Abstract

Agriculture is the most human-involved sector with its mechanization increasing in continuum to reduce the food demand and supply gaps. Mechanization although increases efficiency and productivity, it also enhances accident risks that very often result in lower limb disabilities of the operators. Also, current day mechanization is non-inclusive of disabled workers due to non-availability of appropriate assistive interventions. Therefore, a study was undertaken on design, development, and evaluation of (1) ergo-mechanical tractor operator ingress-egress system and (2) sensor-based wireless hand control system for tractor clutch and brake operations, the assistive technologies. Anthropometric assessment was conducted for lower limb disabled workers to develop an optimum hand reach envelope and compared with tractor workplace dimensions to select the representative tractor. Assessments determined horizontal hand reach range of 384–645 mm and vertical hand reach ranges of 212–499 mm from seat reference point. The operator ingress-egress system consists of a vertical lift unit to shift a disabled operator from ground to tractor seat level, lateral rotating unit to move the operator closer to seat, and horizontal slide to transport the operator closest to the tractor seat. Sliding unit is mounted with an ergonomic seat with belt for safe transportation of the operator. All these sub-operations are controlled by custom developed double pole double throw type switch control unit. System safety was evaluated through Finite Element Analysis for a maximum design load of 1200 N and maximum stress was obtained as 6.9×10^7 N/m^2 which was lower than the yield strength for alloy steel (6.2×10^8 N/m^2). Ergonomic evaluations were conducted for disabled male and female workers where mean arterial pressure (MAP) were in the ranges of 88–98 mmHg and heart rates (HR) in the ranges of 83–104 beats/min, all within safe recommended limits for any physical operation (MAP: 100 mmHg, HR: <90 beats/min as light and 90–110 beats/min as moderate).

In second part, actuation force and speed, and dynamic load on lower limb muscles were evaluated for ten tractor operators during conventional tractor clutch and brake operation to select electric linear actuators (clutch operating force: 92–295 N, brake operating force:106–329 N, clutch operating speed 38–43 mm/s, brake operating speed: 57–63 mm/s) for hand-controlled automated clutch and brake operations. Hand-control system consists of a transmitter node on operator end and receiver node on clutch/brake end. Transmitter node has a single board computer, operator input keypad, Radio Frequency (RF) transmitter module and battery power source and placed on the operator side. The receiver node has a single board computer, RF receiver module, relay switches, voltage regulator, boost converter connected to the electric linear actuators integrated to the clutch and brakes linkage units. The input keypad enables automated operating modes of (a) left wheel brake, (b) right wheel brake, and (c) both left and right wheel brake together, with or without clutch operation, alike in conventional tractors. The response time of hand control mechanism was 100 milliseconds and stopping distance with automated braking ranged from 44.0 to 190.7 cm at forward speeds of 2.1–7.9 km/h. Ergonomic evaluation revealed foot control usage to be high energy consuming (9.7–15.1 kJ/min) compared to the hand control usage (7.3 to 14.1

kJ/min). Body parts discomfort score (BPDS) and overall discomfort rating (ODR) identified hand-controlled operation to be less strenuous. Muscle load signals for some upper limb muscles ranged from 14.76–45.29 μV and was affected by forward speed, gender, subject variability, and control type (brake/clutch). Overall muscle workloads were within the recommended limits (<30%). The automated ingress-egress and hand control systems require minimal workplace modification and provide comfortable inclusion of disabled tractor operators into mechanised agriculture systems. The systems also avail the facility to abled females to operate the tractor with minimum effort. The developed assistive technologies will give the lower limb disabled agricultural workers a new vision and purpose to lead their life independently.

Keywords: Mechanized agriculture, lower limb-disabled workers, assistive technologies, muscle workload, energy expenditure, inclusive agriculture.