Development of a Quantitative Ergonomic Assessment Method for Helicopter Cockpit Design in a Digital Environment*

Kihyo Jung[1], Jangwoon Park[1], Wonsup Lee[1], Jooho Uem[2], Byunggil Kang[2], Seikwon Park[3], Heecheon You[1]

[1]Department of Industrial and Management Engineering, POSTECH, Pohang, South Korea, 790-784
[2]KHP Program Division, Korea Aerospace Industries, LTD, Sacheon, South Korea, 664-802
[3]Department of Industrial Engineering, Korea Air Force Academy, Cheongwon, South Korea, 363-849

For the development of a better product which fits to the target user population, physical workloads such as reach and visibility are evaluated using digital human simulation in the early stage of product development; however, ergonomic workload assessment mainly relies on visual observation of reach envelopes and view cones generated in a 3D graphic environment. The present study developed a quantitative assessment method of physical workloads in a digital environment and applied to the evaluation of a Korean utility helicopter (KUH) cockpit under development. The proposed assessment method quantified physical workloads for the target user population by applying a 3-step process and identified design features requiring improvement based on the quantified workload evaluation. The scores of physical workloads were quantified in terms of posture, reach, visibility, and clearance, and the 5-point scales were defined by referring existing studies. The postures of digital humanoids for a given task were estimated to have the minimal score of postural workload by finding all feasible postures satisfying task constraints such as the contact between the tip of index finger and target point. The proposed assessment method was applied to evaluate the KUH cockpit in the stage of preliminary design and identified design features requiring improvement. The assessment method of the present study can be utilized in ergonomic evaluation of products using digital human simulation.

INTRODUCTION

For the development of a better product which fits to the target user population, ergonomic evaluation in a digital environment is conducted. Lee et al. (2005) evaluated two layout designs of operator's workstation for an overhead crane using Jack^{TM}. In addition, You et al. (1997) evaluated a proposed interior layout design of bus operator's workstation in terms of posture, visibility, and clearance. The digital ergonomic design and evaluation reduce the design and engineering cost by introducing the ergonomic concept in the early stage of product development process (Chaffin, 2001).

Digital ergonomic evaluation relies on visual observation of reach envelopes and view cones generated in a digital environment. Nelson (2001) evaluated maintenance tasks of an aircraft based on 3D graphic images generated by Boeing Human Modeling System (BHMS). Bowman (2001) also examined reach envelopes and clearances of heavy vehicle's operator workstation by using JackTM. Such visual observation on interaction between digital humanoids and the product of interest is useful to check whether the proposed design is acceptable or not.

To identify design features requiring improvement or prioritize design alternatives in a systematic way, a quantitative assessment method of physical workloads in a digital environment is necessary. The previous researches (Nelson, 2001; Bowman, 2001) conducted digital evaluation based on visual observation of the digital humanoids interacting with the product. The visual observation is helpful to qualitative evaluation of the proposed design; however, quantitative evaluation on physical workloads is needed to investigate design features requiring improvement. In addition, to select a better design among design alternatives, quantitative information on physical workloads is essential. Lastly, quantified workloads can be aggregated to calculate overall workload score which indicates the overall level of the ergonomic design quality.

The present study developed a quantitative assessment method of physical workloads for a helicopter cockpit in a digital environment and applied to the evaluation of a Korean utility helicopter (KUH) cockpit. To quantify and aggregate four physical workloads (posture, reach, visibility, and clearance), the proposed assessment method consisted of a 3-step: (1) selection of operating tasks and evaluation criteria, (2) estimation of operating posture, and (3) calculation of physical workloads. The proposed assessment method utilized in the evaluation of KUH cockpit to investigate design features required improvement and calculate the overall workload level.

PHYSICAL WORKLOAD EVALUATION METHOD OF HELICOPTER COCKPIT

Tasks and Evaluation Criteria

For the physical workload evaluation of a helicopter cockpit, helicopter operating tasks were identified by reviewing a helicopter operating manual. The identified operating tasks consisted of 57 subtasks in 4 flight stages as illustrated in Table 1. For example, in the pre-flight stage, subtasks such as ingress, seat adjustment, and armor plate installation are conducted. In the in-flight stage, subtasks like cyclic operation, collective operation, and yaw pedal operation are accomplished.

