# Development of a System for Anatomical Landmarks Localization using Ultrasonic Signals

Janusz Kulon, Michael Voysey
Faculty of Computing, Engineering and Science
University of South Wales
Pontypridd, CF37 1DL, UK
j.kulon@southwales.ac.uk

Adam Partlow, Paul Rogers and Colin Gibson
Rehabilitation Engineering Unit, Artificial Limb and
Appliance Service
Cardiff & Vale University Health Board
Treforest CF37 5TF, UK

*Abstract— A review of the current protocols and techniques for the anthropometric measurements and postural assessment for wheelchair users and individuals with severe musculoskeletal problems was given. It was concluded that both contact and non contact methods have a number of significant limitations including time consuming measurement procedure, high cost and risk of excessive exposure to radiation. Many current approaches do not enable clinicians to accurately record and analyze the patient's musculoskeletal configuration. The challenge still remains to combine the body shape data with the precise identification and localization of anatomical landmarks for postural assessment. To address the need for easy to use, low cost, reliable measurement of anatomical landmarks ultrasound measurement system has been proposed. The main elements of the system are: ultrasound transmitters, receiver, digital-analog converter, signal conditioning equipment and laptop executing the signal processing algorithm. The prototype of the system was build and tested. The preliminary measurements of ultrasonic signals were realized and demonstrated the potential for this technique to be used in anthropometric and postural assessments in the future.*

*Keywords— Anthropometric Measurements, Localization System, Anatomical Landmarks, Ultrasounds, Time of Flight*

## I. INTRODUCTION

Poor sitting posture has been identified as one of the major causes of pressure sores, significantly affecting the function, comfort, physiology, and mobility of wheelchair users [1]. The consequences of poor musculoskeletal configuration upon health and well-being are many and varied including pain, tissue damage, skeletal deformity and impaired respiration [2]. Aside from the obvious health benefits, good musculoskeletal configuration is known to facilitate function. Currently the healthcare professionals undertaking postural assessments tend to use observations external to the patients to imply internal musculoskeletal configuration [3]. When conducted in the clinic, postural assessments are often subjective, and abnormalities are visually inspected. This form of qualitative assessment has low sensitivity and it is largely dependent on past experiences and subjective interpretations. In addition, the current assessment processes do not enable clinicians to accurately record the musculoskeletal configuration [4].

There are many objective techniques to measure musculoskeletal configurations [4]. However, these techniques either rely on the use of time consuming procedures, resource intensive equipment or the ability for the service user to stand so that a measurement can be captured. As a result, it is often very difficult to interpret, to record and compare subjective postural information with sufficient accuracy and precision to measure improvement or deterioration reliably. Techniques relying on imaging such as MRI, CT or X-RAY, for example, are very accurate in determining the underlying musculoskeletal configuration, however it is very often not practical to deploy these techniques in a clinical environment [5]. These techniques also carry a risk of increased exposure to radiation. Hence, the need for readily applicable and cost effective clinical tool that can accurately and precisely measure the anatomical features and help clinicians to identify changes in musculoskeletal configuration. The novel application which is investigated in this study is to use ultrasound signals to accurately measure anatomical landmarks. These skeletal landmarks can be also used to calculate clinical measurements such as pelvic obliquity/tilt/rotation, leg abduction/adduction, severity of spinal curvature and position of the head and centre of gravity. The paper is organized as follows. In Section II, the overview of the anthropometric measurements is presented. Section III gives a brief review of the relevant literature. The localization method and the measurement system are described in Section IV. The preliminary experimental results are presented in Section V.

