Method for Comparing and Verifying Physical Data Concerning Pruning of Plum Tree Branches by Wearable Sensing Systems

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***Abstract*—We have developed a multitudinous analysis system for agricultural applications. The system investigates and verifies the accuracy of kinematic direct sensing and visual analysis systems for workers and trainers engaged in pruning and shaping tree branches using small saws. The purpose of these activities is to improve ventilation and provide nourishment to trees more efficiently. In addition to aesthetic reasons, they also prevent infections in trees and stop the breeding of harmful insects. We used existing wearable sensing equipment that uses IPhone applications and MS Excel's VBA program to get the Fast Fourier Transform (FFT) of signals for obtaining the characteristics of the difference of motion between experienced and inexperienced workers carrying out various agricultural tasks. For this purpose, the Direct Current (DC) value and Standard Deviation (SD) of acceleration and angular velocity were used. As pruning of trees is a universal activity, our proposed system and methodology can prove to be useful around the world.**

***Index Terms*—pruning work, wearable sensing modules, acceleration sensor, angular velocity sensor, iPhone application**

I. Introduction

Agricultural informatics societies of several countries are making efforts to improve methods that characterize the motion of agricultural workers and their machinery. This has led to increased efficacies of agricultural works [1]-[8]. However, problems remain about the critical shortage of beginners in agriculture and their lack of skills. On the other hand, keeping in view the expansion and sophistication of methodologies, the field of agricultural informatics is certainly growing. To the best of our knowledge, no study on the pruning of branches of plum trees using special small saws, cutting branches of trees, forming shapes to improve ventilation, and the efficient provision of nourishment to trees is reported in the literature. The main aim of this study is the improvement of the analysis of physical motion in agricultural work. Our research utilizes electronic technologies, index data obtained from physical measurements, and feedback from practical workers and trainers. We obtained both immediate and distant time-line data and obtained sheet-based questionnaires before and after trials. Consequently, experimental studies of the bio-dynamic vibrations and responses related to physical data were conducted to optimize body dynamics and to develop scientific models representing specific aspects of body movements [9]-[14]. Despite the advent of new technologies, the characteristics and mechanisms of dynamic body responses are not fully understood yet. In the light of this background, we suggest the use of promising direct, wearable measurement systems. In particular, we use general acceleration and gyro sensors and iPhone application in obtaining and analyzing time-line physical data.

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II. Material and Method

A. System Designing, Creating, and Testing

After reviewing published literature (goods, patents, and academic papers), and discussions with actual workers and farmland managers, we reached the conclusion that past studies are insufficient for addressing current problems. For bridging this gap, we designed a system to measure and analyze acceleration data, angular velocity data, and visual data (3.5 meters from the subject) to obtain the entire motion of the body comprehensively. We executed enough volumes of indoor experiments to estimate their utility and suitability. Three multi-sensors (TSND121, ATR Promotions Inc., Japan), two Arduino UNO microcomputers (Arduino LCC, Italy), four acceleration sensors (MMA7361L, Freescale Inc., U.S.), four angular velocity sensors (ENC-03R, Murata Manufacturing Inc., Japan), and four Eneloop secondary batteries (SANYO Inc., Japan) were included in our wearable systems (Fig. 1, Fig. 2 and Fig. 3). All of them were wired by concrete lines. Additionally, we selected

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and utilized iPhone application (app) Accelerometer Data Logger (30 South LLC, U.S.) to detect subtle vibrations on subjects' lower arms (Fig. 4 and Fig. 5). The app can set measurement frequency (Hz), and both high- and low-pass filters to eliminate arbitrary power spectrums in unwanted ranges, and accumulate and send time-line data as a CSV formatted file attached with a common email.

Figure 1. An experienced subject wearing our wearable sensing system.

Figure 2. An experienced subject pruning a plum tree with a saw.

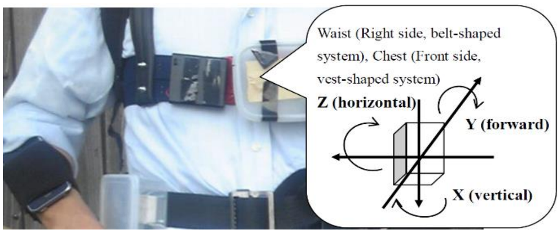

Figure 3. Location of the attached vest-shaped motion sensing system on a subject's chest, and the relative coordinate axis.

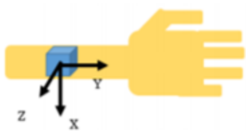

Figure 4. Location of the attached iPhone on a subject's dominant lower arm, and the relative coordinate axis.