To quantify the physical workloads of the identified operating tasks, four evaluation criteria and scales were defined in the Table 2. First, a 5-point scale for posture—1: very unsatisfactory, 2: unsatisfactory, 3: moderate, 4: satisfactory, 5: very satisfactory—was developed based on comfortable range of motion (CROM) and range of motion (ROM) provided in Diffrient et al. (1981) and Kroemer et al. (1994). For example of Figure 1.a, the posture scale of hip abduction/adduction motion was defined by dividing the CROM and ROM. Second, a 5-point scale for reach was developed by considering trunk and arm reach envelops provided in Department of Defense (1987) and Sanders and McCormick (1992). For example of Figure 1.b, arm reach envelop was divided into normal and maximum envelops and trunk motion was also divided depending on with or without harness. Third, a 5-point scale for visibility was adapted from Ryu et al. (2004). Ryu et al. (2004) defined the visibility scale based on eye and neck's comfortable and acceptable motions as shown in Figure 1.c. Lastly, a 5-point scale with a 3-grade for clearance—1: insufficient space, 3: posture change required, 5: sufficient space—was devised.

Table 2. Evaluation criteria

Criteria	Description
Posture	Extent to operate a designated task in comfortable posture
Reach	Extent to reach a designated controller or button
Visibility	Extent to see a designated component or outside of the cockpit
Clearance	Extent to move the body without interference

Evaluation criteria for each operating task were determined by analyzing the relationship between the operating tasks and the evaluation criteria as shown in Table 1. For example, the criteria for operation intensive tasks such as cyclic operation task were selected as posture, reach, and clearance; however, the criteria for observation intensive tasks such as magnetic compass watch were determined as posture and visibility. The present study evaluated the operating tasks in the evaluation criteria selected for the corresponding operating task.

Operating Posture Estimation

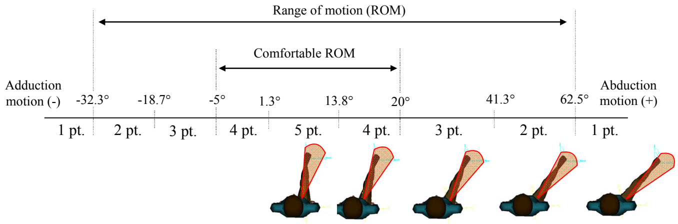
Pilot's posture operating a designated task was estimated

Table 1. Helicopter operating tasks and evaluation criteria (Illustrated)

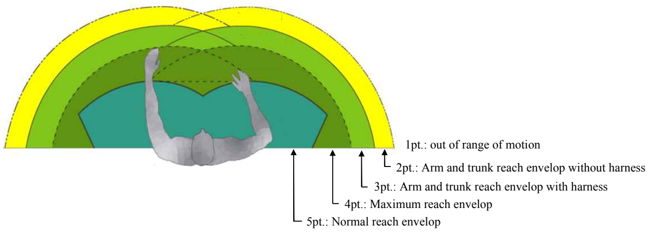
Flight stage	Subtask		Evaluation criteria*			
			Posture	Reach	Visibility	Clearance
Pre-flight	Ingress		○	×	×	○
	Seat adjustment		○	○	○	○
	Armor plate installation		○	○	○	○
	Safety belt installation		○	○	○	×
In-flight	Cyclic operation		○	○	×	○
	Collective operation		○	○	×	○
	Yaw pedal operation		○	○	×	○
	Instrument panel	MFD button operation	○	○	○	×
		Flight control panel operation	○	○	○	×
	Center console	Rotor de-ice control	○	○	○	○
		Fuel control panel operation	○	○	○	○
		FLIR control panel operation	○	○	○	○
		CMDS control panel operation	○	○	○	○
	Front watch		○	×	○	×
	Side watch		○	×	○	×
Emergency	Pilot escape		○	×	×	○
	Door jettison operation		○	○	○	○
Post-flight	Parking brake operation		○	○	○	○
	Rotor brake operation		○	○	○	○
	Egress		○	×	×	○

* Description on the evaluation criteria are shown in Table 2.

