Development of Upper-Limb Assist Suit for Reduction Physical Load in Leaf Photosynthesis Measurement

Toshitake Araie, Ikeda Tomozumi, Akira Kakimoto, and Shunsuke Adachi

***Abstract*—Agricultural tasks result in significant strain on the arms, thereby necessitating posture support. One such task is measuring the photosynthetic capacity of individual leaves. This task requires the operator to hold a measuring device for long periods, which is physically demanding. This study aims to develop an assist suit to reduce the physical load involved in photosynthesis measurement work. We used work posture evaluation methods to quantify the workload of this task and identified the parts of the body at high-risk of injury. Then, we designed an assist suit based on the required specifications and verified its effectiveness.**

***Index Terms*—Agricultural work, leaf photosynthesis measurement, upper-limb assist suit, work posture evaluation, surface EMG.**

I. Introduction

In view of both the global population growth and the promotion of agriculture in Japan, achieving higher yields of rice crops is required both in Japan and overseas. In particular, rapidly cultivating new varieties that will lead to dramatic increase in the yield is considered important.

The photosynthetic capacity of individual leaves of rice crops is measured using a high-speed photosynthetic rate measuring device, with the aim of improving the photosynthetic rates of leaves and increasing the biomass and yield of rice [1]. Numerous sample measurements are required because of the individual differences in rice plant growth, and the task of holding the measuring equipment for long periods is physically demanding.

Our laboratory has been developing and evaluating agricultural power assist suits [2]-[6].

The purpose of this study is to develop an upper-limb assist suit to reduce the physical load involved in photosynthesis measurement work. This paper provides the results of an interview survey of operators involved in this work, as well as the results of the risk assessment conducted using work posture evaluation methods. Additionally, it is demonstrated the construction of the designed suit and verify its effectiveness.

Manuscript received May 23, 2020; revised July 23, 2020. This work was supported by the Japan Science and Technology Agency CREST grant (number JPMJCR15O2 to S.A.).

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II. Interview Survey and Work Posture Evaluation

A. Interview Survey

We visited the agricultural land belonging to Tokyo University of Agriculture and Technology, where we interviewed three subjects: a male aged 22 (height 175 cm, weight 60 kg), male aged 35 (height 160 cm, weight 63 kg), and male aged 39 (height 166 cm, weight 75 kg). The following responses were obtained.

- The measuring device weighs approximately 2 kg.
- The task is performed 2–4 times per week.
- The working time is 3 h per day. The operators take a 10-minute break per hour.
- Approximately 300–400 leaves are measured each time.
- The measurement time is 15–20 s per leaf.
- Some operators measure by bending at the waist; however, the task basically involves repeated bending and stretching.
- To avoid damaging leaves during measurement, the measuring device is tilted in the growth direction of the leaf, which requires the posture to be maintained.
- Basically, the elbows are bent; however, occasionally they are stretched.
- The range of motion of the upper arm joints in the left and right directions is around the body width.
- The measuring device is held at an almost fixed position around the waist, and there is no movement involving raising the arms.
- The operators hold the measuring device with their dominant hand. With the other hand, they grasp the leaf to be measured and move away the other leaves. The measuring device must be held continuously during the task.
- The platform where the operator stands is narrow and unstable.
- Occasionally the work is performed by stepping into the paddy field.
- The operators feel most fatigue in their forearms and wrists.

B. Work Postures

We filmed the work posture of one operator (male, 22, height 175 cm, weight 60 kg) using a video camera. From the differences in the posture depending on the distance between the operator and the object being measured, we classified the work postures into the seven patterns, as listed in Table I. These are two categories for the bending of the trunk, three categories for the degree of knee extension/flexion, and two

DOI: 10.7763/IJMO.2020.V10.768

categories for the degree of shoulder extension/flexion.

Posture A Posture B Posture C Posture D Posture E Posture F Posture G

Fig. 1. Work postures during the measurement of photosynthetic capacity.

TABLE II: OWAS AND RULA RISK ASSESSMENT RESULTS

		Posture						
OWAS（whole body）		A	B	C	D	E	F	G
Posture code	Back	1	2	2	2	2	2	2
	Upper limbs	1	2	1	2	1	1	1
	Lower limbs	2	2	4	2	4	4	4
	Load/force	1	1	1	1	1	1	1
OWAS score		1	2	3	2	3	3	3
RULA（Upper arm）								
Upper arm		1	4	2	4	3	4	4
Forearm		1	2	1	2	1	1	2
Wrist & arm		4	7	5	7	6	7	7
RULA score		5	7	6	7	7	7	7

no action required
action required in near future
action required soon
action required immediately

Posture A is a standing one, and Postures B and D are standing postures with the knees extended and the trunk bending forward. Postures C and E are postures with bending at the waist with the knees bent, and Postures F and G are crouching/squatting postures.

