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Ergonomic study for comfort operating the pedals of the agricultural tractors

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Aging and feminization of farming population are a major burden on current agricultural sector, and some measures are demanding to adjust this trend. The agricultural mechanization has relieved farmers of most of the hard physical labor, but still work environments are poor, and there are a lot of harmful factors affecting human health. Therefore, improvement of safety and comfort in agricultural machinery is needed. In case of the most commonly used domestic agricultural machinery, agricultural tractors, operation device location and operating force are regulated by international rules such as ISO 4253, but the rule is not sufficient for domestic operators, since it was not developed for operator's comfort and was drawn out based on the westerners.

In this study, we developed a technique that evaluates the conformability of tractor driving operation device for all Korean farmers including senior and women farmers. We also established evaluation equipments and inspection method of tractor operation conformability to promote dissemination of tractors that suit for Korean farmers' physique. In the future, the result allows tractor manufacturers to propose design guidelines for proper location and operating force of tractor operating device. It also allows domestic agriculture manufacturers to develop agricultural machinery that considered the conformability of farmers from the design stage.

Key words: tractor, convenience, operating device, guideline, expediency

INTRODUCTION

Aging and feminization of farming population are a major burden on current agricultural sector, and some measures are demanding to adjust this trend. The aging (18.6% , National Statistical Office, '05) and feminization (51.2%, Ministry of Agriculture and Forestry, '05) of the farming population have increased the occurrence rate of farmer syndrome (42.7%, '04 MAF), and the population of musculoskeletal disorders among farmers are 2.4 times higher than that among the non–farmers ('04 National Institute of Agricultural Science and Technology). Especially, the prevalence rate on back pain and shoulder pain of farmers are higher than other workers by 50% and 37%, respectively. Therefore, supports for improving work environment and preventing agricultural disease are recommended. The agricultural mechanization has relieved farmers of most of the hard physical labor. However, there are still poor work environments and harmful factors affecting human health. Therefore, the development of agricultural machinery considering the body type of farmers is needed to improve safety and comfort.

To provide a comfortable work space for tractor drivers, ISO 4253 and ISO 15077 regulate the location of driving and operation device, and operating force. However, the rule was made to fit westerners, and it is not suitable for domestic drivers. In particular, Park *et al*., (2002) investigated the degree of inconvenience while using tractors, subjected to the domestic tractor drivers. The drivers responded only 67% in the pedal position, 79% in the gear shift lever, 84% in the handle height, and 52% in the handle distance are suitable for use; and the authors recommended that ensuring convenience of the tractor is required. The current domestic manufacturers are mainly focusing on the work performance of tractors at the developing stage, and they do not consider the tractor drivers' comfort while driving. Therefore, a device which evaluates the comfort of tractor operating is needed to be developed for all Koreans farmers including women and senior farmers. This study intends to establish an evaluation method and inspection criteria of comfort for Korean farmers. By providing the result as a guideline for tractor design, encourage the domestic agricultural manufacturers to develop agricultural machinery with the convenience of the Korean farmers in consideration.

In this study, we have investigated the status of the tractor operation device arrangement, developed convenience analysis tools for tractor operation devices, and performed bio–mechanical analysis on lower body including the waist in order to evaluate the tractor pedal operation convenience. All the processes were to support the ergonomic design of the tractor for convenience and safety of agricultural work, and provide basic data for the development of convenience evaluation system of the main operation device of agricultural tractors.

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MATERIALS AND METHODS

TECHNOLOGY DEVELOPMENT

When considering the current status of research at home and abroad, several agricultural machinery human engineering researches have conducted in the U.S. such as an ergonomic study on farmers' safety which provided ergonomic measures on the neck pain and back pain through musculoskeletal disorder risk assessment with EMG. Researches on the safety of agricultural machinery in Japan focused on the improvement of safety and amenity. To develop agricultural machinery which comfortably fit to Korean farmers including mature men, women, and seniors the machine designers should investigate the operators' body size, psychosomatic, and stamina. John Deere (Corp.) in United States conducted lots of simulation studies such as, evaluation of comfortable tractor driving with dynamic simulator, collaboration work simulation between combines and grain buggy, and tractor driving simulation. The John Deere (Corp.) also conducted an analysis on the work motion during agricultural work, and several studies on ergonomic cockpit batch design. Agricultural machinery manufacturers like Kubota and Yanmar in Japan designed agricultural machinery modified to Japanese farmers' body type by applying ergonomic skills such as universal design.

Studies on the comfortable levels of domestic agricultural machinery are at the early stages, and few studies have been carried out at the research institutes and universities. The rural development administration (RDA) have set a criteria for preventing farmers' musculoskeletal disorders and have used it for agricultural or extension worker education. Moreover, the RDA has conducted a project for the competitiveness of domestic tractors by establishing test criteria and making evaluations.

