APPENDIX

Definition of the Performance Metrics

Accuracy, recall, precision, specificity and F1 score have been illustrated in the following formulae:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \tag{12}$$

$$\text{Precision} = \frac{TP}{TP+FP} \tag{13}$$

$$\text{Recall} = \frac{TP}{TP+FN} \tag{14}$$

$$\text{Specificity} = \frac{TN}{TP+FP} \tag{15}$$

$$\text{F1 Score} = \frac{2\times \text{Precision}\times \text{Recall}}{\text{Precision}+\text{Recall}} \tag{16}$$

(where, TP = True Positive, TN = True Negative, FP = False Positive, and FN = False Negative)

The total number of correctly classified positive samples is denoted as ‘True Positive’ (TP). The total number of wrongly classified positive samples is denoted as ‘False Positive’ (FP). The total number of wrongly classified negative samples is denoted as ‘False Negative’ (FN). True Negative (TN) refers to the total number correctly classified negative samples. A measure of inter-rater reliability for the categorical items is done Cohen's kappa (kp). It measures the agreement between two raters who each classify items into different mutually exclusive categories [48]. The higher the value of these parameters, the better the performance of a classifier model.

Static Structural analysis of the ‘Robotic Physiotherapeutic Device’

In order to perform static structural analysis of the 'Robotic Physiotherapeutic Device', first, the 3D structure of the device is modelled with the proper dimensions using CATIA (Version 5). Finite element method is employed for performing static structural analysis of the designed model. Linear tetrahedron mesh is used in the static structural analysis process. A simulation is performed to analyse the effect of the loading (static) conditions in the structure of the device. The Von Mises stress, principal stress, structural deformation value of the device structure due to application load is computed from the simulation process. The selected simulation parameters are provided in Table XI. Properties of the materials (i.e., aluminium and steel), used in the static structural analysis process is shown in Fig. 17. Fig. 18 shows the boundary conditions which are set for static structural analysis of the designed model. In the Fig. 19, ‘yellow’ arrows signify applied load and ‘blue’ arrows signify restraints (support). Fig. 20 shows the deformation report.

TABLE XI
SIMULATION PARAMETERS

Parameter	Value
Material of the ‘Base’ Part	Steel
Material of the ‘Cage’ Part	Aluminium
Applied load on the ‘Base’ Part	1000 Kg.
Applied load on lower part of the ‘Cage’	20 Kg.
Applied load on lower part of the ‘Cage’	60 Kg.
Direction of the applied force/load	Perpendicular to the surface

Material	Steel
Young's modulus	20394.324kgf_mm2
Poisson's ratio	0.266
Density	7.86e-006kg_mm3
Coefficient of thermal expansion	1.17e-005_Kdeg
Yield strength	25.493kgf_mm2

Material	Aluminium
Young's modulus	7138.014kgf_mm2
Poisson's ratio	0.346
Density	2.71e-006kg_mm3
Coefficient of thermal expansion	2.36e-005_Kdeg
Yield strength	9.687kgf_mm2

Fig. 17. Material Properties.

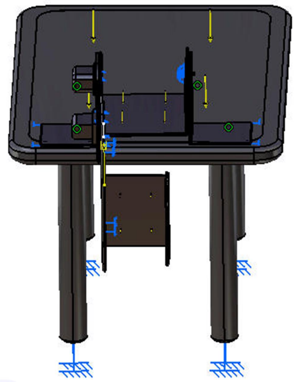

Fig. 18. Boundary Conditions set for the static structural analysis process.

While using the designed ‘Robotic Physiotherapy Device’, a patient is supposed to seat/lie on the ‘base’ and put his leg into the ‘cage’. So the ‘cage’ part will carry the weight of a patient’s thigh, leg, and toe. To be more specific, the upper part of the ‘cage’ will bear the weight of the thigh, and the lower part of the cage will bear the weight of the leg and toe. The average weight of a complete leg (i.e., thigh, leg and toe), thigh, leg, and toe are 17.55 kg., 11.12 kg., 5.01 kg., and 1.38 kg., respectively [47]. Considering dynamic load (i.e., the load generated in the structure while it is in motion) as three times of the static load, we apply 60 kg and 20 kg as loads at the upper and lower parts of the cage, respectively, for structural analysis.