## II. ANTHROPOMETRIC MEASUREMENTS

Anthropometry is the measurement of individuals physical characteristics, body shapes and functional capacities [3]. The anthropometric measurements are important for the ergonomic design of the industrial environments, clothing, consumer products, tools, equipment, architectural planning etc. The primary focus of this research, however, is on individuals with severe neuromusculoskeletal and postural conditions resulting in limited body movement. Many clients of Rehabilitation Engineering Units may, for example, suffer from spina bifida, cerebral palsy, hemiplegia, dysplegia muscle rigidity and are affected by cardiac or respiratory problems [6,7]. These clients often have little or no automatic postural control thus, specific requirements for anthropometric measurements and postural management. Wheelchairs fitted with custom contoured seating (CCS) systems are often prescribed to meet the postural and mobility needs of such individuals.
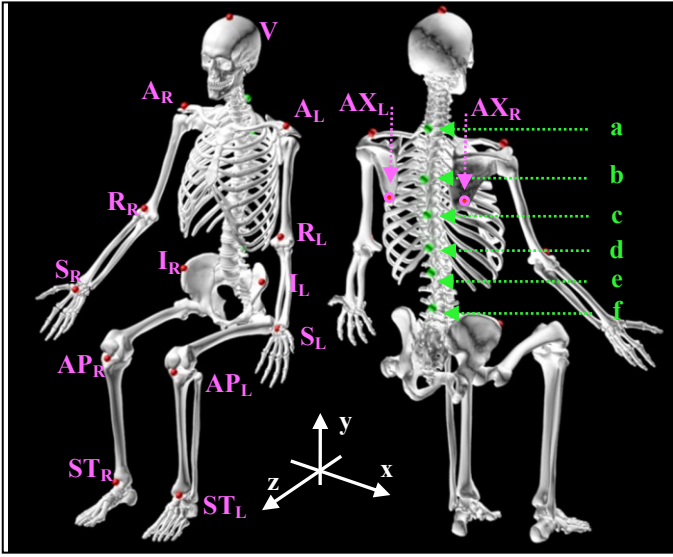
Fig.1. Anatomical landmarks on a human body measured during postural assessment. V-Vertex, {$S_R$, $S_L$}- Stylion , {$R_R$, $R_L$} – Radiale, {$I_R$, $I_L$} – Iliocristale, , {$A_R$, $A_L$} – Acromiale , {$AP_R$, $AP_L$} – Anterior patella, {$ST_R$, $ST_L$} – Sphyrion tibiale; where index L stand for left and R for right. (a-f) spinal markers. Image was generated using 3D interactive human model developed at the University of South Wales and based on skeleton mesh from Zygote Media Group Inc., Provo, UT, USA.

In clinical practice, posture assessments are conducted as part of the client's physical examination by experienced clinical engineers. First objective of the physical assessment is to determine if there are any barriers to achieving a functional, comfortable, upright seated posture. The anthropometric measurements taken during the assessment are also used in the design of the shape of CCS and the selection of the appropriate wheelchair and seating product dimensions. For instance, the clinicians may have to account for postural support pieces such as hip guides and lateral trunk supports that can add width to the client in the wheelchair. Anatomical measurements are taken in sitting, but it is crucial that the client is supported in the posture which will be assumed in the wheelchair. The anthropometric neutral seated posture is shown in Fig. 1. This is an optimal position used as a reference for recording actual postural/anatomical measurements.

The anatomical landmarks shown in Fig. 1 are identifiable skeletal points which generally lie close to the body's surface and are the 'markers' which identify the exact location of the measurement site. These landmarks include: A - acromiale (the point at the most superior and lateral border of the acromion process); R- radiale (the point at the proximal and lateral border of the head of the radius corresponding to the lateral dimple of the elbow), S - stylion (the most distal point on the lateral margin of the styloid process of the radius), ST - Sphyrion Tibiale (the most distal tip of the medial malleolus), I - Iliocristale (the point on the iliac crest representing the most lateral aspect of the iliac tubercle), AP - Anterior Patella (the most anterior and superior margin of the anterior surface of the patella identified when the knee bent is at a right angle) and V- vertex (the most superior point on the skull). In

addition a number of vertebra prominencs (a-f), which are palpable from the skin surface can be measured.

Table 1 shows the anthropometric measurements and their relationship to anatomical landmarks measured during the clinical assessment. Hip Width (HW) is used to assist in determining cushion width, seat width or width between side hip supports. Leg Length (LL) is measured to obtain seat depth and prevent seat base digging into calf muscles. Lower Leg Length (LLL), which is the distance between popliteal fossa and heel, determines the seat height and the placement of the footrests. Chest Width (CW) is used to calculate a distance between thoracic lateral supports, if required, and to ensure free upper limb movement. Axilla Height (AH), which is a distance between seat surface to axilla, effects the height of the thoracic lateral support. The maximum height allowed should be around 25mm less of this measurement to prevent impingement of axillary nerve [1]. Shoulder Height (SH) is a distance from the surface to shoulder. It is used to determine the backrest height from seat surface for those who use tilt in space for pressure management. External Knee Width (KW) is used to assist in determining seat width and footplate hanger style. Shoulder Width (SW) determines the minimum distance between arm supports, if upper limb positioning and arm supports are required. Head Height (HH) is a vertical distance from a horizontal sitting surface to the highest point of the head  known as the Vertex (V).

