Responsive Scene Modelling for Quasi-static manipulation by a DHM

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***Abstract*—This paper presents a coupled object-human behaviour in a Digital Human Modelling (DHM) environment. It argues that responsive co-evolution of the configurations of objects and human is essential for realistic performance assessment for a given task. DHM-poses respecting the conditions of stability and effort-budget, while the objects respecting the laws of mechanics, emerging behaviour during a quasi-static push operation demonstrates the significance of the proposed scene modelling scheme. The method extends the prevailing simulation paradigm of assessment of a given pose for a task by enabling energetic interaction between the objects and the DHM to make it more realistic.**

***Index Terms*—DHM, performance variation, object behaviour modelling**

I. Introduction

Digital Human Modelling and Simulations (DHMs) for ergonomic evaluations refer to the digital representation of human inserted into a simulation or virtual environment to facilitate prediction of safety and performance [1]. However, the DHMs available in the literature mostly concerns kinematics-based posture predictions which can then be superimposed with external loading for the assessment of safety. In natural human performance, posture emerges for a given load, task and environment. Therefore, for a realistic and meaningful simulation, the interaction and inter-dependence of the above factors need to be included in the simulation environment.

In the advanced DHM, viz. Siemens JACK system [2], [3], the user sets the tasks and postures of DHM and evaluate its performance. Its inverse kinematic tool automatically generates the motion for the given initial and final positions. The force input is explicitly given by the user to evaluate the joints stress. However, the posture itself is insensitive to the applied force which is unrealistic. The DHM, SAMMIE emphasised that generating an efficient and effective human motion is an important issue [4]. SANTOS [5] took the approach to find the posture and motion by using the optimizing technique instead of pre-recorded data. Providing the posture and motion to DHM is an important part of DHM simulation practice. But providing this information manually demands expertise and yet it is both tedious and error-prone. To overcome this problem, one generates the data by using a motion capture system. This technique is fast but needs a life-size mock-up of the scene which needs to be changed for every new study. But providing posture and motion for realistic simulation we must include the variation in the posture with the applied force for effective ergonomics assessment. Thus, mock-up and MoCap path are probably good only for the assessment of final designs.

Many studies reported that there is an inevitable variation in human postures and applied force while performing a task. Babikian et al [6] in their study found out that human cant apply precise load and they dont even know how much load they are applying. This suggests the application of varied force by the subject for achieving a given goal. Moreover, Delleman et al [7] state that the human postures are not the same and do vary between repetition, with some coefficient of variation. For the small cyclic task, variation may be small but not zero, and variation may increase with cycle time. Granata et al [8] concluded in their study that variation is there during lifting task, this variation may differ according to experience. The human body has kinematic redundant DOFs of its joints. Humans can perform a manual task in many possible ways [9], [10]. Even for an identical task, there is intra-individual variation seems to exist. Different Individual uses a different motion pattern for an identical task [11], [12], [13]. But this natural behaviour which has its bearing on the posture and effort are difficult to model in the existing DHMs. Breslin F.C. et al [14] observed that new workers are at more risk of acute injury in the first year of their jobs. However, they could not establish the relationship between new employees versus the elevated risk of musculoskeletal injury. Thus, understanding unpredictability in human behaviour is important to evaluate the task. This cannot be done in a purely prescriptive modelling and deterministic simulation paradigm as available in the current DHMs.

It is suggested by Wary RE el al [15] that the variation should be introduced through rich interactions with the environment and should avoid the deliberate introduction of variability. To bring the natural variation in DHM behaviour Interaction of DHM with objects in the virtual environment can be used to induce the natural variation in human performance. All available DHM tools have given focus on the development of the human model and ignored the importance of objects in the environment that may affect their performance or is limited to the synthesis of collision-free paths.

