HIGH SPEED ULTRASONIC DETECTION SCHEME FOR SPORTS PERFORMANCE MONITORING

M. Zakir Hossain and Wolfgang Grill

Institute of Experimental Physics II, University of Leipzig
Linnéstr. 5, D-04103, Leipzig, Germany

To observe muscle performance of athletes with high resolution a novel ultrasonic detection scheme has been developed. It is based on bulk waves passing the monitored muscle. The detection is obtained along a line between two acoustic transducers with similar size and shape as stick-on electrodes, mounted on the skin. The time-of-flight from which all the data is derived is observed with the aid of a computer controlled arbitrary function generator and a synchronized transient recorder. An available separate channel can be used for synchronous monitoring of the force or pressure or the EMG-signals. The demonstrated movement and time resolution is ± 0.02 mm and 0.01 ms respectively. The equipment of lap-top size is battery operated and suitable for on-field monitoring.

KEY WORDS: Time resolved detection, ultrasonic detection scheme, quantification of sports performance, non-invasive monitoring of muscle performance.

INTRODUCTION: The high-level athletic performance achievement is increasingly associated with careful monitoring of all key dynamic and metabolic functions, both during the effort and during the recuperation phases. Novel ultrasonic detection schemes for motion monitoring have been reported lately. These include non contact monitoring by airborne ultrasonics (Barany, L. P. 1993) operated in reflection to detect the vertical component of any motion of the body surface (skin). Furthermore ultrasonic waves travelling at or near the surface have been used to monitor the dilatation of the skin (Juergen, 1993). Detection in the volume of the body has been realized for respiration related movements (Friedrichs, A.,Voegeli, F. 2006) with a demonstrated temporal resolution of about 80 ms.

Lately we have contributed to these developments with a detection scheme suitable for monitoring of muscle dynamics with a demonstrated temporal resolution down to 0.01 ms (Hossain, 2008). The system has also been used to monitor the sonic velocity under voluntarily activated muscle (Hossain, 2009). The observed variations of the velocity below 0.1% justify the here employed scheme to detect the muscle extension by variations of the observed time of flight (TOF). Monitoring is based on chirped ultrasonic wave-trains passing through the observed muscle. The TOF from which all the data is derived, is observed with the aid of a computer controlled arbitrary function generator (AFG) and a synchronized transient recorder (TR). The implemented software allows rapid and objective quantitative determination of relevant training parameters for evaluation and support of the optimization of the training procedures. The aim of this paper is to demonstrate the developed schemes including applications where the high temporal resolution is essential. Empirical fitting has been implemented to derive parameters demonstrating the capability to deliver quantitative and objective information to assess the monitored athlete's reaction time, muscle performance and energy expenditure.

METHODS: For the demonstrated measurements chirped pulses were employed to allow signal compression following the detection with the TR. The Lab-view based software facilitates selection of appropriate chirp signals, repetition rates and averaging during monitoring to enhance signal to noise ratio prior to processing.The athlete was instructed to isometrically contract the monitored gastrocnemius muscle with maximum possible effort and to hold the maximal contraction as long as possible and then suddenly cease the effort. The contraction was initiated by visual sensing of a thrown ball (Figure 1, left; enclosed in the small circle) at unpredictable time to determine the reaction time. To ensure the maximal isometric contraction, the knee joint was flexed at about 90° while sitting on a chair. To keep the upper body in fixed position, the athlete was instructed to grasp the chair from below with both hands (figure 1, left). Monitoring and evaluation was performed by custom developed LabVIEW software. Empirical curve fitting has been employed for data analysis.