TABLE I.        ANTHROPOMETRIC MEASUREMENTS

| Symbol | Clinical Measurements | | |
|--------|------------------------|---------|------|
| | *Measurement* | *Formula* | *Unit* |
| SS | Seat Surface | Reference | cm |
| HW | Hip Width | $\left| II_L \text{-} II_R \right|$ | cm |
| $LL_R$ | Leg Length (Right) | $\left| AP_R \text{-} II_R \right|$ | cm |
| $LL_L$ | Leg Length (Left) | $\left| AP_L \text{-} II_L \right|$ | cm |
| $LLL_R$ | Lower Leg Length (Right) | $\left| AP_R \text{-} ST_R \right|$ | cm |
| $LLL_L$ | Lower Leg Length (Left) | $\left| AP_L \text{-} ST_L \right|$ | cm |
| CW | Chest Width | CW | cm |
| $AH_R$ | Axilla Height (Right) | $\left| AX_R \text{-} SS \right|$ | cm |
| $AH_L$ | Axilla Height (Left) | $\left| AX_L \text{-} SS \right|$ | cm |
| SH | Shoulder Height | $\left| A_R \text{-} SS \right|$ | cm |
| SW | Shoulder Width | $\left| A_R \text{-} A_L \right|$ | cm |
| HH | Head Height | $\left| V \text{-} SS \right|$ | cm |
| KW | Knee Width | $\left| AP_L \text{-} AP_R \right|$ | cm |

## III. RELATED WORK

### A. Anthropometric Measurements

Over the years, a number of techniques have been used to perform anthropometric measurements and postural assessment. These techniques can be grouped into contact and non-contact categories. The contact methods include simple

tactile devices such as anthropometric tapes, stadiometers or scoliometers [8]. Non-contact techniques are radiography [9], Moire´ fringe topography [10], structured light methods [10], laser scanning [11], pressure mapping systems [12] and mechanical displacement sensors [4]. The main disadvantages of the tactile devices are time-consuming procedure, a lack of 3D information and a patient's discomfort. The contact of a device with a skin of a patient may cause him/her to react and change body posture, which can have an adverse effect on the accuracy of the measurement [13]. The non-contact techniques usually have greater accuracy, often providing 3D shape data. However, the main disadvantage of these methods with regards to the sitting postural assessment is the requirement for direct exposure of an individual's back to the measurement instrumentation, preferably in the erect, standing position. In addition, the non-contact methods are often very expensive and difficult to deploy in a clinical environment. Finally, radiographs require medical approval and increase the risk of excessive exposure. There have been a number of studies reported in the literature using ultrasound to identify anatomical landmarks in an interrogated tissue (e.g. sacral hiatus for caudal epidural anesthesia in pediatric patients [14] or anatomic landmarks for soft tissue correction in the diagnosis of osteoporosis [15]). The main characteristics of these medical diagnostic techniques is the use of imaging modalities that relay on the interaction (reflection and scattering) between the medium and the ultrasound emitted into the medium. These modalities are not suitable for long distance localization of anatomical landmarks in the medium of air and therefore cannot be considered as a viable alternative to the method discussed in the paper.

## B. Postural Assessment

Assessment forms have been used to collect patient's personal data, wheelchair equipment, anthropometric measurements, and document evaluations of typical body postures [16]. Clinical engineers use these forms to record descriptive categories and numerical scores of musculoskeletal configurations. These categories include pelvic orientation (such as obliquity, tilt and rotation), head anterior/posterior tilt, lower limb position and spinal deformities [17]. Newer approaches to anthropometry and posture classification involve the simultaneous consideration of multiple dimensions through various types of multivariate analyses that include 3D human modeling [18]. Recent work published by the authors of this paper [6-7] described a bespoke feature extraction algorithms, which were developed to classify the musculoskeletal position of clients' pelvises and sitting postures. It was accomplished by extracting anthropometric features from a 3D body shape measurements captured in the Cardiff Body Match system. However, in spite of these advances, the challenge still remains to combine the body shape data with the precise identification and localization of anatomical landmarks for postural assessment.

