Design and Development of an Automated Hand Shovel

Mohammed Rajik Khan and Aditya Rahul Gupta

Abstract The present research makes an attempt to design and develop an automated hand shovel (AHS) as a hand attachment that assists in mud removal during gardening and thereby increases efficiency of the task and reduces hand-arm strain. A four-bar mechanism with a slider-revolute joint powered by a high torque DC motor has been designed for this purpose. Proper experimentations had been conducted to trace the actual path/trajectory of hand movement for 06 healthy participants during shovelling mechanism by three-dimensional motion-tracking cameras. The device is designed to imitate the motion curve followed during actual shovelling operation. The tool end is modified to ensure minimum resistance to the mechanism during piercing. The structure of AHS aligns the handwrist-arm posture and provides sufficient support to the human arm during operation. A conceptual and functional prototype has been fabricated for physical visualization and to assess the feasibility of the design. The proposed device is helpful for a gardener/user to perform gardening task with increased efficiency and higher comfort at handwrist arm. The proposed AHS can be further modified to serve multiple gardening operations.

Keywords 3D motion capture · Hand shovelling trajectory · Novel automated hand shovel · Prototype development

1 Introduction

Gardening is a versatile occupation; it is practised as a hobby and as a job. For this purpose, many gardening tools have been developed to assist humans. A trowel (hand shovel) is a tool employed for digging, spreading, levelling or removing few particulate materials manually. Trowelling is a repetitive manual task which imposes stress and can also lead to severe musculoskeletal disorders (MSDs) in the wrist,

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M. Muzammil et al. (eds.), *Ergonomics for Improved Productivity*,
Design Science and Innovation, https://doi.org/10.1007/978-981-15-9054-2_59

elbow and shoulder of the user. In spite of increase in automation, material handling tools/devices still require human power to perform such tasks in the present modern consumer and technological world.

In the field of comfort/ergonomic tools, researchers are motivated towards developing assistive devices in order to ensure higher efficiency and comfort to user. Ko et al. [1] have worked on the design of suspended handles for petrol-driven grass trimmer. Zheng et al. [2] have discussed the physical aspects considered in the design of hand drill. Naeini et al. [3] have studied the ergonomics in agricultural tasks and have proposed a model to promote health for farmers. Kumar and Murugan [4] have developed a selective tea leaf plucking robot. Bridger and Sparto [5] have developed a two-handle spade design that reduces the probability of back injury by 8%. Schoemarklin and Marras [6] state that handwrist disorders caused by hammering can be reduced if hammer handles are bent in range of 20–40°. Freivalds [7] has carried out an experimental study on shovelling and shovel design and has suggested the geometry design of shovel for improved performance. Sen and Sahu [8, 9] have developed multipurpose shovel-cum-hoe and shovel-cum-kodal used by agricultural workers. Handle modifications in terms of anatomically shaped handles and their detailed ergonomic assessment in comparison with conventional handles have been discussed by Bisht and Khan [10]. Also, a brief review on ergonomic assessment methods of powered and non-powered hand tools has been presented by them [11]. However, not much work has been done in the field of developing a powered hand shovel.

The present work aims to develop an automated hand shovel for gardening. This experiment has been carried out on six healthy candidates to find out the actual trajectory traced by the hand shovel during shovelling. The trajectory is recorded using 3D motion capture cameras (Qualysis Opus 5+). Force data were also recorded using a force plate. The strain in the arm was measured using electromyography setup. The path was then optimized, and a four-bar mechanism with a slider-revolute joint was designed to trace this path. The automated hand shovel consists of two parts: the support structure and the shovelling mechanism. The support structure is ergonomically designed for 95th percentile persons. Two prototypes have been fabricated for visualization and to check design feasibility. Further studies are required to analyse the human comfort quantitatively during its use.

2 Methodology

An experiment was performed to capture the actual trajectory traced by the hand shovel during shovelling. Six (06) healthy candidates of age range 18–22 volunteered for the experiment. The candidates were provided with proper information about the experiment. The candidates signed a consent form, and the experiment was carried forward. Apart from the shovelling trajectory, the dynamic forces imparted on the shovel, and the strains developed in the muscles of the arm were recorded for future validation.

2.1 Experimentation

Figure 1 shows the experimental setup to replicate a garden scenario. A box with a mixture of gardening mud and sand, a standard hand shovel, 3D motion capture cameras (Qualysis Opus+), force plate (Kistler) and a customized electromyography setup [12, 13] are arranged for the experimentation.