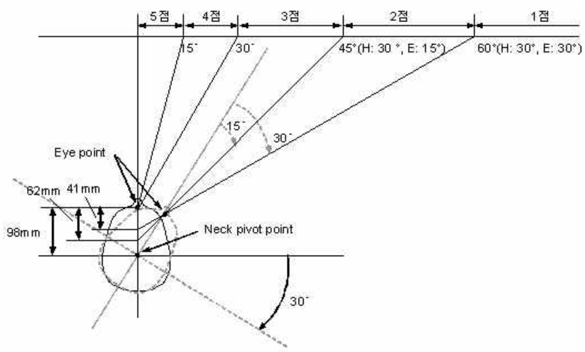
by a 3-step process as shown in Figure 2. In the first step, geometrical relationship equations (GREs), which are estimating the position of a particular body part based on geometrical relationship among body parts, were developed. GREs of the present study were prepared by applying a previous method (Jung et al., 2007) which develops GREs by investigating the relationship between body parts using dependency structure matrix (DSM). For example, the GRE for eye position was developed by mathematizing the geometrical relationship among the body parts influencing pilot's eye position as shown in Figure 3.



(a) Posture scale for a hip motion



(b) Reach scale



(c) Visibility scale adapted from Ryu et al. (2004)

Figure 1. Evaluation scale (illustrated)

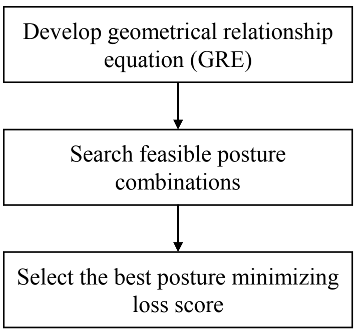


Figure 2. Estimation process of pilot's operating posture

DEP height = SRP height + BD3 × cos (AD3) + BD4 × cos (AD4)

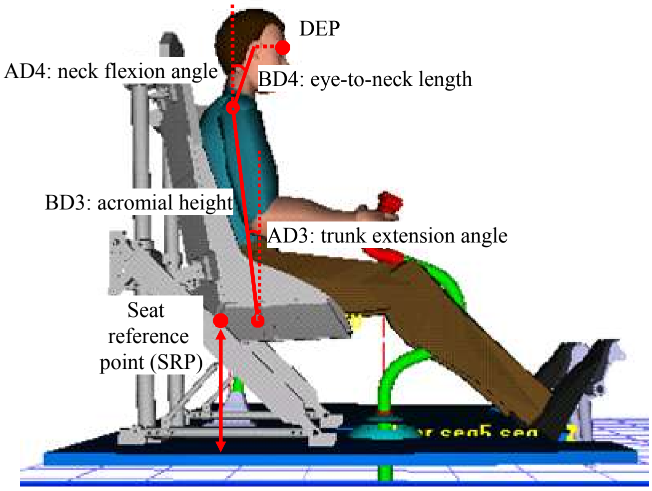


Figure 3. Geometrical relationship equation (GRE) for eye position

In the second step, all feasible posture combinations operating a designated task were found by postural simulation with GREs. For example of Figure 3, the feasible posture combinations that meet pilot's eye point to the designated design eye point (DEP) can be found by changing angular values in the GRE when the DEP and SRP heights are given.

In the last step, the best posture having minimum loss score was selected among the feasible posture combinations. The loss score—extent to postural discomfort— was estimated by loss functions as illustrated in Figure 4. For example, when pilot's posture is within CROM, the loss score is linearly increased with slope 0.5 as the posture deviated from the design reference posture (DRP). The DRP of the present study, as shown in Figure 5, was determined by adapting previous studies (Department of Defense, 1987; Diffrient et al., 1981) and opinions of experts such as 2 ergonomists, 1 pilot, 2 cockpit developers.