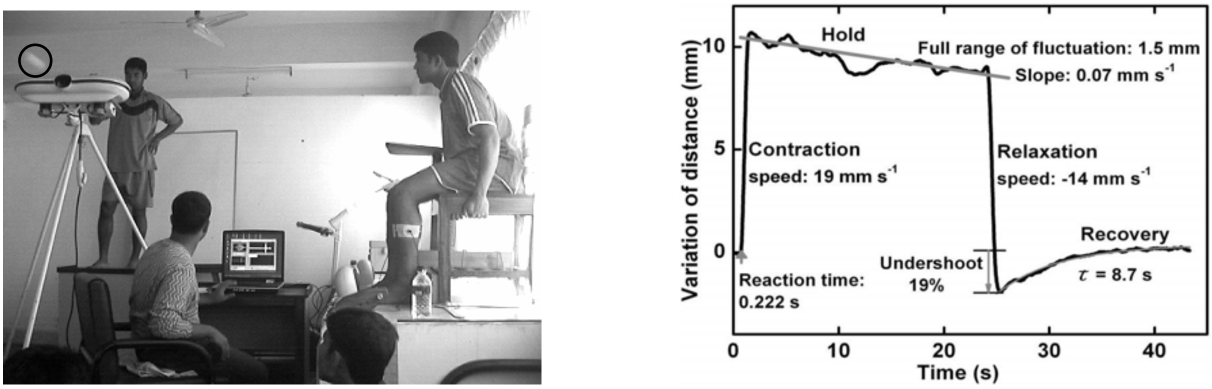

Figure 1. The image (left) shows the arrangement and data acquisition procedure of the continuous ultrasonic monitoring of the gastrocnemius muscle of an athlete and the graph (right) represents the results of the monitoring and data analysis.

RESULTS: From respective readings and fits as illustrated in Figure 1 (right) the reaction time was found to be 222 ms, the hold time 22.62 s, holding variations are within 1.5 mm and the slope of the observed drop is 0.07 mm s^{-1}. For the monitored muscle a contraction and relaxation speed of 19 mm s^{-1} and 14 mm s^{-1} respectively are determined. A fit to the recovery phase allows the determination of a time constant (τ) of 8.7 s for recovery from the initiated action which is a quantitative measure for the ability to recover from post isometric tetanus effect. The observed post isometric 19% undershoot represents also an example for a scientifically relevant result related to post isometric stretch (Brenner, 1990; Alter, 1996).

Contraction and relaxation data has been evaluated for a range of 2.25 s (Figure 2) together with the second order derivative to characterise the dynamics of the monitored muscle. For contraction three different stages, namely acceleration, constant speed and deceleration, are identified whereas for the muscle relaxation phase only two different stages, acceleration and deceleration, are observed and quantified.

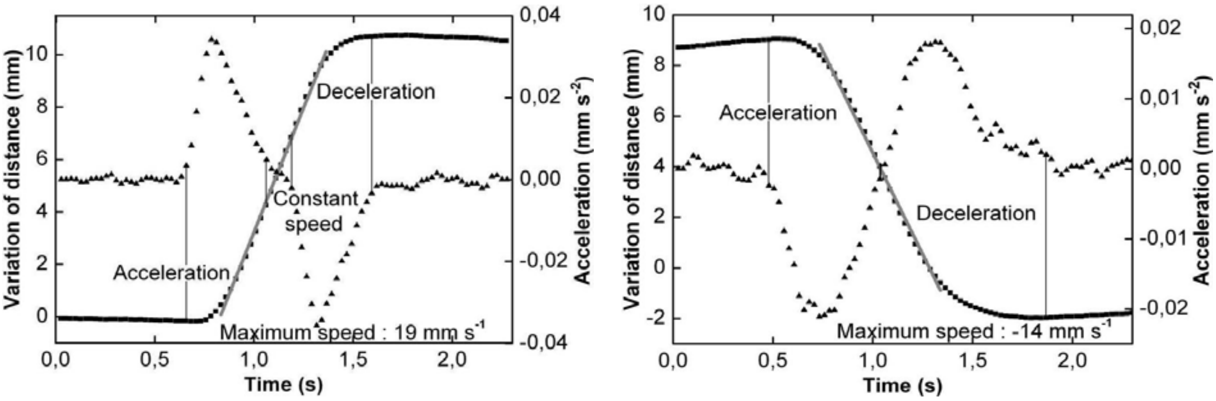

Figure 2. Displayed are the transients for muscle contraction (left) and relaxation (right) together with a second order derivative to evaluate the dynamics of the gastrocnemius muscle. The interpretation of the different phases is indicated.

Comparative study of pre and post physical loading session:

Studies have been conducted on maximal isometric contraction of the gastrocnemius muscle performance of five hockey players with an average age (18.4 ± 0.55) years, height (165.32 ± 1.55) cm, weight (60.38 ± 4.67) kg, and body mass index (BMI) 22.08 ± 1.5. Data have been recorded to observe the effect of pre and post exercise loading on the athletes. The session was organised as follows: gradual increase of speed from walking to running up to a speed of 12 km h^{-1} for 3 min after that 15 min of continuous running on a treadmill at zero grade Just after finishing the physical loading the monitoring was repeated. The athlete's total reaction time and the muscle dynamics were evaluated. The reaction was initiated with a thrown ball (figure 1, left; enclosed in the small circle).The time dependent lateral extension of the monitored gastrocnemius muscle is displayed for one of the athletes in figure 3.