But this interaction between objects can affect DHM behaviour e.g. sliding an object over a table may require more or less force than lifting the object. This variation in force required cannot capture by only weight information. Kallmann and Thalmann [16] talk about the smart object which actually prompts the DHM how to manipulate it. This makes animations easy and more realistic; this is unrealistic in the context of simulating natural human performance and remove the possibility of modelling variation and uncertainty in DHM-behaviour. Kuo and Wang [17] introduced the concept of Meta-CAD to enable more information about the object model along with its geometrical and topological aspects, viz. physical attributes of the object (mass, centre of inertia, friction etc). Physics modelling in animation is commonplace in the gaming applications [18]. Use of such physics engines in DHM for rigorous and dynamic human-object interaction could not be found in the literature.

From the above discussion, it is understood that we need detail object modelling and a model of interaction between objects for a more reliable evaluation of human performance in a DHM framework.

II. IISC MAYA MANAV FOR DEMONSTRATING OBJECT BEHAVIOUR MODELLING

In this work, we use IISc Maya Manav (Figure 1) developed in-house [19], to demonstrate the variation in behaviour and performance by introducing detail object modelling. Maya Manav uses an optimization-based posture prediction to simulate tasks, where factors such as stability and joint torque strength are modelled as constraints. Here, we introduce the concept of the budgeted capacity of each joint for a given task. We defined the budgeted capacity as a fraction of maximum capacity which depends upon other physiological and psychophysical factors.

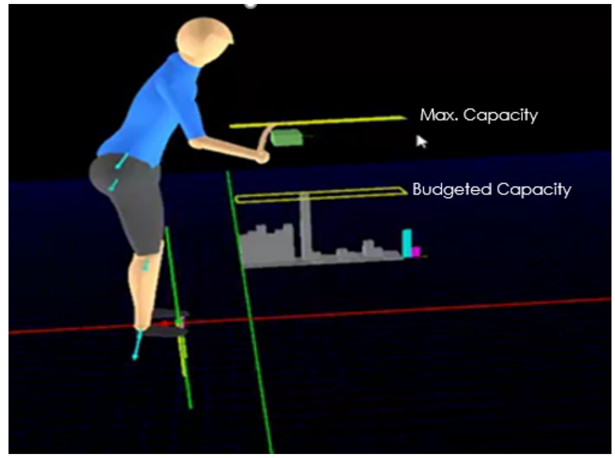

Fig. 1. IISc Maya Manav

III. OBJECT BEHAVIOUR MODELLING

As discussed in section I, to get a credible assessment of task performance, the DHM's behaviour in the virtual world should be a faithful representation of the human. In real-world, a human operator experiences forces while performing physical tasks. But in existing DHM tools, the information of the external force from the object is supplied by the user. This approach of prescribing the external force rules out the possibility of assessing the variation that may arise while performing the task. To overcome this issue, force information should be provided to DHM automatically through object behaviour model. To simulate the behaviour of an object, we need the information about an object itself as well as its interaction with other objects. To capture the interaction between the objects it is required to model relationship between the objects. The details of modelling object and its relationship with other object are discussed in subsequent sections.

A. Object modelling

It includes the modelling of information about each object. Object information includes mass and centre of mass (COM) of the object. This two information is always associated with the object. The effort required to manipulate an object necessarily but not solely depends upon its mass. COM is important to capture the effect of a force applied by DHM and the variation in the final configuration of the objects. The DHM system is modelled in the way that if DHM is unaware of the effort required to manipulate the object, it increases the force gradually to the value until the object starts giving a response.

B. Relationship modelling

The effort required to lift the object could be different than the effort required to slide the object. The interaction of one object with another object may affect the effort required to manipulate the object. This is because of the constraints in the relative motion inherited by the relationship. Two capture the effect of an object to object interaction, we are using a relationship model. Relationship model holds information related to interaction between the objects. The information provided relationship model are information about relative behaviour and friction information between the objects.