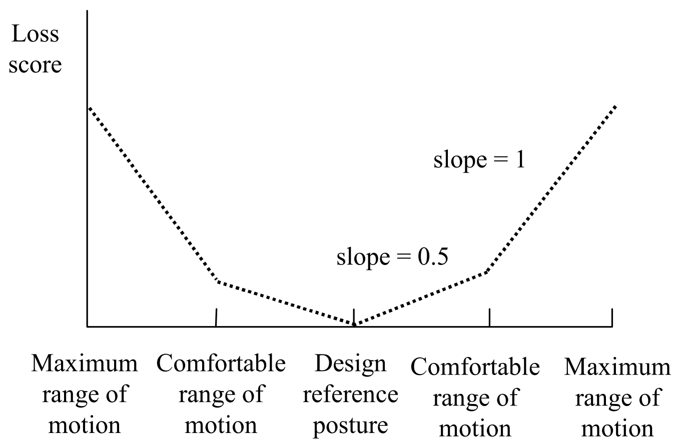


Figure 4. Loss function (illustrated)

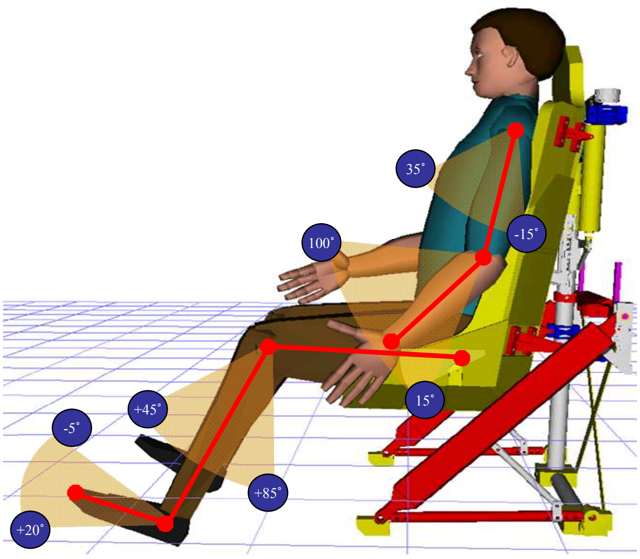


Figure 5. Design reference posture (illustrated)

Workload Quantification

Physical workload was calculated by a workload quantification schema as displayed in Figure 6. For example, posture score conducting the collective operation in Figure 6 was quantified by taking weighted average of body parts' scores and task level workload of the collective operation was calculated by taking weighted average of physical workload scores in posture, reach, visibility and clearance. On the other hand, overall score obtained by taking weighted average of representative human models' workload scores was normalized to 100 point scale. The quantified overall score is useful to judge the overall design level of the developing helicopter cockpit, and the detailed scores on tasks and body parts are effective to identify the design features requiring changes to reduce physical workloads.

APPLICATION TO EVALUATION OF A KUH COCKPIT

The physical workload quantification method proposed in the study was applied to the evaluation of a cockpit of KUH in the preliminary design stage. The weight information to aggregate workload scores was obtained by research team discussion (ergonomist: 2, pilot: 1), and target pilot and developer review (pilot: 2, developer: 2). The main purpose of the evaluation was to find design features requiring improvement in a preliminary cockpit design to better accommodate a designated population.

Evaluation results showed that a few component of the preliminary design should be improved to fit the body sizes of the target pilots. For example, the length of the collective control should be changed because the posture scores on wrist were less than 2 points (unsatisfactory) for the 3 percentile RHMs (see Figure 7.a). In addition, head clearance didn't meet the recommendation of MIL-STD-1333B (Department of Defense, 1987) since the clearance scores in forward watch task were 3 points (posture change required to secure clearance) (see Figure 7.b). The design features requiring improvement identified in the study were changed to better accommodate the target pilots in the detailed design.