The base part will carry the weight of the patient and other parts of the ‘Robotic Physiotherapeutic Device’. The average weight of an Indian person is 65 kg [25]. Assuming one or two people may also sit on the ‘base’ while a patient is doing exercise using the device and dynamic load three times as the static load, the applied load on the base is set as 1000 kg. for the structural analysis process.

Fig. 22 describe the overall static structure analysis report obtained by the performed simulation process, and the design appears to be good as per the obtained stretch value of the report.

Entity	Size
Nodes	16372
Elements	51759

ELEMENT TYPE:

Connectivity	Statistics
TE4	51759 (100.00%)

ELEMENT QUALITY:

Criterion	Good	Poor	Bad	Worst	Average
Stretch	51413 (99.33%)	346 (0.67%)	0 (0.00%)	0.098	0.567
Aspect Ratio	37362 (72.18%)	13970 (26.99%)	427 (0.82%)	19.557	2.291

Fig. 19.Overall static structure analysis report.

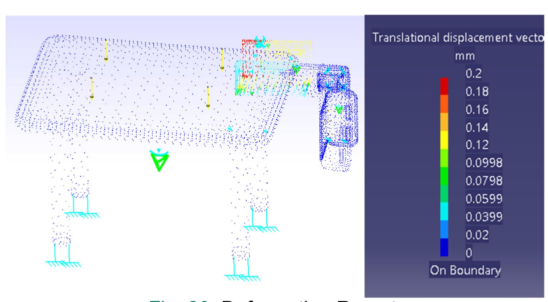

Fig. 20. Deformation Report.

Von Mises stress is characterized as a quantity used to determine whether a given material will yield or fracture. According to the von Mises yield criteria, a material will yield if the von Mises stress is equal to or less than the yield limit of the same material (under simple tension). The normal stress is defined as the stress perpendicular to the oblique plane. The normal stress that is operating on one of the principal planes when the value of shear stress is zero is known as the principal stress.

It is found from the simulation process that maximum von Mises stress and principal stress measured in the structure due to the application of load is 3.07 kgf/mm^2,3.07 kgf/mm^2 , respectively. The maximum von Mises stress and principal stress measured are less than the yield strength of the structure materials of the device (yield strength of steel (material of base): 25.493 kgf/mm^2 and aluminium (material of cage): 9.687 kgf/mm2). It is observed from Fig. 20 that the maximum displacement (deformation) of the structure under load is extremely minimal, with a value of 0.2 mm. The simulation results show that the Von Mises stress and primary stress generated in the device's structure as a result of the load application are lesser than the material's yield strength.

Hence, it can be concluded that the structure of the designed 'Robotic Physiotherapeutic Device' appears to be stable from the obtained results.

Assessing the effectiveness of the designed robotic physiotherapeutic device (Experiment 8)

An additional experiment is also carried to study the effectiveness of the developed robotic physiotherapeutic system in alleviating knee pain of the different subjects. In this experiment, the changes in the knee pain levels of 10 subjects (all male and having different pain levels), who were put through a daily physiotherapy exercise practise session for a month using the designed robotic physiotherapeutic device, are analysed. All the ten subjects, who took part in the study, shows considerably lower pain levels (Fig. 21) after utilising the designed robotic device every day for a month.

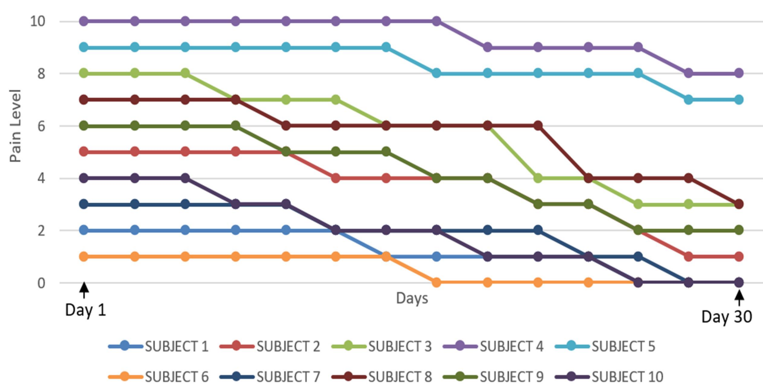

Fig. 21. Changes in the pain level of the subjects during the 30 day experimental time frame.