In this paper a stride length measurement system is described which calculates the distance travelled of a running person. The basic principle is an ultrasonic distance measurement technique. Data from the electronic circuitry built into the shoes are transmitted wireless to a computer box which has the size of a pocket calculator. The system can be applied in the field of competitive or popular sport and also for observation of heart patients in the rehabilitation phase. During running the computer box displays online the distance travelled with an accuracy of about 5%. It can respond by acoustic signals if the runner does not follow a predetermined running speed profile.

**Introduction**

The performance of an athlete running on a cinder track is judged by measuring the time to run a predetermined distance. To stay on top athletes are under controlled conditions. However, it is almost impossible to determine the precise distance travelled and the comparison of physical conditions for the individual runs becomes very difficult. At this point the desire for a mileage meter or for a speedometer for joggers or cross-country runners has started to grow.

**Methods for distance measurement during running**

In this paragraph only methods which allow low cost implementation are considered. Furthermore due to the specific properties of the human kinetics during walking or running the theory of motion can be reduced to a single dimensional problem. By this simplification we assume the running path consists of a large number of linear segments. Each segment is characterized by the instantaneous stride length and direction.

**Mechanical stride counter**

Normally a spring loaded mass is used as a acceleration sensor and replaces the balance wheel of a watch. Each time a foot hits the ground the spring mass system is excited by the periodic acceleration. Quite similar to a watch the stride counter has two arms. The gear-ratio between the arms is either 1:100 or 1:1000. On the dial the number of accumulated strides are indicated by the two arms. To determine the running distance one has to multiply the number of strides by the average stride length. To find the average stride length a calibration run for a known distance is necessary. The distance must be divided by the number of strides measured. Mechanical stride counters are very cheap, robust and easy to use. The accuracy however is very limited because the stride length depends on the terrain and is not constant as assumed.

**Electronic stride counters**

The basic principle of operation is very similar to the mechanical counter part. The mechanism is replaced by electronic counters. Electronic pressure sensors in the running shoes or again spring mass systems with digital output signals are triggered by the periodic acceleration. A built in calculator converts the number of strides directly to the running distance which is shown on a digital display. Again a constant stride length is assumed and a calibration run becomes obligatory. Beside the more convenient readout all the limitations and restrictions apply as mentioned above.

**Distance measurement based on stride count and elapsed time**

In 1983 Prof. Cavanagh from Pennsylvania State University, USA, found a more precise way of measuring the running distance [1]. He discovered a relationship between stride count and elapsed time when athletes were running a constant distance at different speeds. Fig. 1 shows the result of four calibration runs which can be approximated by a straight line. This calibration function is specific for each individual athlete and must be determined by a series of test runs. For the convenience of the users software on a home computer has been developed which gives guidance for the calibration procedure. The athlete enters the results of the calibration runs in a dialog mode into the home computer. The calibration function is calculated by linear regression.
The measurement system itself is built into the heel of a running shoe and consists of an electronic stop watch and an electronic stride counter which is activated by an inertia switch[2]. After running the shoe is connected to the computer by a cable and the contents of stride counter and stop watch are transferred to the computer. Then depending on the elapsed time the proper stride length is calculated from the calibration function. Finally the product of stride count and stride length results in the running distance which is stored in conjunction with the actual date and additional remarks in a database. Comprehensive software is available for graphic presentation of the results [3].

By taking the calibration function into account a better accuracy of the running distance measurement is achieved. But even if the calibration procedure is done very carefully the errors may range up to 15%. Other drawbacks are the need for a home computer and the missing read out for intermediate results during running. Of advantage is the rather low hardware complexity of the measurement electronics.

**Continuous measurement of stride length**

**Basic principle**

For a training aid the errors of a distance and velocity meter should not exceed 5%. To achieve this accuracy the distance of each stride of a runner has to be determined and accumulated. Very soon we found out that a simplified system which measures every other stride will fulfill the requirements too.