Relative behaviour can be explained by the example of the nut-screw behaviour model . Figure 2 shows the conceptual model of nut-screw behaviour. The translation motion of nut depends upon its rotation over the bolt. This kinematic of nut-screw behaviour has been captured in this behaviour model. Here horizontal axis is representing the rotation of the nut over the bolt. Vertical axis is representing the length move by the nut over the bolt. The configuration axis represents the configuration of the nut over the bolt. The slope of configuration axis with respect to the rotation axis represents the pitch of the threads. Length moved by a nut on its rotation depends upon the pitch of the thread. The torque required to rotate the nut at a given configuration is given by toque axis. The curve captures the configuration of the nut over the bolt and corresponding torque required to rotate the nut at that configuration. Initial when the nut is completely fastened to the bolt, the torque requirement is very high. When nut starts rotating, it also moved along the axis of the bolt depending upon the pitch of the thread. After some change in configuration, the torque requirement suddenly dropped and becomes constant. In the final phase of removing the nut, torque requirement keeps on reducing and finally becomes zero units when the nut has completely come out from the bolt. We can also incorporate the concept of budgeted torque above which DHM can not apply torque without using any tool.

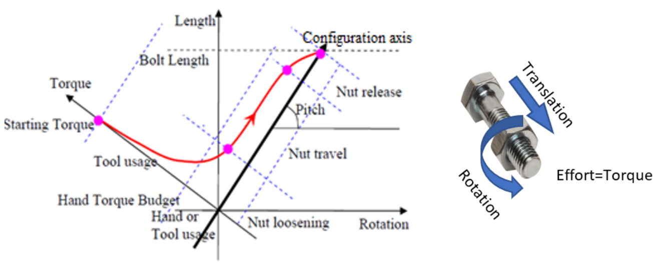

Fig. 2. Nut-Screw behaviour model

It is understandable that if the slope of configuration axis is zero i.e. configuration axis coincides with the rotation axis, it represents the cylindrical joint between the objects. By varying the slope of configuration axis we can capture many aspects of nut-bolt behaviour. Also, by changing the shape of the curve, we can model different scenarios e.g. broken or rusted thread. Figure 3 shows the overall idea of the information required to model object behaviour.

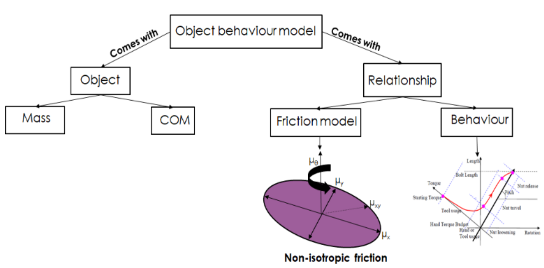

Fig. 3. Object behaviour model scheme

IV. DEMONSTRATION OF OBJECT BEHAVIOUR MODEL

Posture attain by IISc Maya Manav depends upon the position of the end-effector (Palm) and the reaction force at the end effector. Presently the user must provide both the information. After which, using the optimizing technique for minimizing joints stress value, it gives the final optimal posture. The object lacks any information about itself. The position of the end effector is always fixed during simulation run while applying force since object behaviour is not modelled. If two objects are at the same position with respect to DHM, the final posture of DHM will depend upon the force input from the user. If forces are different final posture will be different based upon the optimization results. By introducing object behaviour modelling, we have made DHM take force required to manipulate the object directly from the virtual environment. By providing this autonomy we have removed the need of the user for force input which eliminate the possibility of any variation in DHM performance.

Following two scenarios were simulated to demonstrate the effect of object behaviour model on DHM.

A. Scenario 1: Posture variation for an unresponsive object

This simulation demonstrated the posture variation of DHM when the object was unresponsive. The task was to apply the force on the box. Figure 4 shows the initial posture of DHM before applying force. later, DHM increased the force gradually from an initial value of zero units. With increased in applied force, DHM tried to bring the joints stress value under the budgeted limit by coming up with different optimal postures. Since hand position was fixed, the posture was only depending upon the force applied by DHM. Figure 5 shows the final posture of DHM which is different from its initial posture.