We obtained image data for the seven identified postures shown in Fig.1, determined the measurement points based on the body measurements, and generated stick pictures, as displayed in Fig. 2. The solid lines in Fig. 2 indicates the stick picture, and the dashed lines indicate the reference lines.

(a) Posture E (b) Posture G

Fig. 2. Stick picture of posture E and G.

The joint angles of foot, knee, hip, shoulder, and elbow on a sagittal plane were calculated from each of these stick pictures. The angles of Posture E, as presented in Fig. 2(a), were foot: 8°; knee: 24°; hip: 119°; shoulder: 89°; and elbow: 116°. The angles of Posture G, as illustrated in Fig. 2(b), were foot: 35°'; knee: 148°; hip: 52°; shoulder: 48°; and elbow: 122°.

III. WORK POSTURE EVALUATION

To evaluate the work postures, it was performed a whole-body risk assessment using the Ovako working posture analysis system (OWAS) [7] and an upper limb risk assessment using the rapid upper limb assessment (RULA) [8]. The results are presented in Table II.

TABLE I: CLASSIFICATION OF WORK POSTURES

Posture	Trunk		Knee			Shoulder	
	90°≥	90°<	0°	90°≥	90°<	90°≥	90°<
A	✓		✓			✓	
B	✓		✓				✓
C	✓			✓		✓	
D		✓	✓				✓
E		✓		✓		✓	
F		✓		✓		✓	
G	✓				✓	✓	

OWAS can be used to evaluate the posture of the whole body. Recording and analysis can be performed immediately on site. OWAS captures the work posture at a certain point in time using four aspects: back, upper limbs, lower limbs, and load. The results are recorded as a coded four-digit number (posture code), and the risk is assessed on a scale of 1–4.

The OWAS score of Posture A was 1, indicating "no action required". The OWAS scores of both Postures B and D were 2, indicating "action required in near future." Postures C, E, F, and G have the highest risk for this task, with each having an OWAS score of 3, indicating "action required soon." This suggested that numerous postures in this task require improvement.

RULA is a survey method developed for use in workplaces where upper limb disorders have been reported. RULA scores are calculated for certain postures generated during work, and then the risk is assessed. Scores for the upper limbs (including upper arm, lower arm, and wrist) and lower limbs (including neck, trunk, and legs) are evaluated by adding scores for the time a posture is held for, number of times it is repeated, and force/load. Based on this, a final score is calculated on a scale of 1–7 (1, 2: "no action required"; 3, 4: "action required in near future"; 5, 6: "action required soon"; 7: "action required immediately".)

A risk assessment was performed by the RULA method using CATIA Human Builder and Human Activity Analysis. The evaluation parameters were set as follows. side: right, posture: static, and load: 2 kg.

All the postures resulted in high RULA scores of 5–7, indicating "corrective action required." In particular, the results for postures B and D, with the shoulder joint in the extended position, had wrist and arm scores of 7, indicating "action required immediately."

If the weight of the measuring device could be reduced by half, to approximately 1 kgf, then regardless of the upper limb posture, the upper limb score would be reduced by 2. This would improve the result from the "action required immediately" level to the "action required in near future" level. This suggests that the risk could be reduced by an assist suit that could support the weight of the measuring device.

IV. Structure of Assist Suit

Fig. 3 displays the structure of the developed assist suit. This assist suit consists of an upper limb frame to hold the posture of the upper limb handling the measuring device, a back frame connected at the shoulder of the upper limb frame, and a lumbar frame supporting the whole structure. It is fixed with straps at the waist, upper arm, and forearm.

The upper limb frame consists of two frames for the upper arm and the forearm. These are designed to fit the length of the average human body; therefore, there is no joint position adjustment mechanism. As presented in Fig. 4, there is a built-in ratchet mechanism for the shoulder and elbow joints, allowing the upper limb to be supported by fixing it at any position when the arm is lifted. The ratchet mechanism is released by pressing the index plungers at the shoulder and elbow to remove the pawl from the gear. The arm rest of the forearm frame has a part angled at 30 °, allowing the forearm and the wrist to lean on the frame.