TRACTOR OPERATING DEVICE RELATED STANDARD AND ARRANGEMENT INVESTIGATION

For 40 models of tractors are sold in Korea, we have investigated the horizontal and vertical height of clutch pedal, brake pedal, accelerator pedal from the SIP. By using the design specifications that have been presented by each company as attachment of agricultural tractors type checking at the National Academy of Agricultural Sciences, driving operating device data were acquired, and the data were compared with KSB ISO 4253 and KSB ISO 6682 (driving operating device reach and comfortable range for earth–moving machine). ISO 4253 is the most basic and widely used international standard. Basic point of driver seat as reference point, ISO 4253 indicates the proper arrangement range of the pedal and handle, but has defined the position simply and do not have the standards concerning convenience and operating force. The disposed range of pedal following the ISO 4253 is determined to be excessively narrow, and it is hard to design the operation device with ease of drivers since the criteria does not provide information related to the operation force or convenience. The recently published ISO 15077 standard establishes a maximum operating force and maximum distance for all operating devices can be presented in the tractor driver seat. The standard is defined as follows: 100 mm minimum lever operating distance, maximum actuation force 80N, minimum pedal travel distance 30 mm, and maximum pressure response 300 N. Accordingly, it have been believed that tractor designer can design the operating force of the operating device with reference to the standard. However, this standard does not present the criteria for the driver convenience as well, and has difficulties in tractor design with a consideration for various operations. Besides, KSB ISO 6682 (Earthmoving machine – convenient and accessible operation area) shows the range of proper placement in a controllable range of operating device for earth–moving machineries such as excavator and loader. However, it is a standard that directly applied an ISO standard to Korea rather than those developed for domestic agriculture. As steerable region or convenient areas were defined based on the figure of westerners primarily domestic, it is unknown whether the standard is suitable for domestic driver, especially for the domestic agriculture.

DEVELOPMENT OF COCKPIT MOCKUP AND OPERATING FORCE MEASURMENT DEVICE

Tractor cockpit mockup which follows the standards ISO 4253 (operator's seating accommodation) and ISO 6682 (zone of comfort and reach for controls) is developed. The cockpit mockup has a height–adjustable driver seat, a clutch and brake pedal in the pedal part, and a steering wheel made with aluminum profiles in the steer-

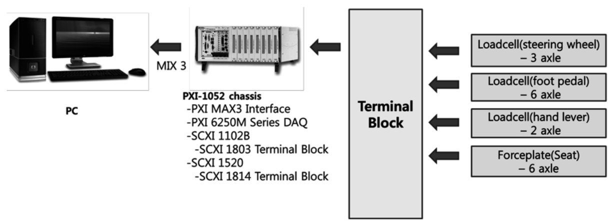

Fig. 1. Schematic of the operating force measurement system.

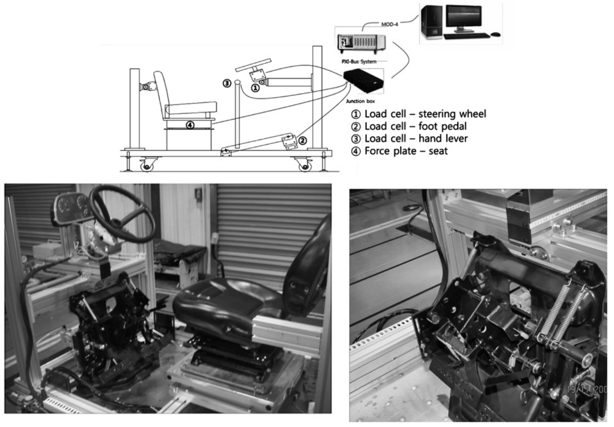

Fig. 2. Schematic of the mounted operating force measurement system on the cockpit mockup.

ing part. Pneumatic manipulation load generation system is installed at hinged–type pedal, and the pedal part is designed to generate 0~800N. A force plate and load cells are equipped to measure the reaction force in the driver's seat and pedals, levers, and handle parts. And data collecting device is mounted for reaction force collection. Schematic diagram of the simulated cockpit and cockpit mockup, and force generate device developed to

Table 1. Human body measurements DB of the Korean males aged 40~59 (SizeKorea)

No.	Items	Average	S.D.	5 quintile	50 quintile	95 quintile
1	Weight (lbs)	69.63	9.35	54.7	69.2	85.45
2	Standing Height	1672.4	56.27	1580.5	1670.5	1765
3	Right Shoulder Height	1366.87	50.93	1283.5	1366.5	1452.5
4	Left Shoulder Height	1366.87	50.93	1283.5	1366.5	1452.5
5	Right Armpit Height	1239.12	48.59	1158	1237.5	1317.5
6	Left Armpit Height	1239.12	48.59	1158	1237.5	1317.5
7	Waist Height	1026.02	45.57	951.5	1024.5	1098.5
8	Seated Height	907.21	32.17	854.5	906.5	960.5
9	Head Length	176.08	22.05	146.5	169	206.5
10	Head Breadth	153.63	19.31	128.5	145	182.5
11	Head to Chin Height	212.67	29.97	174.5	202	255.5
12	Neck Circumference	382.53	22.87	344.5	382.5	420.5
13	Shoulder Breadth	389.88	23.04	349.5	390.5	424.5
14	Chest Depth	218.74	17.67	189.5	218.5	248.5
15	Chest Breadth	314.17	20.67	280.5	312.5	347.5
16	Waist Depth	235.79	28.26	186.5	236.5	279.5
17	Waist Breadth	289.44	21.87	251.5	289.5	325.5
18	Buttock Depth	241.65	23.1	205.5	241.5	279.5
19	Hip Breadth Standing	328.47	15.62	302.5	328.5	353.5
20	Right Shoulder to Elbow Length	329.78	15.13	304.5	329.5	354.5
21	Left Shoulder to Elbow Length	329.78	15.13	304.5	329.5	354.5
22	Right Forearm Hand Length	261.67	12.91	238.5	261.5	283.5
23	Left Forearm Hand Length	261.67	12.91	238.5	261.5	283.5
24	Right Biceps Circumference	304.62	25.12	262.5	304.5	344.5
25	Left Biceps Circumference	304.62	25.12	262.5	304.5	344.5
26	Right Elbow Circumference	289.58	23.4	251.5	289.5	329
27	Left Elbow Circumference	289.58	23.4	251.5	289.5	329
28	Right Forearm Circumference					
29	Left Forearm Circumference					
30	Right Wrist Circumference	170.36	8.8	155.5	169.5	183.5
31	Left Wrist Circumference	170.36	8.8	155.5	169.5	183.5
32	Right Knee Height Seated	497.31	22.87	460.5	496.5	536.5
33	Left Knee Height Seated	497.31	22.87	460.5	496.5	536.5
34	Right Thigh Circumference	494.3	37.65	431.5	494.5	552.5
35	Left Thigh Circumference	494.3	37.65	431.5	494.5	552.5
36	Right Upper Leg Circumference	544.18	42.79	471	545.5	611.5
37	Left Upper Leg Circumference	544.18	42.79	471	545.5	611.5
38	Right Knee Circumference	365.55	19.86	33	365.5	399.5
39	Left Knee Circumference	365.55	19.86	33	365.5	399.5
40	Right Calf Circumference	364.78	26.81	320.5	363.5	408.5
41	Left Calf Circumference	364.78	26.81	320.5	363.5	408.5
42	Right Ankle Circumference	255.24	14.01	233.5	255	278
43	Left Ankle Circumference	255.24	14.01	233.5	255	278
44	Right Ankle Height Outside	67.17	5.01	59.5	66.5	75.5
45	Left Ankle Height Outside	67.17	5.01	59.5	66.5	75.5
46	Right Foot Breadth	100.58	4.68	92.5	99.5	107.5
47	Left Foot Breadth	100.58	4.68	92.5	99.5	107.5
48	Right Foot Length	250.51	10.37	233.5	249.5	267.5
49	Left Foot Length	250.51	10.37	233.5	249.5	267.5