## C. Precise Indoor Localization Systems

Many attempts to develop indoor localization systems have been reported in the literature. These systems make use of a range of technologies including infrared beacons, lasers, video cameras, Radio Frequency and ultrasonic signals [19-23].
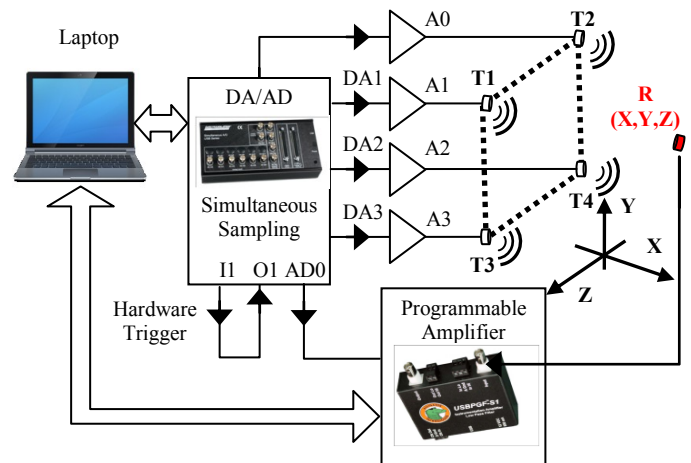


Fig.2. The measurement system for ultrasound localization of anatomical landmarks. Positions of anatomical landmarks, indicated by the receiver R(x,y,z).

An important limitation of video technology is the line of sight requirement, which means that video systems cannot be used in situations with the frequent blockage of the light by different structures and obstacles. Moreover, video localization is highly dependent on the camera resolution, which often results in poor spatial resolution. In comparison, ultrasonic methods can be used to estimate location with a high degree of accuracy at low cost. The accuracy is mainly due to the low velocity of ultrasound propagation coupled with the high resolution of Time of Flight (TOF) measurement.

To the best of our knowledge, no applications employing ultrasonic localization systems of anatomical landmarks have been reported in the literature.

## IV. METHOD AND EXPERIMENTAL SETUP

The prototype of the proposed Anatomical Landmarks Localization System (ALLS) is shown in Fig. 2. The main elements of the system are: four ultrasound transmitters (T1-T4), ultrasound receiver [R(x,y,z)], DA/AD converter, transmitter amplifiers [A1-A4], programmable receiver amplifier and a laptop running a signal processing algorithm. The transmitters are placed at the vertexes of a rectangular reference frame with known coordinates. The localization process can be divided into three phases: 1) signal transmission and measurement, 2) signal processing and 3) receiver position calculation. In the first phase, signals are transmitted and captured by the receiver placed in the location of an anatomical marker. In the second phase the signals captured by the receiver are digitized and processed to extract useful parameters such as arrival time, signal strength and frequency. A signal processing unit performs further signal filtering and validation identifying and discarding possible false signals due to echoes and environmental noise. In the third phase the physical position of the receiver is determined based on the signal parameters obtained in the second phase. The operation principle of ALLS is based on measuring the

absolute travel time (time of flight (TOF) of the ultrasonic signals from a transmitters to a receiver. The Euclidean distance between the receiver and the transmitters can be derived by the multiplication of TOF by the wave speed (i.e. speed of sound). Under normal conditions this is 340 m/s. In order to localize a position in a 3D space, trilateration requires at least three measured distances between the transmitters and the receiver. The receiver is at the intersection of the spheres whose geometric centres are the transmitter locations and their radii are the measured distances. Since the transmitters are placed on the corners of rectangular frame, one of the solutions is located in front of the frame, while the other solution is located behind it. The second can be discarded, or used for the cross validation of the results, because ultrasonic receiver is known to be in front of the reference plane. Assuming that transmitters and the receiver are synchronized, i.e. their clocks have exactly the same time without significant delays, if at the receiver of unknown position (x, y, z) TOFs to each transmitter is measured, then multiplying TOF by the speed of sound we obtain a set of distances from the receiver to each individual transmitter, $r_k$. From the equation defining a sphere of radius $r_k$ centered at each transmitter at position ($x_k$, $y_k$, $z_k$), a system of N equations (N $\geq$ 3) is derived, whose solution provides the receiver (x, y, z) position as shown below:

$$\sqrt{(x_{Tk} - x_R)^2 + (y_{Tk} - y_R)^2 + (z_{Tk} - z_R)^2} = r_k \quad (1)$$

where: $X_{Tk}$, $Y_{Tk}$, $Z_{Tk}$, are the coordinates defining the position of the k-th transmitter, $r_k$, is the distance between the receiver and the k-th transmitter, and $X_R$, $Y_R$, $Z_R$ are the coordinates of the receiver.

Once the receiver is localized, the position of the anatomical landmark can be recorded. The different component parts of the ALLS prototype are described below:

a) *Ultrasound Transmitters and the Receiver:* PROWAVE 328ST160 and 328SR160 respectively. The transmitters emit pulses in the 30 kHz - 40 kHz band and the center frequency 32.8 kHz. The transmitters maximum driving voltage is 20 Vrms.

b) *Signal processing unit:* a laptop PC running Matlab software (The MathWorks, USA) used both for generating the ultrasonic pulses that are emitted by the transmitters, and for acquiring, storing and analyzing the signals captured by the receiver.

c) *DA/AD converter:* DT9836 (Data Translation, MA 01752-1192 USA). A data acquisition module has four D/A and six A/D converters that can sample data simultaneously and continuously at maximum frequency of 225 kHz per channel for analog inputs and run at 500 kHz for each of the analog outputs. The module is equipped with three quadrature decoders, two user counter timers and 32 bits of digital I/O. All subsystems are synchronized to an on-board 36 MHz clock, isolated to 500 V and communicate with the PC via the USB interface. Each analog input has its own

A/D converter to eliminate phase shift between channels and to allow correlating measurements at the exact same instant in time.

d) *Transmitter amplifiers:* THS6012 (Texas Instruments, USA). The THS6012 has two high-speed drivers capable of providing 400 mA output current. These drivers can be configured differentially to generate a 50-VPP output signal. The drivers are current feedback amplifiers, designed for the high slew rates necessary to support low total harmonic distortion and are ideally suited for the amplification of signals to drive the transmitters.

e) *Programmable amplifier for the receiver*: USBPIA-S1, (Alligator Technologies, USA). The USBPIA-S1 is a standalone USB controllable module and provides a single channel of high-quality instrumentation amplifier and optional AC coupling, for front-end signal conditioning compatible with DA/AD converter. The USBPIA-S1 can be powered with 9 to 12 V DC so it can be connected to a battery voltage source or the supplied 115-220 V AC. The amplifier is programmable from the USB port USBPIA-S1 and provides software-selectable gain up to 1000 as well as differential inputs with high-common mode rejection.

V. PRELIMINARY EXPERIMENTAL RESULTS

In this section, we present preliminary experimental measurements of ultrasonic signals taken using the ALLS prototype as well as the signal processing algorithm.