Sand and mud are mixed in proportion as suitable for gardening and the mixture is sprinkled with water. The mud box is kept on the force plate. The reflectors for the video capture are placed on the candidates arm and the shovel at specific reference points. The two electrodes were placed at extensor carpi radialis longus muscle of the primary hand with a gap of 20 mm. The reference electrode was positioned at elbow joint of the same hand. The muscle is easily selected due to its superficial position and has close association with the wrist movement. The candidate is to sit on one knee whichever suited and perform the shovelling task. Each candidate has to first try for minimum 15 times, and then data for the best five trials are recorded. Video capture data, force plate data and EMG data are then recorded. Table 1 provides the anthropometry data of the selected six participants.

The data captured during experimentation from motion capture camera are in three-dimensional (3D) space which needs to be plotted in two-dimensional (2D)

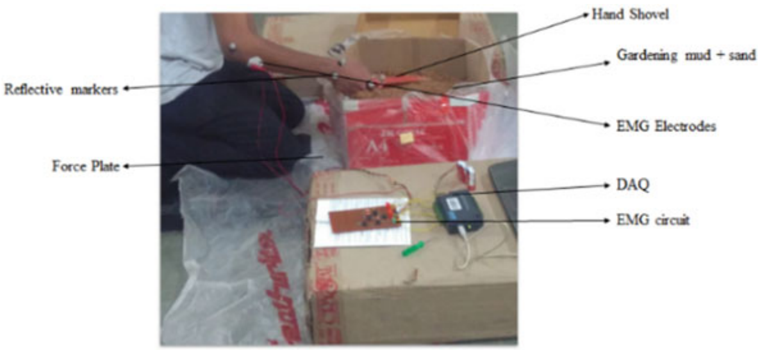

Fig. 1 Experimental setup

Table 1 Anthropometry data of participants

Participant No	Height (cm)	Weight (kg)	Hand length (cm)	Hand width (cm)
1	175	74	19.0	8.5
2	169	67	17.2	7.8
3	171	69	17.9	8.1
4	172	68	18.1	8.3
5	168	71	17.4	7.8
6	170	68	17.5	8.1

plane. Hence, the resultant of the horizontal components is calculated by,

$$R_{xy} = (x^2 + y^2)^{0.5} \tag{1}$$

where x and y are horizontal data points. The motion capture data are plotted as R_{xy} versus Z-axis to depict the curve on 2D. The average path of each candidate is found out, and an average mud piercing angle is measured from all the data point sets. The forces imparted on the mud during the process are recorded by the force plate. The resultant of the forces is calculated as,

$$R_{xyz} = (Fx^2 + Fy^2 + Fz^2)^{0.5} \tag{2}$$

where Fx, Fy and Fz are the forces in X-, Y- and Z-directions. The reaction of this force is assumed to be acting on the shovel, and thus, strain is produced in the muscles in order to produce the necessary stress to impart this force.

2.2 Results and Analysis

The path traced by the shovel during mud removal is to be generalized, and a mechanism is to be developed for replicating it. The average of the five best trials of each candidate has been plotted and superimposed along with the other six candidates. Figure 2a shows six average paths of all the candidates during one cycle. Figure 2b shows six average paths of all the candidates during forward motion of piercing. The actual average path of the hand shovel movement is considered as the ideal path for the mechanism. This path may result in maximum efficiency during the process.

The average path obtained is a straight inclined profile at a slope $\theta = 51.14°$. The curve should follow this angle (θ) at the initial piercing part. From the average force data, it was recorded that a peak force of 40 N arises when the candidate imparts force on the mud box. This maximum force arises at the initial point of contact, when

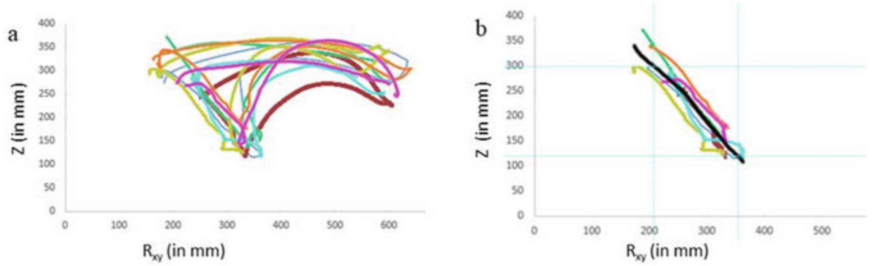

Fig. 2 Average paths traced by six different candidates during **a** shovelling **b** piercing

the candidate pierces the mud. Thus, the design should be able to provide a force of at least 40 N or greater. And the links should withstand greater forces without failure. In Fig. 2a, the curve profile pertaining to the lift of hand shovel and unloading of mud is a three-dimensional curve, and it solely depends on the user.