generate pedal reaction force during the operation are shown in Fig. 2. Also, an operating force measurement system that can measure stamping force during pedal stamp, operating force during lever operation, and force of the steering wheel is developed. The developed operating force measurement system is composed with force plate which measures reaction force at the cockpit, 6–axis load cell for the stamping force measurement in the pedals, 3–axis load cell to measure the forces exerted on the steering wheel, lever operating force sensor with built–in 2–axis load cell for the lever operating force, and NI's PXI–BUS system which receives signals from the sensors, amplifies, and sends data to a computer. Operating force measurement system needs signal conversion from the sensor into operating force and an additional operation measurement program to store and edit data. Fig. 1 is the schematic of the measurement system. In addition, the schematic of the mounted operating force measurement system on the cockpit mockup is shown in Fig. 2.

MOTION ANALYSIS SYSTEM FOR TRACTOR PEDAL CONVENIENCE ANALYSIS

Fig. 3 shows an image measurement system for measuring the driver's behavior while operating. For the motion analysis, eight Hawk–class near–infrared imaging sensors are installed and the motions of driver's body with marker recognition program(Cortex, Motion analysis) are recorded by tracking markers attached to the driver body in three–dimension. The default position of the seat, pedals, lever, and handle in cockpit simulator were adjusted by a subject following the operation system of medium–sized tractor from a domestic company A (Corp.). The subjects were male between 40–59 years old. Test was started in a default setting of the driver's seat and pedal which used in the computer modeling. A motion with 100 N of force at pedaling and the same motions were replicated with adjusting the position of the pedals and seat. The seat points were set as three positions: reference point, 7.5 cm anterior from the reference point, and 7.5 cm posterior from the reference point. The pedal points were also set as three positions: reference point, 5 cm left from the reference point, and 5cm right from the reference point. Each position in the seat and pedals of motion data was entered into the program LifeMOD, and joint angles and joint loads were calculated. Fig. 4 shows a process calculating the load and joint angles by using the LifeMOD. During the process human body model was developed using the average body size of Korean male aged in 40 to 49 years, which was investigated at the Technical Standard Institute. According to the paper reported in Journal of the Korean Society of Clothing and Textiles, human body measurements of the Korean standard male and Korean male farmers have no differences (Journal of the Korean Society of Clothing and Textiles, 2007 Fall). Following the reference, Korean male size measurement, 40~69 olds male size was assumed to be as same as that of the male population of the rice cropping farmers. Under the assumption "Body type factors are same between the Korean males and tractor operators aged from 40 to 60." human body measurements of the Korean males were investigated from the human body measurement data-

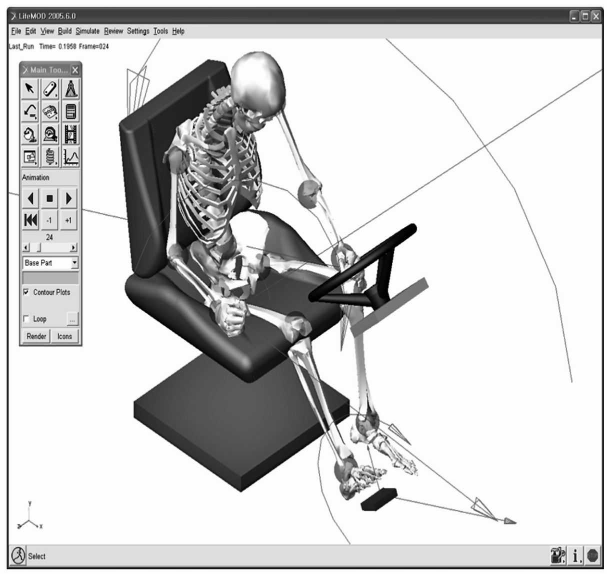

Fig. 4. LifeMOD, Joint angle and joint load calculation.

