Estimation in following the person from behind. The figure 3 shows the flow chart for Human Following:

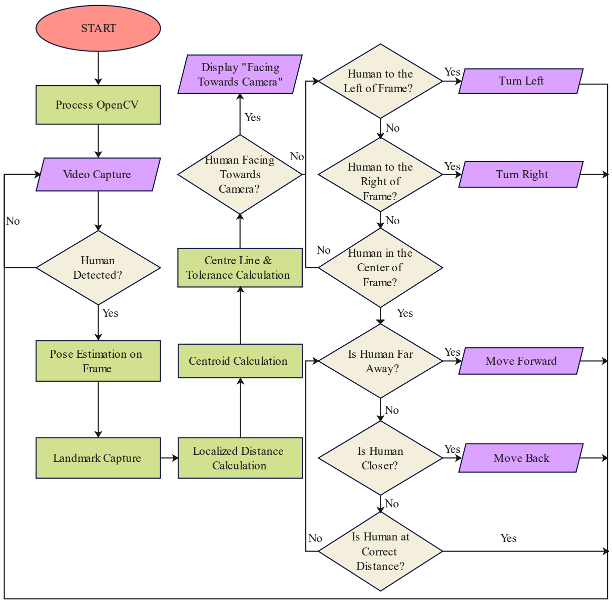


Figure 3: Flow Chart for Human Following

### B. *Fall Detection*

The figure 4 shows the flow diagram for the fall detection system.

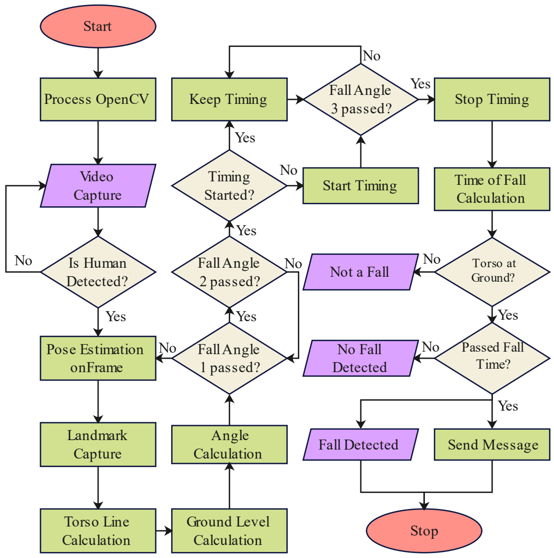


Figure 4: Flow Chart for Fall Detection

Vision-based fall detection systems can also be classified into two types: logical approach and machine learning approach. The logical/analytical approach involves detecting the fall according to logic. The logic depends on the pose of the person. According to the change in pose and the logic implemented, it will be predicted whether a fall is

detected or not. The machine learning approach uses datasets, and the video capture is compared with the datasets to predict whether a fall is detected or not.
In this paper, the logical approach is used for fall detection. No machine learning approaches have been implemented.

### C. *Emergency Notification and Speech Assistant*

The logic implemented in the emergency notification is related to the logic implemented in detecting a fall. If all the conditions in the Fall Detection system are satisfied and if a fall is predicted, then the guardian is immediately notified about the fall through a Short Message Service (SMS) and a WhatsApp message simultaneously. The SIM 800L GSM module is connected to the Arduino Uno, the Arduino sends a signal to the GSM module when a fall is detected, which then sends an SMS to the guardian. The WhatsApp message is sent through the Python algorithm. In order to send a WhatsApp message, the Python library pywhatkit should be installed. The python algorithm can be optimized to send a WhatsApp message to the guardian as soon as a fall is detected.