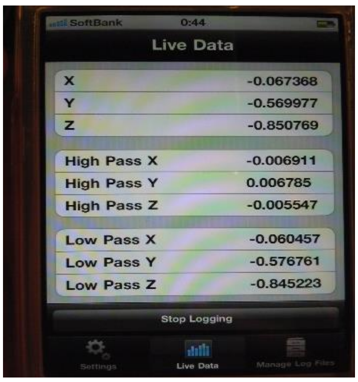

Figure 5. IPhone application "Accelerometer Data Logger".

B. Subject, Field, and Experimental Setting

The timeline of the trials was as follows: 1) waiting time from the previous setup, 2) waiting time, 3) trial time (about 60 seconds, five-nine pieces of tree branches), and 4) post-manipulation time. We executed hearings of the opinions from real farmland managers and searched past studies. We assume that those time spans and volume tasks are balanced trials. Sets of three trials were conducted successively on the same day with an interval of a few minutes between the sets. Before taking the main measurements, we conducted questionnaire-based interviews to obtain information as well as obtained information from lifestyle and health check sheets used all over Japan to monitor the fatigue and condition data obtained from the subjects.

We enlisted two male experienced workers and two beginners; they had no unusual mental and physical characteristics and diseases. Two of those subjects (one skilled and one beginner) had atypical body size for Japanese farmers. Keeping in mind the difficulty in enlisting subjects in this agricultural informatics field, we went ahead with the experiments. The skilled workers had career lengths of 11 and 13 years, ages of 34 and 41 years, heights of 164 and 173 cm, and weights of 71 and 73 kg, respectively. The inexperienced subjects had no experience in agricultural work, were 24 and 34 years old, had heights of 178 and 172 cm, and weighed 65 and 63 kg, respectively.

All four were right-handed and none of them had any recorded past serious physical disorders. The analysis of various physical data was impeded by the complexity of the structure of the human body, difficulties in taking measurements, and inter-individual differences in their responses. Therefore, concerning such studies, researchers have measured the movement and position of various bones, not of various muscles.

C. System and Theory of Data Analysis

We used a common TSND121 multi-sensor to measure acceleration. The multi-sensor was attached on the outer (right) side of a subject's lower arm using a stiff rubber band distributed by the aforementioned ATR-Promotions Inc., and the subjects' chest (over the heart), and placed centrally on the outside of both elbows using original wide bands and screws firmly. However, we recorded only the acceleration data from the hoe and ignored other accelerations, angular velocity, air pressure, and geomagnetic data, as we believe that acceleration is the most dynamic and characteristic variable for agricultural performance. These experimental settings are practical for use by general agricultural workers, directors, and managers to obtain time-series of visual data for diverse analyses of outdoor experiments with reference to past studies.

As for agricultural materials, field and other settings, various small, special saws are available for purchase worldwide. While they differ across districts, climates, and agricultural styles, the main differences lie in the form of the metal head and the haft. After adequate researches, we selected one saw type (U-M Industry Inc., Japan), because it was popular in the Kantou region in

Japan where our research was conducted. The saw weighed 717 g and had dimensions of 648 mm × 152 mm × 38 mm. The haft was made from stiff wood. The subjects grasped the saw with their dominant hand and the branches with the other hand. The targeted experimental field was situated in the graduate school of agriculture, University of Tokyo. In our opinion, the targeted trees were common and adequate for the trials.

III. Results

The results of this study were statistically analyzed and discussed [15]-[21]. First, we showed a set of analyzed data in the Microsoft Excel platform for Windows 10 OS that was handled by the program as previously described. Fig. 6 shows comparison of standard deviation (SD) and the direct current (DC) component from acceleration data related to experienced and inexperienced subjects' lower arm and chest.

On the other hand, Fig. 7 shows comparison of SD and the DC component from angular velocity data related to experienced and inexperienced subjects' lower arm and chest. (The directions of the three axes for all figures are shown in Fig. 3 and Fig. 4).

Fig. 8 and Fig. 9 show the closest data to the average related to the power spectra of vertical acceleration generated by experienced subjects. The statistical functions used in those analyses were given before in this paper. The acceleration data of the subjects' arm and chest indicated the dynamism and quality of the task. These graphs show the main differences between the two subject groups.