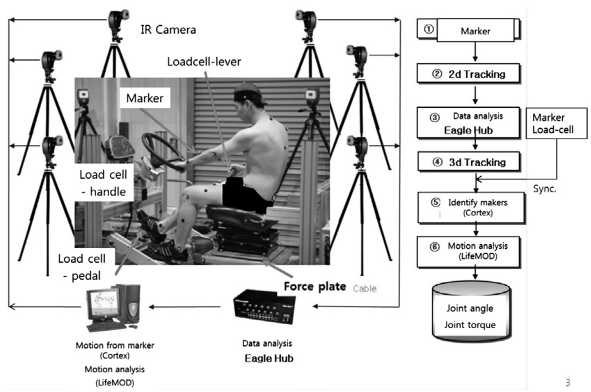

Fig. 3. Image measurement systems.

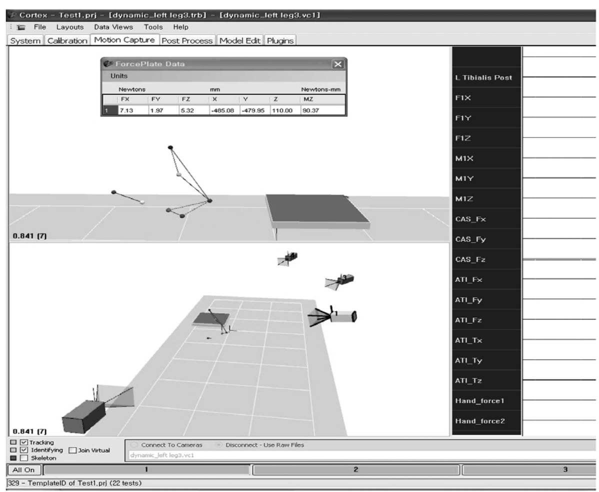

Fig. 5. Image measurement data during pedal stamping.

base provided by the 'Size Korea'. Table 1 shows average, standard deviation, 5 quintile (small size), 50 quintile (medium size), 95 quintile (big size) for each items.

With the developed motion analysis system, the driving positions and postures are measured in real time through the image measurement system, and the reaction force is measured by the measuring device simultaneously. And then the motions are analyzed by motion analysis program. Fig. 5 shows a measurement result of the motion in the driver's leg during a pedaling with the developed image measurement system.

TRACTOR OPERATION POSTUREs AND EVALUATION CRITERIA

According to Ryu *et al*. (2004), driving posture influences the convenience of the drivers. Therefore, for an evaluation on the ease of operating device, extracted the range of motion (angle) in joints according to each tractor operating motions was evaluated following the criteria shown in Fig. 6.

Table 2 below shows criteria on the joint range of motion on the lever and pedal in Fig. 6. If workers perform works within the range of appropriate criteria, they

Table 2. Evaluation criteria for the range of motion in joint

Angle part	Plane	Direction	Posture	Range of the ease
Head	Sagittal	+30	front bow	+30
		– 30	backward	– 30
	Transverse	+	left rotation	model standard
		–	right rotation	model standard
	Frontal	+20	right bow	+20
		– 20	left bow	– 20
R/L Shoulder	Sagittal	+15	backward stretch	+15
		– 35	front stretch	– 35
	Transverse	+	left rotation	model standard
		–	right rotation	model standard
	Frontal	+0	left stretch	+0
		–30	right stretch	– 30
R/L Elbow	Sagittal	+	backward stretch	model standard
		– 40~80	front stretch	– 40~80
	Transverse	+	left rotation	model standard
		–	right rotation	model standard
	Frontal	+	left stretch	model standard
		–	right stretch	model standard
R/L Wrist	Sagittal	+45	backward stretch	+45
		–25	front stretch	–25
	Transverse	+70 (Left:8)	left rotation	+70 (Left:8)
		–8 (Left:70)	right rotation	–8 (Left:70)
	Frontal	+	left stretch	model standard
		–	right stretch	model standard
R/L Hip	Sagittal	+	lower body backward stretch	model standard
		–60~–95	lower body front stretch	–60~–95
	Transverse	+	left rotation	model standard
		–	right rotation	model standard
	Frontal	+	left stretch	model standard
		–	right stretch	model standard
R/L Knee	Sagittal	+45~+85	backward stretch	+45~+85
		–	front stretch	model standard
	Transverse	+	left rotation	model standard
		–	right rotation	model standard
	Frontal	+	left stretch	model standard
		–	right stretch	model standard
R/L Ankle	Sagittal	+0~+20	ankle plantar flexion	+0~+20
		–	ankle dorsiflexion	model standard
	Transverse	+15	left rotation	+15
		–15	right rotation	–15
	Frontal	+	right rotation	model standard
		–	left rotation	model standard

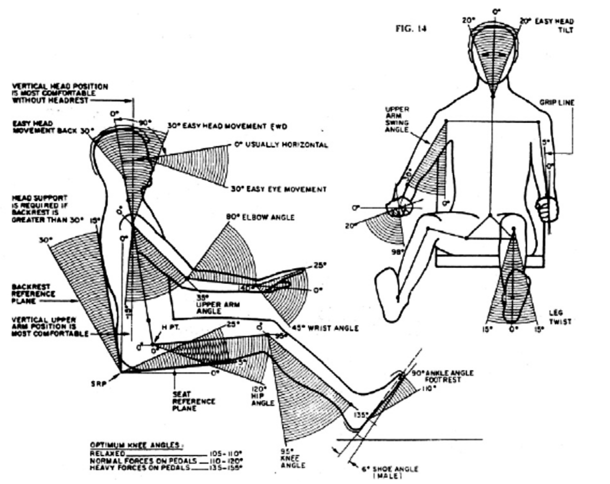

Fig. 6. Joint range of motion for ease operation (2004. Ryu Kwan Hee. Munundang. Tractor engineering).

do not feel significant discomfort during the tractor operation.