The lateral extension of the muscle with elapsed time displays a sharp raise at the initial inflection point. The time from the visual stimulation to the onset of muscle movement of the monitored athlete, that is total reaction time for pre and post physical loading, is found to be 140 ms and 222 ms respectively. The following time span up to the second inflection point of the sharp rising curve represents the muscle contraction phase. A contraction speed of 5.3 m s^{-1} and 9.8 m s^{-1} is derived from the respective slope of the pre and post loading curve respectively. This is followed up to the third inflection point by a comparatively stable slope with a value of 0.001mm s^{-1} and -0.12 mm s^{-1}, which quantify the respective holding phases.

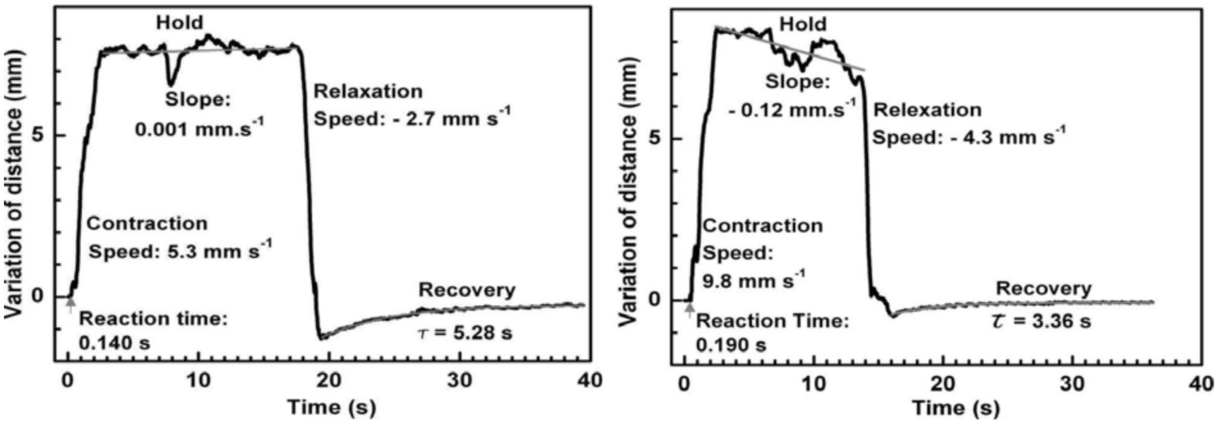

Figure 3. Monitoring for pre (left) and post (right) physical loading session. Displayed is the time dependence of the lateral movement of the gastrocnemius muscle.

The holding time was found to be 18 s and 16 s respectively.The falling slope between the third and fourth inflection points represents the relaxation phase. The muscle relaxation speed is -2.7 mm s^{-1} and -4.3 mm s^{-1} obtained from the respective slopes. Undershoots of 20% and 12% and recovery time constants of 5.28 s and 3.36 s are observed.