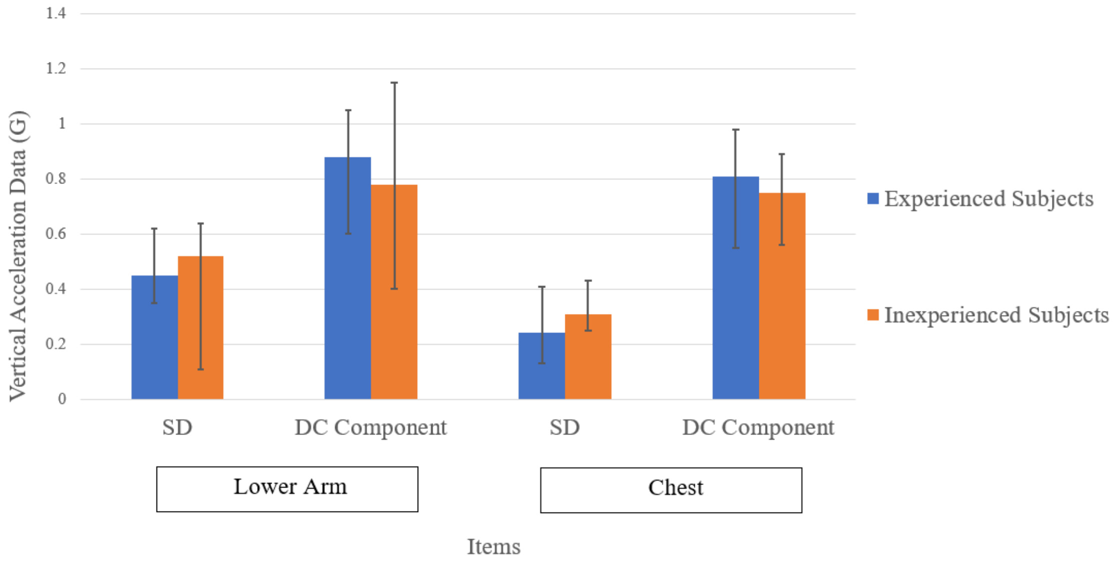

Figure 6. Comparison of SD and the DC component from acceleration data from experienced and inexperienced subjects' lower arm and chest.

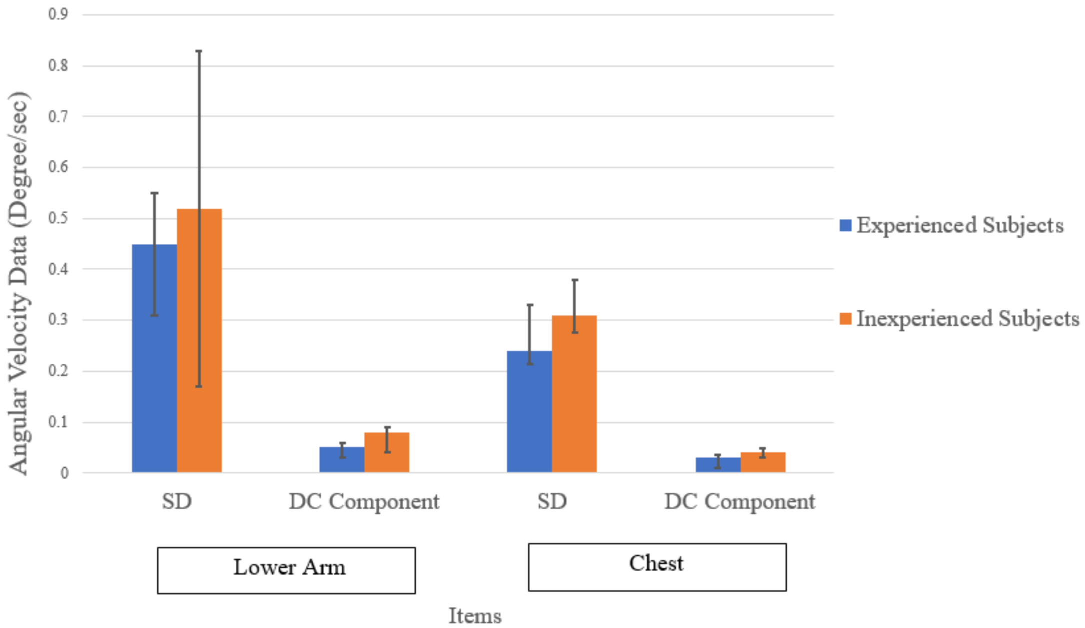

Figure 7. Comparison of SD and the DC component from angular velocity data from experienced and inexperienced subjects' lower arm and chest.