Figure 3a shows a typical example of a sequence of four ultrasound signals which were synthesized in MATLAB and used to drive the transmitters. Each ultrasound burst consists of 137 samples generated at the maximum sampling rate provided by the DA/AD converter of 225 kSamples/s and contains approximately 20 sine-wave cycles of 32.8 kHz frequency. The duration of each ultrasonic burst signal is 0.6 ms. The time delay between consecutive signals was chosen to be 6 ms. This value was empirically determined to minimize the effect of acoustic wave reflections from the obstacles in the environment without compromising the time response of the measurement system. Figure 3b shows the corresponding train of acoustic burst signals captured by the receiver, filtered and normalized. The transmitters are placed at the vertexes of a square with 24 cm side length. The receiver was placed at known locations at the distance varied from 20 cm to 100 cm from the reference plane in X direction (see Fig. 2). A time listening window for each train of burst signals of 30 ms was chosen. It can be seen that the characteristics of the signal captured by the receiver changes both in terms of its envelope and duration. The TOF computation is performed using a Hilbert transformation (see Fig. 3c) of the received signal followed by the frequency threshold detection scheme. A number of preliminary measurements were conducted at different locations of the receiver with the absolute measurement of the receiver localization varying between 0.1 cm and 2 cm.
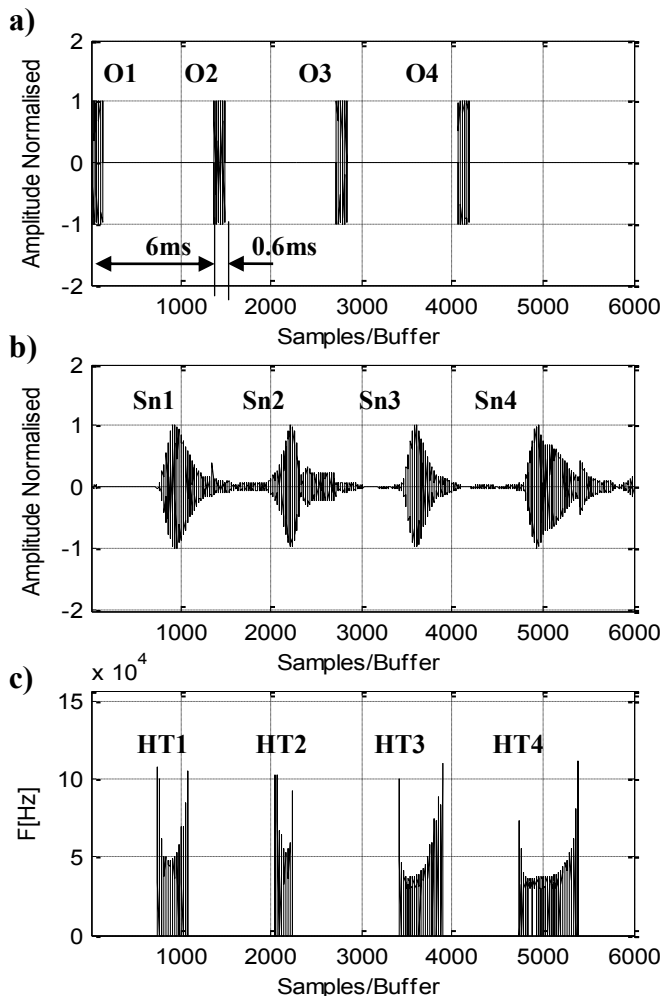
Fig. 3. a) Sequence of four ultrasound signals driving the transmitters, Each ultrasound burst contains approximately 20 sine-wave cycles of 32.8 kHz frequency. b) Train of ultrasound burst signals captured by the receiver; c) Hilbert Transformation of the ultrasound burst signals captured by the receiver.

More work is needed to refine the signal processing scheme, identify optimum shape of the ultrasound burst signals and account for any wave reflections and inherent delay which could be introduced by the system components during signal propagation.

## V. CONCLUSIONS & FUTURE WORK

The paper presented a review of the current protocols and techniques for the anthropometric measurements and postural assessment for wheelchair users and individuals with severe musculoskeletal problems. It can concluded from the literature that both contact and non contact methods have a number of significant limitations including time consuming measurement procedure, high cost and risk of excessive exposure to radiation. The design and preliminary experimental validation of the measurement system for localization of anatomical landmarks using ultrasound was outlined. The main advantages of the proposed system in comparison to other techniques of anthropometric measurements are: relatively low cost of the equipment, ease

of use and noninvasive nature of the measurements. In addition the proposed technique could be easily deployed in a clinical environment and does not pose any restrictions on the patient's posture and movement during the postural assessment session. Although the preliminary results are promising more work is needed to improve the accuracy of the system. The optimum arrangement of the ultrasonic transmitters with respect to the receiving transducers needs to be further investigated in order to achieve greatest space coverage without compromising the accuracy. The presence of echoes or environmental noise in the acquired signal remains a problem. The signal processing algorithm needs to counteract the effect of noise and acoustic wave reflections from the obstacles in the environment very likely to be present during clinical assessment. Further work is needed in order to refine the signal processing scheme and identify optimum shape of the ultrasound burst signals. Finally, a clinical validation of the localization system needs to be conducted including the development of a new measurement protocol for ALLS very likely to be different from conventional anthropometric data collection protocols.

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