The shoulder joint has separate rotation joints for outward/inward and inward/outward rotations. The frame also has a slide mechanism to correct the mismatch between the centers of rotation of the human body joints and the assist suit joints.

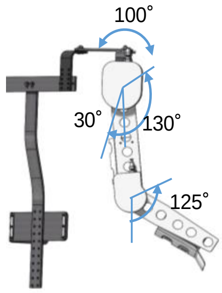
The range of motion in the shoulder joint is limited to 30 ° extension, 130 ° flexion, and 100 ° inward/outward rotation. The range of motion in the elbow joint is 125 ° flexion.

V. Evaluation Methods of Assist Suit

A. Adaptability

Five healthy adults participated in our experiment. The 3D motion analysis equipment, MAC3D System by NAC Image Technology Inc., was used for motion measurement. Markers were positioned at the left and right acromia, right elbow, radial and ulnar sides of the right wrist, and right third phalange. The joint angles of the shoulder, elbow, and wrist were calculated from the marker coordinates.

We evaluated the mechanism of the assist suit using an index indicating the ease of movement (adaptability) [9], as expressed in (1). Here, θ indicates the range of joint motion at not wearing the assist suit, φ indicates the range of joint motion at wearing it.



Weight	Whole	3.5 kg
	Upper limb	1.3 kg
Material	Upper limb	ABS resin
	Back	CFRP
Length	Upper limb	290mm
	Forearm	250mm
	Back	520～340mm *
	Shoulder height	80～50mm **
	Shoulder width	150～120mm **

* Adjustable at 20 mm intervals

** Adjustable at 10 mm intervals

Fig. 3. Structure of the assist suit.

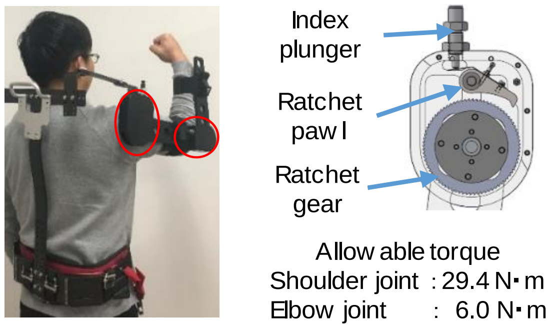


Fig. 4. Ratchet mechanism.

$$n = g(\varphi/\theta) \tag{1}$$

where

$$\begin{aligned} &\text{if} \quad g(\varphi/\theta) < 1 \quad \text{then} \quad g(\varphi/\theta) = (\varphi/\theta) \\ &\text{if} \quad g(\varphi/\theta) \geq 1 \quad \text{then} \quad g(\varphi/\theta) = 1 \end{aligned} \tag{2}$$

If φ is θ or more, then n is maximum, i.e., 1.

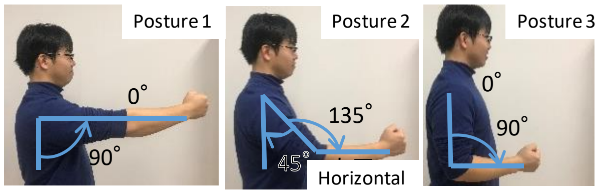


Fig. 5. Measurement postures.

Body part	Direction of motion	Human body (degrees)	Without suit (degrees)	With suit (degrees)
Shoulder	Flexion	180	130	110
	Extension	50	40	34
	External rotation	180	112	82
	Internal rotation	0	0	0
	Abduction	60	45	43
	Adduciton	80	60	43
	Horizontal flexion	135	104	90
	Horizontal extension	30	17	8
Elbow	Flexion	145	108	93
	Extension	5	0	0
Wrist	Flexion	90	55	55
	Extension	70	52	52
	Radial flexion	25	17	11
	Ulnar flexion	55	31	31

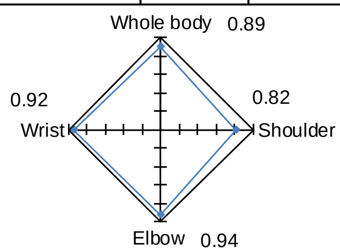


Fig. 6. Adaptability.