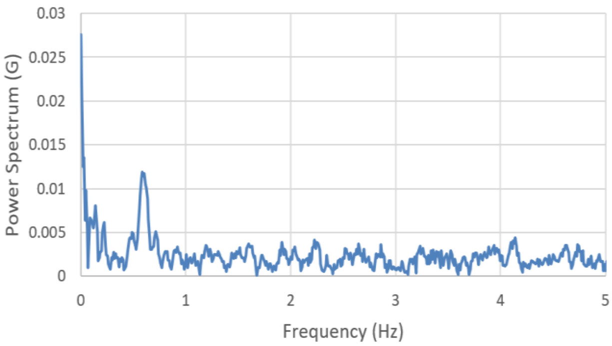

Figure 8. FFT analysis data from experienced subjects' lower arm acceleration data closest to the average one.

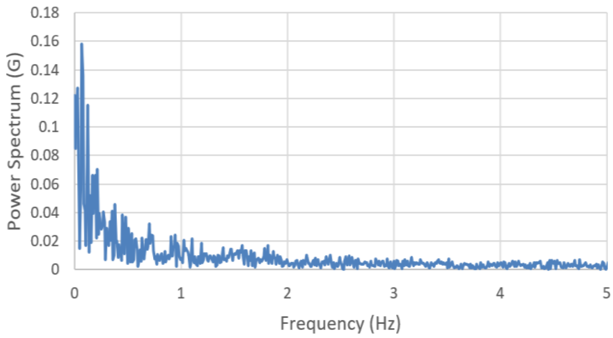

Figure 9. FFT analysis data from inexperienced subjects' lower arm acceleration data closest to the average one.

IV. Discussion

As mentioned earlier, we obtained the data in this study from contributions of agricultural workers and managers. Using this data, we confirmed the specific differences and variations of raw time-line acceleration, angular velocity time-line data, FFT analysis data, and captured video data. Overall, the value of SD and the DC component from experienced and inexperienced subjects showed complicated contrasts and differences, which can be crosschecked against video data shown in Fig. 6 and Fig. 7. In the FFT analysis graphs (Fig. 8 and Fig. 9), experienced workers showed greater peak eminent range (0.41–0.52 Hz) while inexperienced workers generated power-dense areas rather widely (0.05–0.18 Hz). According to Fig. 8 and Fig. 9, the range of power spectrum areas was limited to some extent. From the aforementioned captured video data, we observe and conclude that this is because the experienced workers' movements looked quicker and had higher-tempo than those of inexperienced workers. The experienced workers' working motion characteristics can be attributed to their long careers. As for the interval time of each set's pruning motion (the time interval between catching two branches), the experienced subject group's average value was smaller than that of the inexperienced group's. As for S.D. values of angular velocity data, the peak value of FFT analysis and the frequency range are valid indicators because we judged them as characteristic points, and we assessed workers' movements using them. This system might aid inexperienced workers in achieving diverse competencies and furthering their agricultural skills. We confirm and suggest that these systems may benefit not only agricultural users but also other manual workers in other fields, such as carpenters and traditional craftsmen.

V. Conclusion

We have developed methods for both surface and distant observations of agricultural workers. In this study, we have constructed and demonstrated a new system and have proposed practical measurement and assessment methodologies concerning users' motion in outdoor agricultural work sites. We targeted and presented various types of numerical data related to worker skills and performances in the common task of pruning plum trees branches. These systems analyzed three-axis acceleration and angular velocity data to provide useful indicators of almost full-body working movements of users, and can be used to record their skill progress. By focusing on analyzing the sequential traditional agricultural skills, we verified their usefulness and future validity. In addition, we obtained meaningful results, especially regarding the presentation of FFT power spectra and changes in physical data. Potential future work can deal with the durability, precision, and long-term performance of our system. For instance, we expect to increase the amount of physical information. Future studies should also investigate different parameters, such as different computer settings, trial timelines, agricultural tools, and field conditions. The proposed system has various features that can be used with the latest informatics, electronics, statistics, and human dynamics to contribute to improved agricultural practices. In addition, we hope that these new and promising methods and indicators will be applied to real working sites, included in the teaching of traditional techniques, and cover worker contributions. Our results may allow researchers in the field of human dynamics, agricultural personnel, and engineers from diverse agricultural systems to achieve high-level results with specific instruction.

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References

[1] P. Augustyniak, M. Smoleń, Z. Mikrut, and E. Kańtoch, "Seamless tracing of human behavior using complementary," *Sensors*, vol. 14, no. 5, pp. 7831-7856, May 2014.