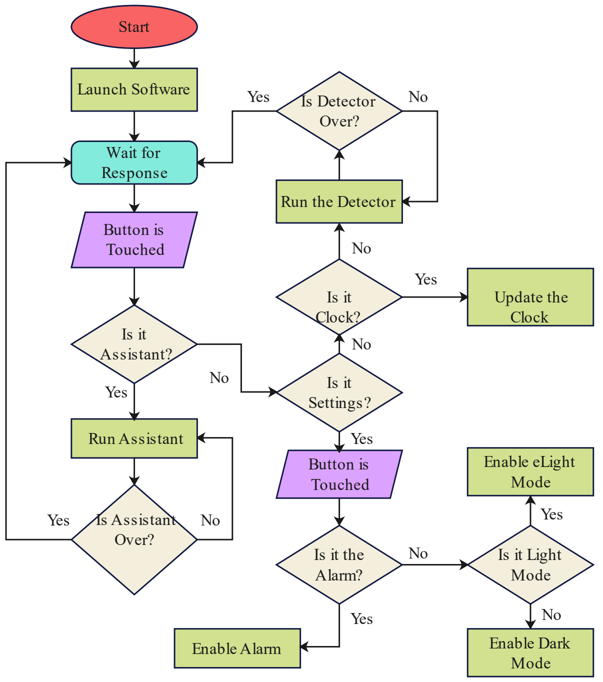


Figure 5: Flow Chart of GUI

### D. *Mechanical Structure and Locomotion*

The importance in the robot being lightweight is, if there is any sort of collision between the robot and the human, the injuries caused by a lightweight robot are null or minimal compared to those of a heavy weight robot. Therefore, by taking all those factors into consideration, we strived to build our robot with the minimum possible weight and by spending the least amount on materials. Figure 6 illustrates the modelled design of the robot.

Figure 6: 3-D Modelled Design of the Robot

## IV. 3-D DESIGN AND FABRICATION

Due to the reduction of the weight of the robot from 10kg to 7kg, we were able to: reduce the torque required for the robot locomotion from 5kg/cm to 3.5kg/cm, reduce the wheel diameter from 83mm to 55mm, and lower the center of mass of the robot. Therefore, the stability of the robot is higher. The figure 7 shows the finalized 3D mechanical design.

Figure 7: Final Fabrication

## V. RESULTS AND DISCUSSION

The main objective and purpose of the indoor human following robot is to follow the elderly person or the differently abled person closely from behind and to detect any falls and immediately contact their guardian.

The main advantages that this robot has are: providing a sense of security to the guardian when the elderly or differently abled person is at home alone, reminding the person to consume their medicine, immediately contacts the guardian via an SMS text or WhatsApp message when a fall is detected, and the capability for the human to request for help from their guardian via the robot. The figure attached below is the robot after complete fabrication.

Figure 8 shows the results of the robot's human following.

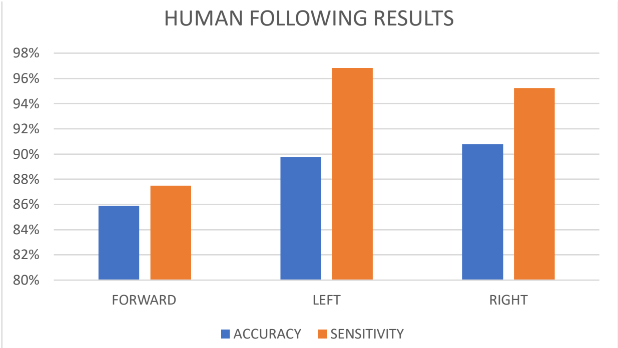


Figure 8: Accuracies and Sensitivities of Human Following

From the above results, it was found out that the overall accuracy of the human following component of the robot was above 85%.

The measure above indicates that the left and right motions are more accurate and sensitive than the forward movement. The left and right movements are perpendicular to the camera's field of vision, which results in a larger variation in the centroid's x coordinate in the recorded video frame, which accounts for the difference in sensitivity. However, the forward movement is significantly less accurate than the two perpendicular motions because the reference distance between the shoulder landmarks, rather than the depth or z coordinate, is calculated when it is considered.

Figure 9 shows the accuracies of the fall detection component of the robot.