3 Design of an Automated Hand Shovel

The AHS is characterized by two main components: the shovelling mechanism and the support structure. The mechanism provides the necessary mechanical advantage to reduce human effort. The support structure is ergonomically designed to reduce strain. The support structure gives the necessary cantilever offset to the mechanism so that it can function without any interference.

3.1 Design of Shovelling Mechanism

To trace the average path from the experimental data, a four-bar mechanism with a slider-revolute joint has been designed to automate the shovelling task [14, 15]. Figure 3a shows the designed shovelling mechanism. The slider-revolute joint consists of a prismatic and a revolute joint. The prismatic joint results in a linear path of the tool end. The revolute joint performs an oscillating motion. The mechanism provides a faster piercing motion and a dwell time in the return path. Hence, the mud removal can take place in the lower half of the path traced. During the dwell time, the mechanism needs to be tilted to unload the collected particles from the tool end. The mechanism is powered by a high torque DC motor.

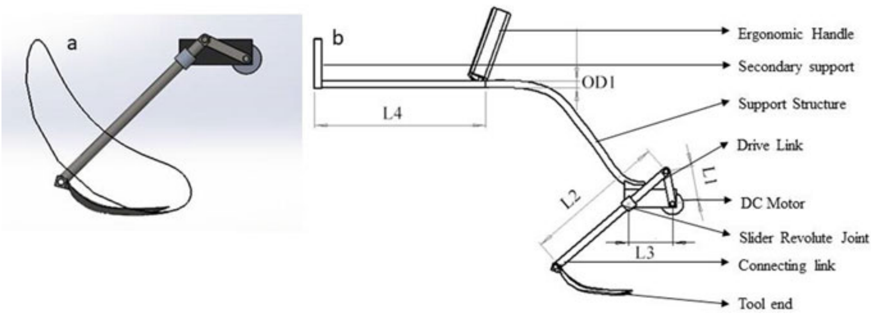

Fig. 3 Automated hand shovel device **a** mechanism **b** assembly

3.2 Design of Support Structure

Figure 3b depicts the support structure in final assembly of AHS. The supporting structure was designed to withstand the load due to the mechanical vibration and its weight. The handle design and orientation have been designed considering the anthropometric measurements of 95th percentile Indian human [16]. The handle is provided with an ergonomic shape having a combination of a triangular and cylindrical prism to fit the closed palm grip [17]. The handle is in the orientation of the wrist's natural angle. The power pressure button for the mechanism is on the top of the handle operated by the thumb. A secondary support (velcro) (Fig. 3b) was attached at the back to grip around the forearm to reduce the cantilever strain due to the mechanism. A slender piper was used to support and immobilize the wrist. The mechanism was connected to the support structure by a welded joint which is offset to the shovelling mechanism path. This connection provides depth to the mechanism, and thus, the user remains in its natural posture with no body movement during the piercing action. The user only needs to tilt his arm during mud unloading.

4 Prototype

Two prototypes were developed based on the above design. A virtual CAD model (Fig. 4a) is developed in SolidWorks environment with the dimensional specifications mentioned in Table 2. Figure 4b shows a first concept prototype developed with a wooden cross-Sect. 20 * 6 mm included with an immobilization band. A DC motor was attached in wooden prototype for visualizing the tool end trajectory during motion. Figure 4c shows the functional prototype fabricated using steel pipes and plates with specifications mentioned in Table 2.