RESULTS AND DISCUSSION

TRACTOR OPERATING DEVICE ARRANGEMENT INVESTIGATION RESULT

Fig. 7 shows the displacement of the tractor driving–operation devices. According to the investigation based on ISO 6682, 30% of the range in the lever, 80% in the clutch pedal, 78% in the handle, 73% in the brake pedal, and 92% in the accelerator were determined to be out ranged from the comfortable range. The proper displacement range ruled by ISO 4253 has much smaller area than that of the ISO6682; it is found that the range of clutch, break, and accelerator in most of the tractor models investigated were out–ranged. Therefore, driving operation device of the tractors available in Korea are determined to be taking into account the convenience of the driver insufficiently.

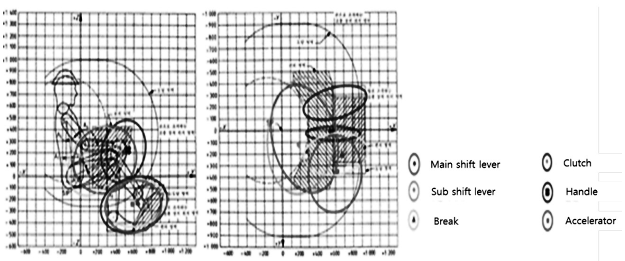

Fig. 7. Investigated range of operation devices.

HUMAN MODEL VERIFICATION

For a bio–mechanical analysis of the tractor worker with human model, kinematic factors and kinetic factors were measured, and simulated using the analysis program 'ADAMS LifeMOD'. The process is same as follows: first, acquired data of the motions by using the 6 infrared cameras, gait and lifting, which will be performed by human simulation model and used for verification of the model. Second, utilizing the data, built a human body model in ADAMS LifeMOD, and set the whole body movements. The parameters examined in gait motion for the model verification were ground reaction force, center of gravity, joint angle, and joint torque. The load at the waist compared with the value joint force floor is measured for model validation from walking, is presented in the bibliography at the operating lift. The first step in creating a human body model is human body segments composition. Nineteen of body segments were built using the anthropometric database. The segments required to build a human model are as follows: head, neck, upper torso, mid torso, lower torso, left and right shoulders, left and right upper arms, left and right forearms, left and right hands, left and right upper legs, left and right lower legs, and left and right foot. Human body is simplified to segments of the body of this 19 pieces, and it is possible to have detailed analysis in a specific region by dividing the segments into several multiple segments. The foot is consisted of multiple bones, and they are connected with tendons or ligaments. In this study, foot was set as one segment, and contact between the foot and the ground was modeled by setting the six contact–ellipsoids. In this study, we take advantage of the Korean integrated research business SizeKOREA DB, one of the human body information DB widely used in kinetic analysis of heavy equipment operator and vehicle.

The study of simulation using the ADAMS LifeMOD need a human body model, and need verification of the model usefulness by implementing motions. The verifying method for the model should be selected with the characteristic of work to be implemented beforehand. The main motions in the tractor work can be classified as follows: motion of pulling the lever and pedaling. Since the verification of the whole body movement is necessary, task of lifting and walking, representative and general movement of human body, were targeted for the verification.

In case of the center of gravity, all three traveling direction (X), lateral direction (Y) and vertical direction (Z) had values less than 10%, and were included within 15% you are of the appropriate standard of analysis. The absolute difference showed a value smaller than the value presented in the previous study (Pen *et al.*, 2004), and correlation was higher with correlation coefficient higher than 0.7 (Jon–Deyon, Basic social statistics).

When the kinematic data are examined, relative position differences of the ankle, knee, and hip joint had values of less than 10%, and all were within 15%, a moderate standard for bio–mechanical analysis. The absolute differences were less than 5 degrees on average, and showed 0.9 or more of high correlation coefficient.

When check out the reaction force occurred during gait, both left and right had a value below 10% in case of the relative position difference value, and it was suitable standard for bio–mechanical analysis, 15% (Wojtyra, 1999). The absolute position, all the values showed under than the value shown in the literature (Gilchrist, 1997). The correlation, except for the left and right side

Table 3. Verification result on Center of gravity

	Absolute Difference			Relative Difference (%)			Correlation (r)		
	X	Y	Z	X	Y	Z	X	Y	Z
Average	–7.0635	–0.1834	–0.8771	3.1662	0.0379	0.1949	0.9990	0.7830	0.7392
SD	7.9434	6.2931	5.4983	2.5934	0.6611	2.4391	0.0017	0.1327	0.1722

Table 4. Verification result on kinematic data of each joint

Left	Absolute Difference			Relative Difference (%)			Correlation (r)		
	Ankle	Knee	Hip	Ankle	Knee	Hip	Ankle	Knee	Hip
Average	1.1655	0.0142	0.6236	–9.1692	0.6986	–1.9676	0.9738	0.9955	0.9917
SD	0.9505	1.3490	1.2673	3.9277	10.0401	5.3587	0.0245	0.0014	0.0069