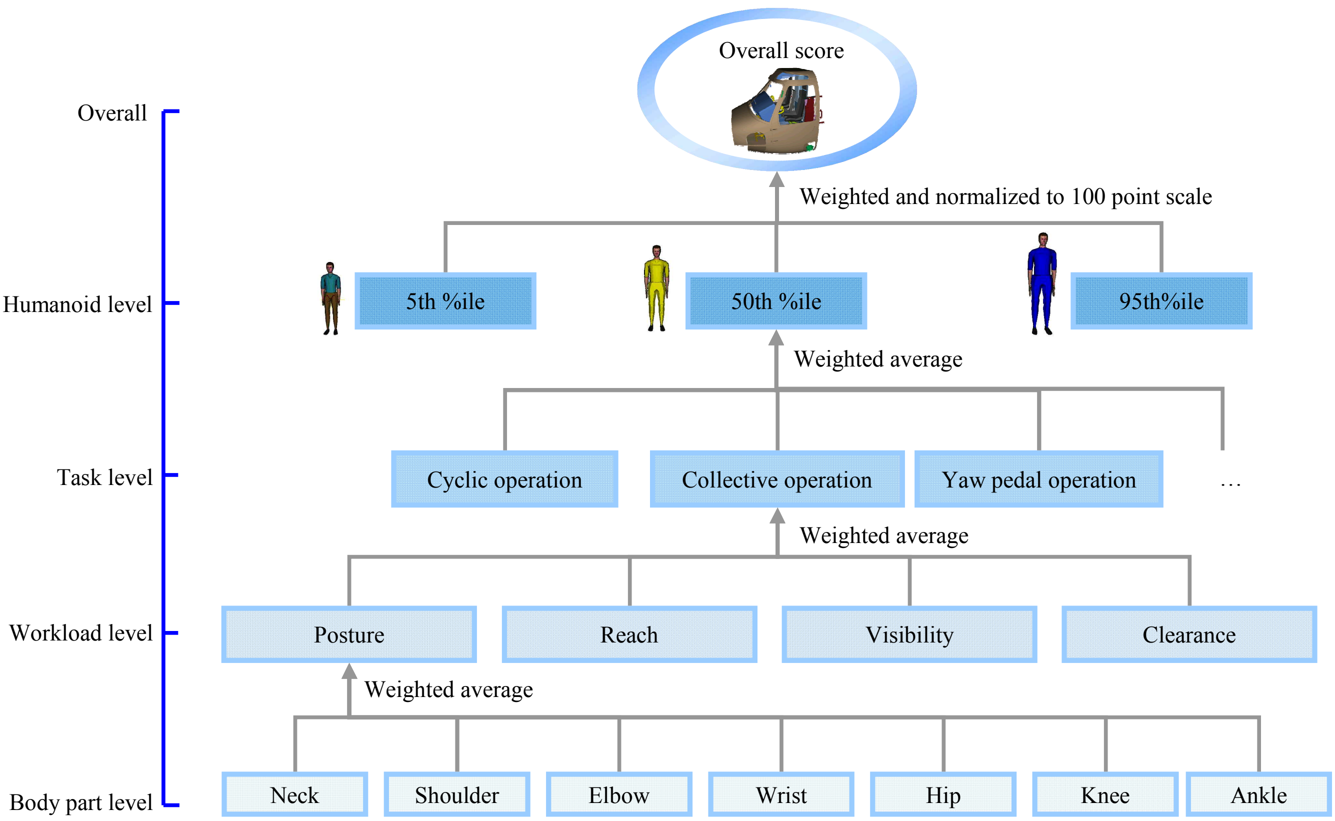
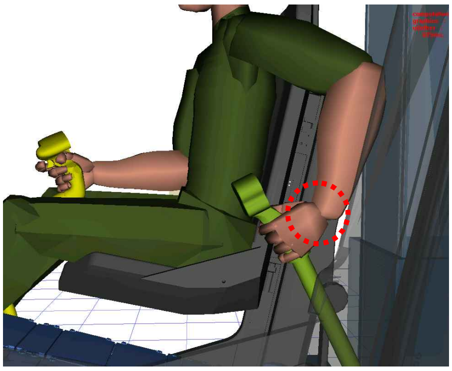
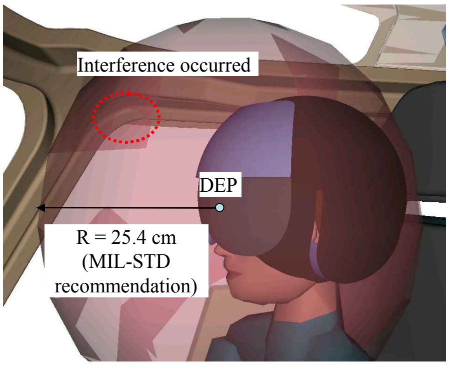