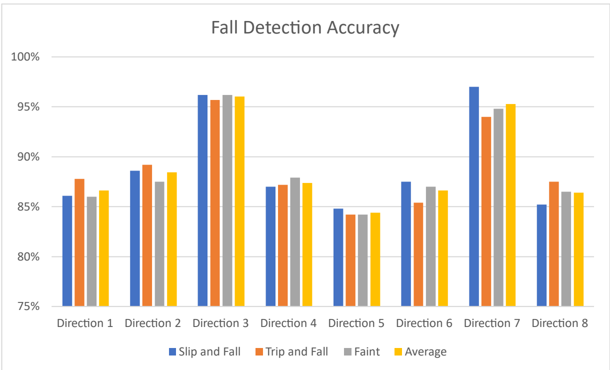


Figure 9: Fall Detection Accuracy

In figure 9, directions 1 to 8 represent the set of 8 cardinal and intercardinal directions starting from North clockwise. It was clear that the overall accuracy of the fall detection component of the robot was beyond 85%. Additionally, it was obvious that direction 3 (East) and direction 7 (West), which are perpendicular to the camera's field of vision, are more accurate than the other directions. The calculation of the torso line's angle is primarily responsible for this. Since the fall is simply in a two-dimensional plane when it is perpendicular to the camera's field of view, the angle calculation's accuracy is better, which improves the fall detection's precision.

## VI. CONCLUSION

This study describes a robotic healthcare companion with indoor human following and fall detection capabilities for the elderly and those with disabilities. The robot was designed, fabricated, and tested successfully in the scheduled time scope. Materials were selected for the robot based on calculations and other factors such as force, stresses, and weight. At the end of the project, all the objectives were fulfilled. It was obvious from the results of both human following and fall detection that the system had 85% for both human following accuracy and fall prediction accuracy across all eight directions.

### A. *Future Works*

The future works include a few sets of improvements that can be done to the robot to improve its overall functionality. Obstacle detection and avoidance in the robot is one of the main improvements because the robot may find obstructions indoors while navigating through rooms. Use of a SIM 900L GSM/ GPRS shield enables the assistant to make calls and connect with the guardian. Creation of a more user-friendly Graphical User Interface (GUI) makes interactions with the robot more convenient. Further structural improvements – self positioning web camera to scan the surrounding for the human.

## REFERENCES


Albers, A. *et al.* (2007) 'Methods for lightweight design of mechanical components in humanoid robots', in *2007 7th IEEE-RAS International Conference on Humanoid Robots*. *2007 7th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2007)*, Pittsburgh, PA, USA: IEEE, pp. 609–615. Available at: https://doi.org/10.1109/ICHR.2007.4813934.

Chin, W.H. *et al.* (2020) 'A Lightweight Neural-Net with Assistive Mobile Robot for Human Fall Detection System', in *2020 International Joint Conference on Neural Networks (IJCNN)*. *2020 International Joint Conference on Neural Networks (IJCNN)*, Glasgow, United Kingdom: IEEE, pp. 1–6. Available at: https://doi.org/10.1109/IJCNN48605.2020.9206637.

El-Bendary, N. *et al.* (2013) 'Fall Detection and Prevention for the Elderly: A Review of Trends and Challenges', *International Journal on Smart Sensing and Intelligent Systems*, 6(3), pp. 1230–1266. Available at: https://doi.org/10.21307/ijssis-2017-588.

Group, T.M. (2019) *Robotics Motion Control: The Complex Relationship Between Movement and Task*. Available at: https://www.medicaldesignbriefs.com/component/content/article/mdb/tech-briefs/34808 (Accessed: 27 April 2022).

*Guardian Camera AI* (2020) *Hackster.io*. Available at: https://www.hackster.io/308965/guardian-camera-ai-272431 (Accessed: 23 April 2022).

Honig, S.S. *et al.* (2018) 'Towards Socially Aware Person-Following Robots', p. 19.

*Human Pose Estimation: Deep Learning Approach [2022 Guide]* (2021). Available at: https://www.v7labs.com/blog/human-pose-estimation-guide (Accessed: 25 September 2022).

Itoh, K. *et al.* (2006) 'Development of a Person Following Mobile Robot in Complicated Background by Using Distance and Color Information', in *IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics*. *IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics*, Paris, France: IEEE, pp. 3839–3844. Available at: https://doi.org/10.1109/IECON.2006.347657.