Right	Absolute Difference			Relative Difference (%)			Correlation (r)		
	Ankle	Knee	Hip	Ankle	Knee	Hip	Ankle	Knee	Hip
Average	0.0339	–0.5427	–0.5551	1.2844	5.4749	–1.5234	0.9665	0.9946	0.9947
SD	0.8405	3.1791	1.7657	9.4505	11.5592	5.0780	0.0287	0.0014	0.0020

Table 5. Verification result on ground reaction force during a gait simulation

Contents	Left Foot			Right Foot		
	X	Y	Z	X	Y	Z
Relative Position Differences (%)	–2.49	–	–4.22	14.53	–	–1.42
Absolute Position Differences (N)	–6.62	–0.68	8.71	–0.97	2.39	10.74
Pearson's Correlation Coefficients	0.94	0.62	0.94	0.94	0.94	0.94

X : Forward–Backward, Y : Left–Right, Z : Upward–Downward

horizontal force, correlation of the all forces were very high. (Jon–Deyon, Basic social statistics)

During the lifting experiment, the task varies according to the distance and height between weight, and need to be same as much as possible with the experiment performed at previous studies. The maximum and average torque values of the lumbar portion were determined, and compared with that of the previous study (Kingma *et al.*, 1998). The comparison result is shown in Fig. 8.

A computer human body model was developed by LifeMOD program. The model was verified by comparing the load generated at the lumbar during lifting task and the lumbar load from the previous study (Kingma *et al*, 1998), and had no great difference. Therefore, the verification of the computer human model developed through LifeMOD was determined to have no problem.

Using the driver seat mockup, the normal force from the computer tractor simulation (Fig. 11) and the force from the load cell were compared. Fig. 9 shows the human body model stepping the brake pedal. Fig. 10 graphically representation the reaction force values obtained by the load cell when press the actual pedal (red line) and results obtained using the human body model (blue line). The results obtained in the human body model was 102.45 (±0.87) N in average, and matched 97.6% with the actual reaction force from load cell 100N.

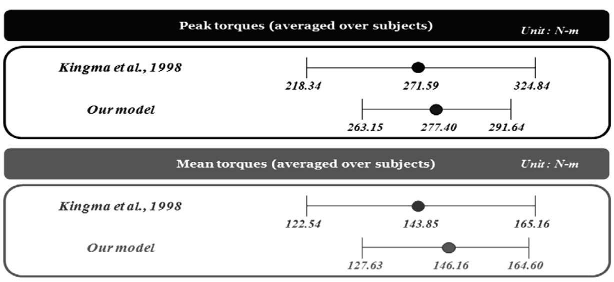

Fig. 8. Comparison of the load at lumber region with the previous study.

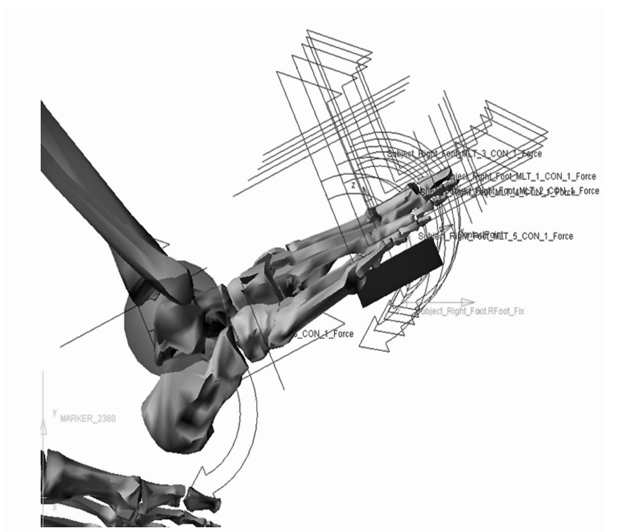

Fig. 9. Clutch pedal modeling.

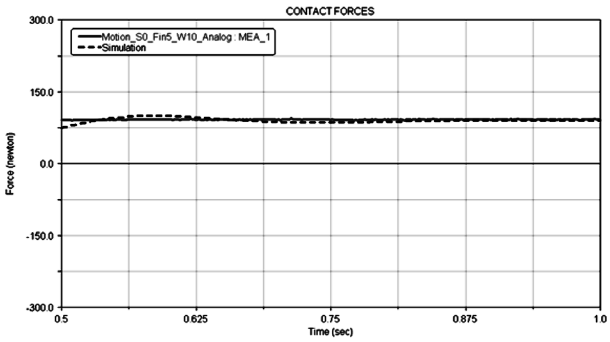

Fig. 10. Comparison between the real and simulation value.

CONVENIENCE ANALYSIS RESULT USING THE JOINT ANGLE

Fig. 11 and 12 shows a scene from pedal and lever operating experiment, and drawn simulation result, respectively.

Fig. 11. Experiment picture – pedal andlever operation.

Evaluation results on the ease of use with the measured joint angles are listed in Table 6.

According to the result, 1, 4, and 6 postures show to be uncomfortable on the sagittal plane, and the cause of this discomfort may be from the position of the sight on pedal while working a pedal. On the sagittal plane of the right knee, discomfort is shown during 7, 8, and 9 postures, and the cause of this may be the far position of pedal. Also, both left and right hip joint on the sagittal plane shows discomfort due to the uncomfortable seat on the cockpit.

CONVENIENCE ANALYSIS RESULT USING THE WAIST LOAD

The shear force and compressive force take at the waist shown in Table 7. Also, when the maximum values shown in Table 7 are displayed as a graph, they are the same as in Fig. 15.