Figure 6. Workload quantification schema



(a) Wrist posture



(b) Head clearance

Figure 7. Illustration of physical workload evaluation for 5th %ile

DISCUSSION

The physical workload quantification method developed in the study can be applied to the ergonomic evaluation of helicopter cockpit in a digital environment. Ergonomic workload assessment in the previous studies (Nelson, 2001; Bowman, 2001) mainly relies on visual observation of reach envelopes and view cones generated in a 3D graphic environment. The proposed method, however, is able to investigate the design features needing changes based on the quantified physical workloads. In addition, the overall score of the physical workloads provides an overall design index as well as a comparison measure among different cockpit designs to helicopter developers and pilots.

The scales of the four physical workloads were determined by considering the previous research results (Department of Defense, 1987; Sanders and McCormick, 1992; Ryu et al., 2004). For example, the scale of the posture workload was defined as a 5-point based on CROM and ROM provided in the previous studies. The scales of the workloads, however, should be established based on experimental data obtained by conducting rigorous experiments.

The posture of a humanoid operating a given task was estimated by GRE and loss function. In the present study, all feasible postures to operate a given task were found by GRE. Next, the best posture having minimum loss score was selected among the feasible alternatives. The loss score quantified from loss function defined based on design reference posture, CROM, and ROM. Therefore, a validation research is necessary to compare the estimated posture and pilots' real posture.

REFERENCES

Bowman D. (2001). Using digital human modeling in a virtual heavy vehicle development environment. In Chaffin, D. B. (Ed.), *Digital Human Modeling for Vehicle and Workplace Design* (pp. 17-36). Warrendale, PA: SAE International.

Chaffin, D. B. (2001). *Digital Human Modeling for Vehicle and Workplace Design*. Society of Automotive Engineers, Warrendale, Pa: SAE International.

Department of Defense (1987). *Aircrew Station Geometry for Military Aircraft* (MIL-STD-1333B), Washington.

Diffrient, N., Tilley, A. R., and Harman, D. (1981). *Human Scale 7/8/9*, Cambridge, MA.

Jung, K., Kwon, O., and You, H. (2007). An anthropometric product design approach using design structure matrix (DSM): Application to computer workstation design (written in Korean). *Journal of the Ergonomic Society of Korean*, 26(3), 111-115.

Kroemer, K. H. E., Kroemer, H. B., Kroemer-Elbert, K. E. (1994). *Ergonomics: How to Design for Ease & Efficiency*. Prentice-Hall, New Jersey.

Lee, S., Lee, M., Cho, Y., Kwon, O., Park, C., You, H., and Han, S. (2005). An ergonomic improvement and evaluation of an overhead crane with digital human simulation (written in Korean).. In *Proceedings of the 2005 Spring joint Conference of ESK & KOSES, and the 8th Korea-Japan Joint Symposium on Ergonomics*.

Nelson, C. (2001). Anthropometric analyses of crew interfaces and component accessibility for the international space station. In Chaffin, D. B. (Ed.), *Digital Human Modeling for Vehicle and Workplace Design* (pp. 17-36). Warrendale, PA: SAE International.

Ryu, T., Shin, S., and You, H. (2004). Development of a quantitative visibility evaluation system for the design of an occupant packaging layout (written in Korean). In *Proceedings of the 2004 Spring Conference of the Korean Institute of Industrial Engineers*.

Sanders, M. S. and McCormick, E. J. (1992). *Human Factors in Engineering and Design*. MGraw_Hill:Singapore.

You, H., Bucciaglia, J., Lowe, B. D., Gilmore, B. J., and Freivalds, A. (1997). An ergonomic design process for a US transit bus operator workstation. *Heavy Vehicle Systems, A Series of the International Journal of Vehicle Design*, 4(2-4), 91-107.