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A QUALITATIVE PERFORMANCE MEASURE FOR UPPER LIMB EXOSKELETON BASED ON LOCK JOINT FAILURES AT MINIMUM MANIPULATION

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Performance measures play a vital role to evaluate physical human robot interaction (pHRI) and cognitive interaction on exoskeleton. Since exoskeleton has a close interaction with wearer, measures directed to evaluate pHRI is significant. Nevertheless, few measures are available in literature to appraise pHRI. Majority of upper limb exoskeletons are used for rehabilitation or motion assist and several active joints are used to generate motion. Failure of joints, specially, lock joint failures cannot be predicted in advance and manipulation under lock joint failure finds an interesting area in upper limb exoskeleton. Typically, lock joint failure occurred at minimum manipulability region may reduce the manipulation and this creates a significant effect on the wearer to perform daily activities in case of motion assist. Therefore, it is important to identify such cases by means of measures at the design stage in order to validate or improve the kinematic chain of exoskeleton against the lock joint failure. However, no measures are reported in literature in order to evaluate this state.

This paper proposes a new qualitative measure to evaluate the performance of exoskeleton based on lock joint failure at minimum manipulability. The manipulation under lock joint failure is determined based on *relative manipulability index* and manipulation for all joints is evaluated based on *manipulability index*. The proposed qualitative measure is based on comparison of joint trajectory region for maximum *relative manipulability index* for lock joints with joint trajectory region for minimum *manipulability index*. According to the proposed measure, one can judge manipulation of exoskeleton at minimum manipulability region with presence of lock joint failure as 'good' or 'bad'.

The proposed measure was used to evaluate manipulation corresponding to minimum *manipulability index* of 6 degree of freedom (DOF) upper limb redundant exoskeleton with lock joint failures at elbow and forearm joint. The *Relative manipulability index* for lock joints and *manipulability index* were plotted for joint trajectory between two joint configurations. Results showed that, joint trajectory range of minimum *manipulability index* is closely overlapped with joint trajectory range of maximum *relative manipulability index* for lock joints. According to the proposed measure, the manipulation of 6DOF redundant exoskeleton is '*good*', since manipulation at minimum manipulability region does not deplete due to effect of lock joint failures at elbow or forearm joint. Therefore, this ensures that the wearer does not face higher risk of performing task/critical task at minimum manipulability region with effect of lock joint failures. Furthermore, proposed measure can be used to evaluate the performance of pHRI in exoskeleton robots.