Fig. 15 shows maximum values of the shear force and compressive force take at the waist with 100N of break pedaling. All the compressive–strength (COMP) satisfies

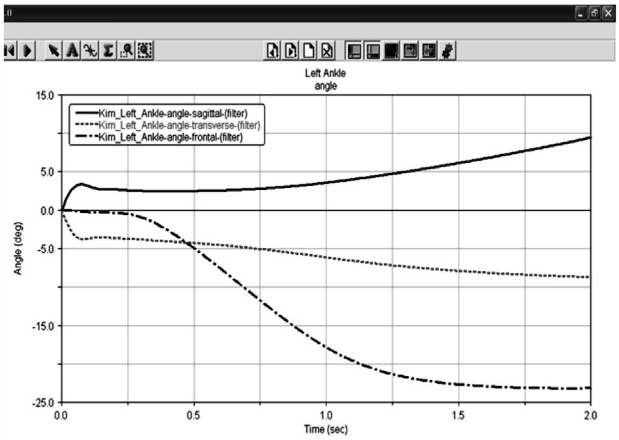

Fig. 12. Left ankle angle at the reference position with middle size tractor.

Table 6. The evaluation result on the ease based on the angles

	Plane	1	2	3	4	5	6	7	8	9
Head	S	discomfort	comfort	comfort	discomfort	comfort	discomfort	comfort	comfort	comfort
	T	–	–	–	–	–	–	–	–	–
	F	comfort	comfort	comfort	comfort	comfort	comfort	comfort	comfort	comfort
R. Hip	S	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort
L. Hip	S	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort	discomfort
R. Knee	S	comfort	comfort	comfort	comfort	comfort	comfort	discomfort	discomfort	discomfort
R. Ankle	S	comfort	comfort	comfort	comfort	comfort	comfort	comfort	comfort	comfort

Author) 1: Default position of the cockpit and pedal
2: Default position of the cockpit, Pedal 50 mm inside
3: Default position of the cockpit, Pedal 50 mm outside
4: Cockpit 75 mm forward, Pedal default
5. Cockpit 75 mm forward, Pedal 50 mm inside
6. Cockpit 75 mm forward, Pedal 50 mm outside
7: Cockpit 75 mm backward, Pedal default
8: Cockpit 75 mm backward, Pedal 50 mm inside
9: Cockpit 75 mm backward, Pedal 50 mm outside

the NIOSH criteria (3,400 N, Waters *et al*., 1993). When the result is analyzed, relatively large load appears in the default cockpit location, and the COMP is reduced as the location adjusted to the forward or backward. Also, the biggest load (3,343 N) is appeared as the pedal locates to the outwards from the default location. The anterior–posterior shear force (ANT_SH) shows significantly higher value at default cockpit location and left/right range of the pedal position than other postures. It exceeds maximum permissible standard (1,000 N) and

Table 7. Shear force and compressive force take at the waist (unit:N)

Class	MAX			AVG			MIN		
	ANT_SH	COMP	LAT_SH	ANT_SH	COMP	LAT_SH	ANT_SH	COMP	LAT_SH
1	384.09	2,561.53	406.55	–97.019	1882.632	47.30346	–285.954	8.76997	–24.4988
2	1380.685	2954.663	12.17424	979.4734	2387.539	–16.6699	–43.5531	2.93843	–81.6843
3	991.6504	3343.159	658.1115	652.5797	2624.722	457.8717	–319.192	7.48619	11.24216
4	364.9477	617.0101	203.0799	330.0011	576.165	149.689	–47.4045	7.15427	8.915806
5	315.1699	633.339	162.696	276.7687	545.1998	143.4227	–37.6722	9.30553	11.37378
6	332.9775	570.4118	199.7597	305.5871	528.4459	170.7862	–72.1741	1.12023	–5.47217
7	661.1428	888.3096	455.7758	612.7965	823.9175	338.7367	–66.7587	4.85235	2.150117
8	405.3107	772.9148	141.0301	330.043	585.0147	78.65405	–37.01	–2.33	5.06
9	262.1468	437.9146	11.01333	234.3021	402.1396	–42.636	–73.441	4.18864	–57.7197

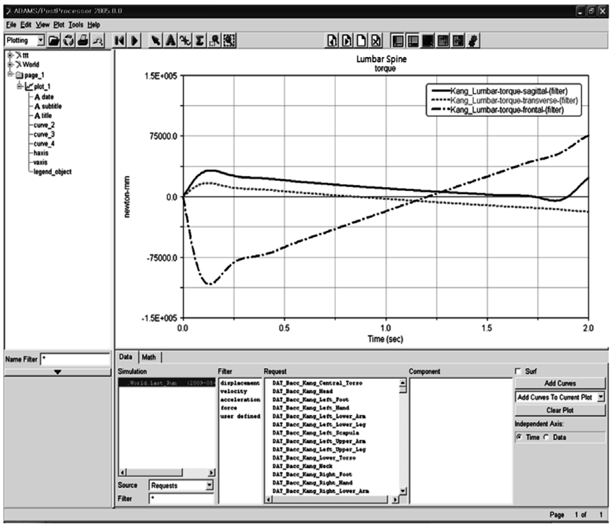

Fig. 13. Lumber spine torque at the reference position with small size tractor.