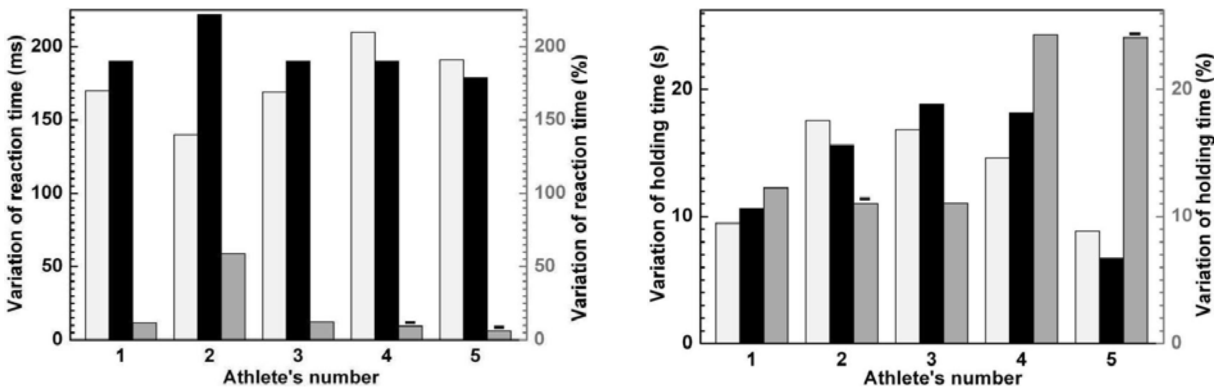

Figure 4. Pre and post exercise reaction time (left) and holding time (right) for 5 different athletes prior (light grey) and post (black) loading with respective variations (in %, right scales) indicated in dark grey. A minus sign above the bar indicates negative deviations.

The reaction times for the 5 monitored athletes are displayed in figure 4 (left). Only athlete number 2 shows a significant variation of the reaction time. The quantification of the holding time (Figure 4, right) for maximal isometric contraction depicts that athlete 1, 3 and 4 hold longer and 2 and 5 hold shorter after standard loading. Variations reach from ±10% to ±20%.

DISCUSSION: The system has been used for temporally resolved monitoring of the muscle performance during isometric movement of the muscle. The values of the reaction time obtained from the monitoring (140 to 222 ms) comply with reported reaction times to visual stimulus (Fieandt et al., 1956; Brebner and Welford, 1980). The developed ultrasonic monitoring scheme is suitable for isometric contraction which cannot easily be achieved by high speed camera monitoring. Different to EMG monitoring the additional delay from the nerve signal to the actual movement is included and can even be observed by synchronized detection of EMG signals. The result of the comparative study indicates with respect to the reaction time that the athlete number 2 is not well trained, since the exhaustion delayed the reaction after exercise significantly. Even though the holding times show a rather large variation for the different athletes, it is clearly indicated that athlete number 5 is not conditioned for endurance since the initially observed already comparatively short holding time dropped significantly by 20% after exercise.

CONCLUSION: The developed monitoring scheme has been applied for monitoring of the gastrocnemius muscle performance of athlete during isometric and isotonic contraction. It has been demonstrated that a quantitative analysis of the different stages of muscle contraction can be achieved. The comparative study results illustrate the possibility to obtain unbiased quantitative parameters to evaluate the performance of athletes. Empirical fitting procedures based on mathematical schemes have been employed for data analysis. Novel accessible parameters like muscle contraction speed, relaxation speed, slope and steadiness of the holding phase, undershoot due to the tetanus effect followed by a recovery. The respective results demonstrate that sports specific quantitative results can be derived from the data. The developed scheme provides a so far not reported temporal resolution.

REFERENCES:

Fieandt, K., Huhtala, A., Kullber, P., and Saarl, K.(1956). Personal tempo and phenomenal time at different age levels. Reports from the Psychological Institute, No. 2, University of Helsinki.

Welford, A. T. (1980). Choice reaction time: Basic concepts. In: A. T. Welford (Ed.), Reaction Times (pp. 73-128). Academic Press, New York.

Brebner, J. T. (1980). Reaction time in personality theory. In: A. T. Welford (Ed.), Reaction Times (pp. 309-320). Academic Press, New York.

Brenner, B. (1990). Muscle mechanics and biochemical kinetics. In: Squire JM (ed) Molecular mechanisms of muscular contraction (pp 77-149). MacMillan Press, London.

Barani, L. P. (1993). Ultrasonic non-contact motion monitoring system. Patent: US 5,220,922.

Juergen, M. (1993). Method for measurement of posture and body movements. Patent: DE 4214523.

Alter, M. J. (1996). Science of Flexibility, Third edition (pp 19-87). Human Kinetics.

Friedrichs, A., Voegeli, F. (2006). Device and method for producing respiration-related data. Patent: US 7,041,062 B2.

Zakir Hossain, M., Twerdowski, E., and Grill, W. (2008). High speed ultrasound monitoring in the field of sports biomechanics. Health monitoring of structural and biological systems, SPIE 6935-70.

Zakir Hossain, M., Voigt H., and Grill, W. (2009). Monitoring of variations in the speed of sound in contrac-ting and relaxing muscle. Health monitoring of structural and biological systems, SPIE 7295-16.

Acknowledgement

The development of the hard- and software employed here has been supported by ASI Analog Speed Instruments GmbH.