*Jetson Nano vs Raspberry Pi 4: The Differences | All3DP* (2022). Available at: https://all3dp.com/2/raspberry-pi-vs-jetson-nano-differences/ (Accessed: 25 November 2022).

Kalinga, T. *et al.* (2020) 'A Fall Detection and Emergency Notification System for Elderly', in *2020 6th International Conference on Control, Automation and Robotics (ICCAR)*. *2020 6th International Conference on Control, Automation and Robotics (ICCAR)*, Singapore: IEEE, pp. 706–712. Available at: https://doi.org/10.1109/ICCAR49639.2020.9108003.

Koshmak, G., Loutfi, A. and Linden, M. (2016) 'Challenges and Issues in Multisensor Fusion Approach for Fall Detection: Review Paper', *Journal of Sensors*, 2016, pp. 1–12. Available at: https://doi.org/10.1155/2016/6931789.

neuralet (2022) *Building Automatic Fall Detection Systems using Computer Vision*, *https://neuralet.com*. Available at: https://neuralet.com/article/building-automatic-fall-detection-systems-using-computer-vision (Accessed: 2 September 2022).

Niloy, Md.A.K. *et al.* (2021) 'Critical Design and Control Issues of Indoor Autonomous Mobile Robots: A Review', *IEEE Access*, 9, pp. 35338–35370. Available at: https://doi.org/10.1109/ACCESS.2021.3062557.

Pannurat, N., Thiemjarus, S. and Nantajeewarawat, E. (2017) 'A Hybrid Temporal Reasoning Framework for Fall Monitoring', *IEEE Sensors Journal*, 17(6), pp. 1749–1759. Available at: https://doi.org/10.1109/JSEN.2017.2649542.

Roy, N. *et al.* (2000) 'Towards Personal Service Robots for the Elderly', p. 7.

Tabbakha, N.E., Tan, W.-H. and Ooi, C.-P. (2017) 'Indoor location and motion tracking system for elderly assisted living home', in *2017 International Conference on Robotics, Automation and Sciences (ICORAS)*. *2017 International Conference on Robotics, Automation and Sciences (ICORAS)*, Melaka: IEEE, pp. 1–4. Available at: https://doi.org/10.1109/ICORAS.2017.8308073.

Yang, L., Ren, Y. and Zhang, W. (2016) '3D depth image analysis for indoor fall detection of elderly people', *Digital Communications and Networks*, 2(1), pp. 24–34. Available at: https://doi.org/10.1016/j.dcan.2015.12.001.

## ACKNOWLEDGMENT

We would like to thank our department lecturers and instructors for helping us out whenever needed.

## AUTHOR BIOGRAPHIES

S.L. Seneviratne is currently a Temporary Demonstrator at General Sir John Kotelawala Defence University in the Department of Mechanical Engineering. He is a graduate of General Sir John Kotelawala Defence University with a BSc. (Hons) in Mechatronics Engineering and is awaiting graduation.

B.C.J. De Zoysa is currently an Autonomation Intern at a leading apparel company. She is a graduate of General Sir John Kotelawala Defence University with a BSc. (Hons) in Mechatronics Engineering and is awaiting graduation.

A.M.S.E Senaratne is currently an Officer Cadet at the Sri Lanka Military Academy, Diyathalawa. He is a graduate of General Sir John Kotelawala Defence University with a BSc. (Hons) Mechatronics Engineering and is awaiting graduation.

E.C Padmasiri is currently a Mechatronics Engineer and Project Manager for a global innovations company with over 7 years of experience in R&D. He graduated from the Department of Mechanical Engineering at General Sir John Kotelawala Defence University in 2016 with a BSc. (Hons) in Mechatronics Engineering.

PSH Pallemulla graduated from the Department of Mechanical Engineering at General Sir John Kotelawala Defence University in 2016 with a BSc. (Hons) in Mechatronic Engineering. He has also completed an MPhil from the University of Moratuwa. He is currently a Lecturer (Probationary) at General Sir John Kotelawala Defence University.