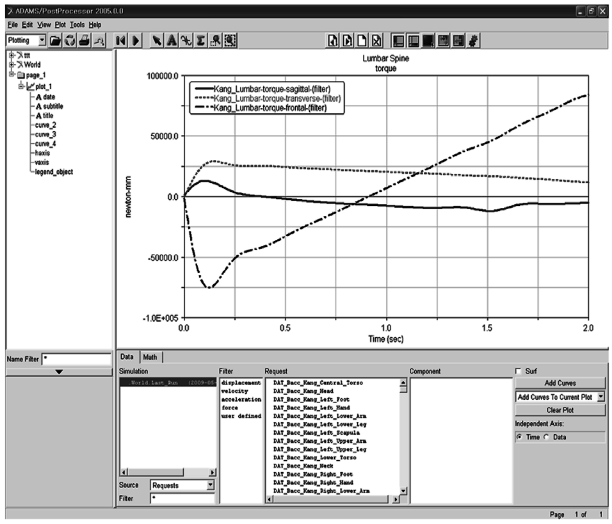

Fig. 14. Lumber spine torque at the 3-point posterior position with small size tractor.

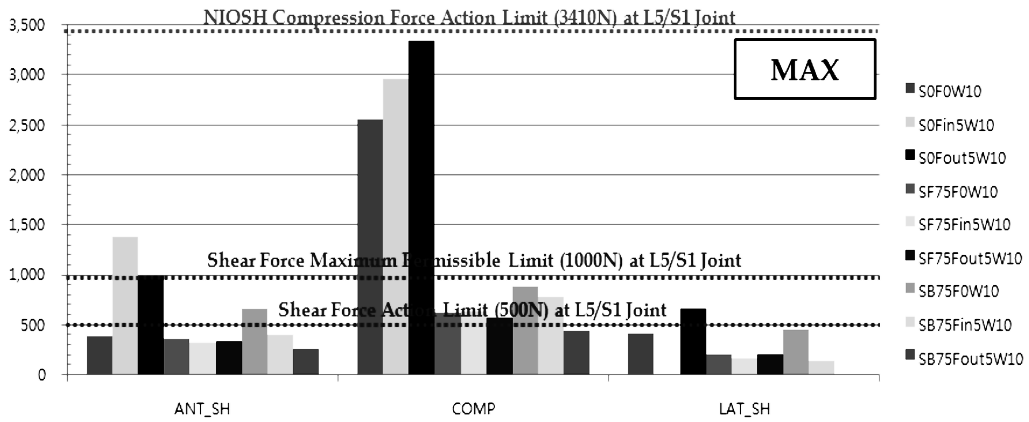

Fig. 15. Maximum values of the shear force and compressive force take at the waist.

permissible operating standard (500N) on NIOSH standards (Waters *et al*., 1993). Additionally, decreasing shear force is measured as the seat location adjusted to the front and rear. To conclude, the default cockpit location is burdening to the average 50 years of middle aged men, and the burden can be reduced by adjusting the cockpit location. The results of this study cannot be applied to the whole domestic tractors' cockpit, because the range of proper placement and navigating method are the only for the simulation.

CONCLUSIONS

The purpose of this study is the comfort evaluation technique development for tractor design. The thchniques can be utilized in operation device design by considering the body size of Korean farmers. In this study, only one result from the one domestic company A's middle–size tractor is recorded for the proper range of operation device placement, nevertheless manufacturers and designers should utilize the testing methods for operating device design by following the same sequence carried out from this study. The results from this study can be summarized as follows:

A. According to the investigation based, 30% of the range in the lever, 80% in the clutch pedal, 78% in the handle, 73% in the brake pedal, and 92% in the accelerator were determined to be out ranged from the comfortable range based on ISO 6682, We could found that tractors without considering the convenience of the driver, when designing the driving operation device of tractors, is supplied.

B. Have developed a tractor driver seat simulator which can accommodate a range of displacement of the driving operation device according to the ISO 6682 and ISO 4253.

C. Have configured a video measurement system for measuring the motion of the driver during driving and operation. The movable angle and load to the joint were estimated by the image sensor measurement data, when the driver sitting in the driver's seat simulator stepped on simulated pedal, and LifeMOD program.

D. The convenience of the brake pedal operation was evaluated. As the result of evaluation, discomfort at left and right hips was observed in the entire positions and postures; discomfort at the right knee was observed when move the seat 7.5 cm backwards; discomfort at the left knee was observed when move the seat 7.5 cm forward.

E. The load evaluation result at waist satisfied the NIOSH criteria, but the load was relatively large when the seat was at the default location, and the compression force reduced when adjusts the seat back and forth. Furthermore, the largest load was observed (3,343N) when moving the pedal outward from the default location. Higher anterior and posterior shear force than other motions was observed at the left and right pedal location, and the default location; especially, allowable operating reference value and the maximum permissible reference value exceeding NIOSH criteria in the default location was observed. When adjust the seat back and forth, the shear force was reduced.

F. The entire process performed in the present study works as a method to perform a convenience evaluation for diverse conditions at the design stage or to evaluate convenience on a developed agricultural tractor. The tractor manufacturers can make an evaluation on the range of operation device placements and can determine optimal location of operation devices and operating force on a targeted developing model by utilizing the ease evaluation system and method developed in this study. Also, it can be used for the quality inspection by conducting individual ease evaluation on the tractors in prototype development phase. Besides, the evaluation method and system from this study can also be utilized at the operating difficulty test that conducted by tractor testing station. To be specific, the ease of use evaluation based on arranging position and operating force, which is considered to be the most significant inconvenience operating device among the agricultural tractors for investigation, can be carried out by using the evaluation system from this study.

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