B. Rate of Reduction in Muscle Activity

Three healthy adult males (A–C) participated in our experiment. The measurement was performed in the three postures, as shown in Fig. 5, with the subjects not wearing and wearing the assist suit. The hand was loaded with a weight of 2 kg, to simulate the actual measuring device. Each subject held the posture for 20 s and then rested for 10 s; this was repeated a total of five times, and the surface electromyography (EMG) of each muscle was measured [10-11]. The measurement points were the anterior deltoid, biceps brachii, and flexor carpi radialis. The measurement device used was a Personal-EMG by Oisaka Electronic Equipment Ltd, and the electrode was a Blue Sensor Electrode by Ambu. The target for the analysis was a period of 3 s after holding the posture for 5, 10, and 15 s, and the muscle activity was determined from the integrated EMG (IEMG).

The reduction in the muscle activity when wearing the assist suit, R_E, was obtained from the following formula:

$$R_E = \left(1 - \frac{IEMG_{with}}{IEMG_{without}}\right) \times 100, \quad (3)$$

where subscript *with* indicates the subject is wearing the assist suit and subscript *without* indicates the subject is not wearing the assist suit. If the reduction rate, R_E, is a positive value, then the muscle activity is considered to be reduced by the assist suit.

VI. Test Results and Discussion

A. Adaptability

Fig. 6 presents the average values of the adaptability of the five subjects. The results exhibited that the adaptability is 0.82 for the shoulder joint, 0.94 for the elbow joint, 0.92 for the wrist joint, and 0.89 overall. The adaptability of the shoulder joint is the least because the shoulder joint of this assist suit restricts the internal and external rotations and the horizontal bending and extension directions. For the other parts, for all the subjects, there was no significant difference depending on whether they are wearing the suit. This confirms that this assist suit provides approximately 90 % of the degree of freedom of the human body.

Rate of Reduction of Muscle Activity

Fig. 7 shows the rate of reduction in the muscle activity for each posture. For Postures 1 and 2, there is a reduction of 50 % or more for the deltoid and bicep. This demonstrates that the muscle activity was reduced by wearing the assist suit. For Posture 3, the activity of the bicep was reduced by 59 % or more for subjects A and C, but only by 13 % for subject B. The lower value for subject B than those of the other two subjects was because the forearm could not be rested on the frame sufficiently owing to the insufficient adjustment of the assist suit. As for the flexor carpi radialis, for subject C there was a reduction of approximately 60 % for all the postures, but for subjects A and C the reduction rate was approximately 40%.

These results indicate that the assist suit can reduce muscular burden in the deltoid and biceps by approximately 60 %; therefore, we believe that wearing the assist suit should reduce the RULA risk assessment score by 1 point. The activities of the flexor carpi radialis muscle was no significant difference when wearing the assist suit.

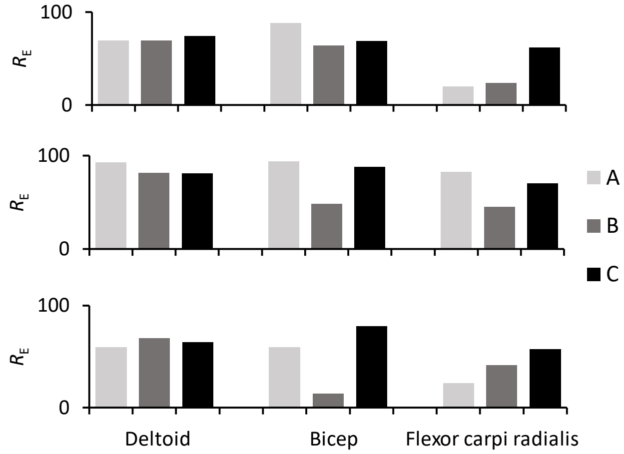


Fig. 7. Reduction in the muscle activity.
(Upper: Posture 1, Middle: Posture 2, Lower: Posture 3).

VII. Conclusion

In this study, with the aim of developing an assist suit to reduce the physical load involved in photosynthesis measurement work, we interviewed operators, performed a risk assessment of the work postures, and built and evaluated an assist suit. From the results of the interview survey, we found that the operators wanted the load on their upper limbs to be reduced. The evaluation of the work postures revealed that the postures for this task require corrective action immediately and involve high risks for the wrist and arm.

We quantified and evaluated the ease of movement in the ranges of motion of the joints and the physical load of the developed assist suit. The results demonstrated that there was no major difference in the adaptability with or without the assist suit. There was a reduction rate of 60% or more in the muscle activity for this task. Therefore, our assist suit is considered to be useful for the task of measuring photosynthetic capacity.

In our future study, we intend to investigate the adjustments of the upper arm and forearm to fit the operator, to reduce the burden on the wrist.

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