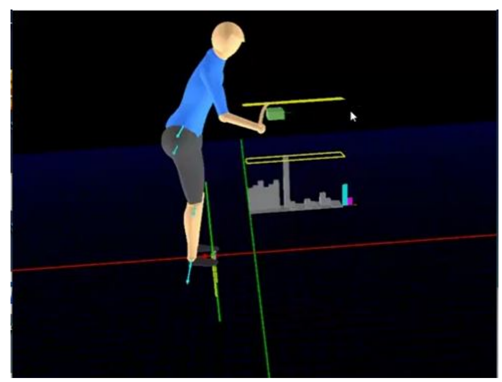

Fig. 4. Initial Posture of DHM before appyling force

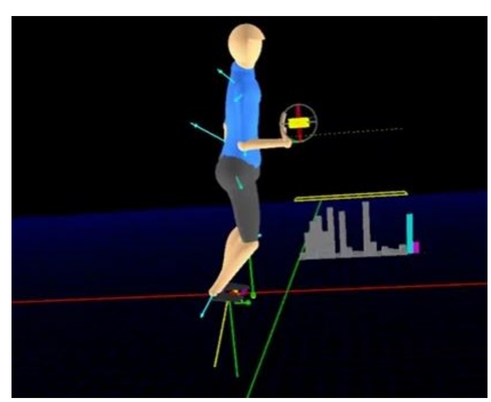

Fig. 5. Fianl Posture of DHM after applying force

B. scenario 2: Posture variation for a responsive object

In this case, the object was responsive to the force applied. The box was on the table. When the force applied by the DHM overcame the friction force between the box and the table, the box started moving. At this instance of the simulation, the force required to move the box was constant and the motion of the box was isokinetic. But, the end position of the hand which was applying the force was changing. This changed in the position of the box produced a new configuration of DHM.

Figure 6 shows the initial postures of two identical DHMs (i.e. DHM A and DHM B). Initial postures were same for two DHMs. The task was to slide the box. The final positions of the two boxes were same. Although these two boxes were geometrically identical, they were having different friction forces with the table (i.e. 200N and 100N in case of DHM A and DHM B respectively). Figure 7 shows the comparison between the final posture attain by two DHMs while sliding the boxes. Even though the task was identical (i.e. sliding the box) for two cases, but Since, friction forces were different, therefore the effort required to manipulate the boxes were different. This demonstrated the variation in DHM performance by response modelling of objects' behaviour.

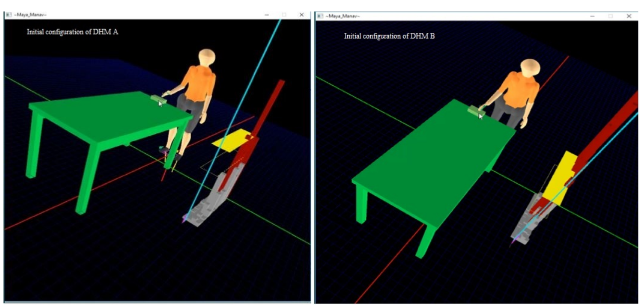

Fig. 6. Initial Posture of DHM A (left) and B (Right)

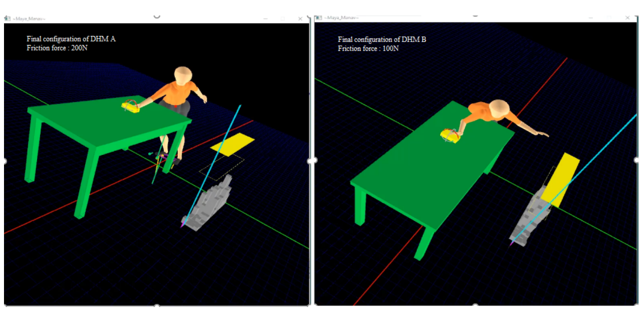

Fig. 7. Final Posture of DHM A (left) and B (Right)

V. Conclusion

In this paper we establish the need for including variation in DHM model for assessment of its performance. We also showed the need for object behaviour modelling to induce the variation in DHM performance. We modelled the responsive behaviour of objects. Finally, using object behaviour modelling with Maya Manav, we demonstrated the variation in its performance.

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