[2] Y. Fujii, T. Nanseki, H. Kobayashi, and K. Nishitani, "Information management and cultivation of employee capabilities at large-scale paddy field farms: a case study of raising rice seedlings," *Agricultural Information Research*, vol. 21, no. 5, pp. 51-64, June 2012.

[3] Y. Fujii, T. Nanseki, H. Kobayashi, and T. Kojima, "The characteristics of expert know-how in agricultural planning on large-scale paddy field farms: A case study of a corporate farm in Shiga prefecture," *Agricultural Information Research*, vol. 22, no. 3, pp. 142-158, April 2013.

[4] T. Nanseki, S. Takeuchi, and Y. Shinozaki, "Business development, ICT use, and personal training in agricultural corporations: An analysis of nationwide questionnaire survey," *Agricultural Information Research*, vol. 22, no. 3, pp. 159-173, May 2013.

[5] A. Shinjo and M. Kudo, "The practical use of IT in agriculture: the movement into high-value-added crops and integrated solutions," *The Journal of the Institute of Electronics, Information, and Communication Engineers*, vol. 96, no. 4, pp. 280-285, April 2013.

[6] N. Wang, N. Zhang, and M. Wang, "Wireless sensors in agriculture and food industry—Recent development and future perspective," *Computers and Electronics in Agriculture*, vol. 50, pp. 1–14, September 2006.

[7] S. C. Mukhopadhyay, "Wearable Sensors for Human Activity Monitoring," *A Review: IEEE Sensors Journal*, vol. 15, no. 3, pp. 1321-1330, March 2015.

[8] E. D. Pritchard, Y. J. Lee, and L. Bao, "Mathematical learning models that depend on prior knowledge and instructional strategies," *The American Physical Society* (*Physical Review Special Topics - Physics Education Research*), vol. 4, no. 1, pp. 010109-1-010109-8, May 2008.

[9] P. P. Pradhan and S. P. Dhanure, "Child activity monitoring using tri-axial accelerometer," *International Journal of Advanced Research*, vol. 3, no. 6, pp. 222-224, June 2015.

[10] S. Qiu, Z. Wang, H. Zhao, and H. Hu, "Using distributed wearable sensors to measure and evaluate human lower limb motions," *IEEE Transactions on Instrumentation and Measurement*, vol. 65, no. 4, pp. 939-950, April 2016.

[11] N. Raveendranathan, S. V. Galzarano, R. Loseu, R. Gravina, M. Giannantonio, J. R. Sgroi, and G. Fortino, "From modeling to implementation of virtual sensors in body sensor networks," *IEEE Sensors Journal*, vol. 12, no. 3, pp. 583–593, March 2012.

[12] Y. Matsumoto and M. J. Griffin, "Dynamic response of the standing human body exposed to vertical vibration: Influence of posture and vibration magnitude," *Journal of Sound and Vibration*, vol. 212, no. 1, pp. 85-107, April 1998.

[13] S. Kawakura and R. Shibasaki, "Timeline effects of vocal instructions from computer programs on agricultural technical teaching," *Journal of Advanced Agricultural Technologies*, vol. 1, no. 2, pp. 104-112, December 2014.

[14] S. Kawakura and R. Shibasaki, "Supporting systems for agricultural worker's skill and security," in *Proc. Asian Conference Remote Sensing*, South Kuta, Bali, Indonesia, 2013, pp. 71-77.

[15] N. Funao, *The R Tips―Data Kaiseki kankyou R no Kihonwaza・Graphics Katsuyou Syuu*, Tokyo, Japan: Ohmsha, 2009.

[16] T. Kan, *Excel de Manabu Toukei kaiseki Nyuumon*, Tokyo, Japan: Ohmsha, 2013.

[17] T. Kan, *Excel de Manabu Toukeiteki Yosoku,* Tokyo, Japan: Ohmsha, 2014.

[18] T. Oomori, M. Handa, and H. Yadohisa, *R Commander Niyoru Data Kaiseki*, Tokyo, Japan: Kyouritsu Syuppan, 2014.

[19] P. Teetor, *R Cook Book*, Tokyo, Japan: O'Reilly Japan, 2011.

[20] N. Toyama and M. Tsujitani, *Jissen R Toukei Bunseki*, Tokyo, Japan: Ohmsha, 2015.

[21] T. Yamada and T. Sugisawa, *R Niyoru Yasashii Toukeigaku*, Tokyo, Japan: Ohmsha, 2008.

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