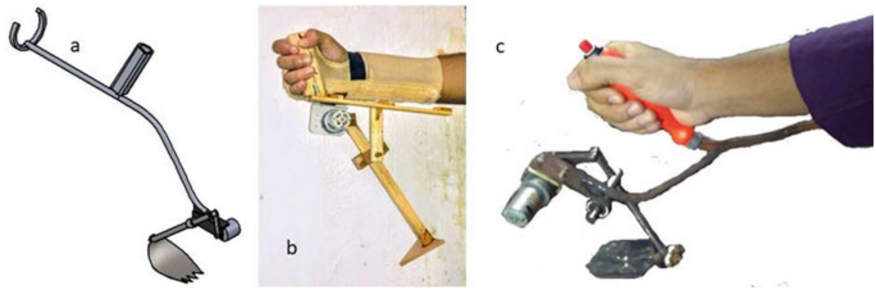

Fig. 4 Prototypes developed **a** CAD model **b** wooden **c** functional

Table 2 Dimensional parameters of AHS prototype

Sr. No	Attribute	Notation	Value (mm)
1	Drive link length	L_1	60
2	Connecting rod length	L_2	24
3	Distance between motor shaft to slider	L_3	70
4	Hand attachment length	L_4	300
5	Pipe outer diameter	OD_1	10

5 Conclusion

This work presents the design and development of an automated hand shovel. This device will ensure higher work efficiency and reduce the strain on human arm during garden shovelling. Wooden and functional prototypes of the device were developed to visualize and to check the design feasibility, respectively. Real-time testing and validation of the AHS need to be performed in future work. It can further be modified to serve different gardening operations. The AHS can be used at home or by professional gardeners.

References

1. Ko, Y.H., Ean, O.L., Ripin, Z.M.: The design and development of suspended handles for reducing hand-arm vibration in petrol driven grass trimmer. Int. J. Ind. Ergon. **41**(5), 459–470 (2011)
2. Linxin, Z., Jialin, C., Deyin, Q.: Physical ergonomics analysis for power hand drill. In Computer-Aided Industrial Design and Conceptual Design, CAIDCD'06. 7th International Conference on (pp. 1–5). IEEE (2006).
3. Naeini, H.S., Karuppiah, K., Tamrin, S.B., Dalal, K.: Ergonomics in agriculture: an approach in prevention of work-related musculoskeletal disorders (WMSDs). Journal of Agriculture and Environmental Sciences **3**(2), 33–51 (2014)
4. Sureshkumar, A., Muruganand, S.: Design and Development of Selective Tea Leaf Plucking Robot. Automatic Control and Information Sciences **2**(2), 45–48 (2014)
5. Bridger, R.S., Sparto, P., Marras, W.S.: Spade design, lumbar motions, risk of low-back injury and digging posture. Occupational Ergonomics **1**(3), 157–172 (1998)
6. Schoemarklin, R., Marras, W.S.: Effect hand angle and work orientation on hammering. Hum. Factors **31**(4), 397–411 (1998)
7. Freivalds, A.: The ergonomics of shoveling and shovel design-a review of the literature. Ergonomics **29**(1), 3–18 (1986)
8. Sen, R.N., Sahu, S.: An ergonomics design of a multipurpose shovel-cum-'Kodal'for manual material handling. Advances in Industrial Ergonomics and Safety **6**, 561–566 (1994)
9. Sen, R.N., Sahu, S.: Ergonomic evaluation of a multipurpose shovel-cum-hoe for manual material handling. Int. J. Ind. Ergon. **17**(1), 53–58 (1996)
10. Bisht, D.S., Khan, M.R.: A novel anatomical woodworking chisel handle. Applied Ergonomics **76**, 38–47 (2019)
11. Bisht, D.S., Khan, M. R.: Ergonomic assessment methods for the evaluation of hand held industrial products: a review. In: Proceedings of the World Congress on Engineering 2013, vol. I, pp. 559–564. Online (2013)

12. Pradhan, A, Nayak S.K., Pande, K, Ray, S.S, Pal, K, Champaty, B., Anis A., Tibarewala, D. N.: Acquisition and classification of EMG using a dual-channel EMG biopotential amplifier for controlling assistive devices, IEEE Annual India Conference (INDICON), pp.1–5, Bengaluru(2016).
13. Khan, M.R., Singh, N.K.: Prevalence of musculoskeletal disorders among Indian railway sahayaks. International Journal of Occupational and Environmental Health **24**(1–2), 27–37 (2018)
14. Zhou, H., Ting, K.L.: Adjustable slider–crank linkages for multiple path generation. Mech. Mach. Theory **37**(5), 499–509 (2002)
15. Wang, X.: The Optimization Design of Six-bar Linkage Mechanism, TELKOMNIKA, 11(7), (2013).
16. Chakrabarti, D.C.: Indian anthropometric dimensions for ergonomic design practice.National Institute of Design (1997)
17. Bisht, D. S., Khan, M. R.: Anatomically Shaped Tool Handles Designed for Power Grip. In International Conference on Research into Design, pp. 135–148, Springer, Singapore (2017).