Our approach was to develop a system which allows measurement of the distance between both feet at the moment the left foot hits the ground. Fig. 2 shows the system configuration. In the left shoe an ultrasonic transmitter and a radio transmitter are built in. The right shoe holds an ultrasonic receiver and a radio transmitter too.

**Calculation of stride length from feet distance**

During walking the feet distance is equal to the stride length. This does not apply for running. In Fig. 3 the difference between both motions is pointed out. During running we can notice a so called "flying phase", the period when neither the right nor the left foot are touching the ground. To calculate the flight time a lift off sensor in the right shoe and a touch down sensor in the left shoe provides the necessary information. The stride length can be calculated with the knowledge of feet distance, flight time and the time between two strides. The equation to model the motion sequence also takes into account empiric constants which have been determined by extensive tests of athletes on a treadmill. By a data acquisition system a large number of parameters have been collected and stored on a magnetic disc for statistical evaluation.

![Fig. 3: Difference between walking and running motion.](image)

**Implementation**

**System components**

The measurement system is comprised of three major components (Fig. 4):

- **computer box**
  This unit receives timing information from both shoes by a radio receiver and calculates the stride length. A built in temperature sensor measures the outside temperature in order to correct the velocity of sound. An alphanumeric LC display provides a read out for the dialog with the user and displays the distance travelled and also the instantaneous velocity.

- **left shoe**
  The electronic circuitry built into the sole consists of a radio transmitter, an ultrasonic transmitter and a touch down sensor.

- **right shoe**
  Similar to the left shoe a radio transmitter is built in. The rest of the electronics is distinguished from the left shoe electronics by an ultrasonic receiver and a lift off sensor.
Results and conclusions

A stride length measurement system has been developed up to the state of prototype in cooperation between PUMA AG in Herzogenaurach and the Fraunhofer-Gesellschaft (AIS) in Erlangen, Germany. The cooperation was based on contract research [4]. The prototypes have been field tested by PUMA with positive results. The accuracy was about 5% under normal running conditions (speed, style). A very strange running style or excessive high running speed may result in larger errors.

In order to start mass production the computer box must be reduced from the size of a pocket calculator to the size of a wristwatch. Furthermore some problems related to mass production have to be solved in order to provide low cost devices.

References

[2] Pirner, Hagelauer, "Sportliches" Gate-Array, Elektronik, Nr. 9, 1985, Franzis-Verlag München

Implementation aspects

The running shoe sole does not leave much room for electronic circuitry. Therefore the circuitry has to be built very compact. This also applies for the lithium battery which has to power the electronics for the life-time of the shoes. Extremely low power consumption and an automatic power shut down if the shoe is not moved within 20 seconds are important requirements.

The frequency selection of the ultrasonic signal depends on the position resolution, the attenuation of the signal while propagating through the air, the size of the transducers and the necessary distance to the audible spectrum. The final trade off resulted in a 40 kHz frequency for which low cost transducers are already commercially available.

For the radio frequency we had to make a similar decision. The long wave range was promising because very compact magnetic antennas can be used. Furthermore the postal regulation are less severe below 150 kHz. In our compromise we decided for the frequency of 140 kHz.

Potential application areas

In the area of competitive sport our developed measurement system serves as a valuable training aid for top level athletes which had no means of objective evaluation of their running parameters before. In addition to the data collection a predetermined velocity profile can be followed by the athlete if acoustic signaling is informing the runner about his performance.

But also in the field of popular sport, joggers indicated their interest in a reliable milage counter, which allows them to monitor their physical performance on a day to day basis. For this application a low cost system is the most important aspect.

A very interesting application is to observe the reentry in sport activities of patients, which have suffered a heart attack. In this rehabilitation phase any overload condition is very dangerous. On the other hand daily physical training like jogging is a necessity. To prevent over-exertion an individual running programme can be tailored to the patient. Acoustical signals provide a feedback to the patient and warn if the limits are exceeded.

This method can be substantially improved by integrating the measurement of heart rate, and, possibly, additional physiological parameters.