Adapting Magnetic Resonant Coupling Based Relative Positioning Technology for Wearable Activitiy Recogniton

Gerald Pirkl, Karl Stockinger, Kai Kunze, Paul Lukowicz
Embedded Systems Lab, University of Passau, Germany
www.wearable-computing.org

Abstract

We demonstrate how modulated magnetic field technology that is well established in high precision, stationary motion tracking systems can be adapted to wearable activity recognition. To this end we describe the design and implementation of a cheap (components cost about 20 Euro for the transmitter and 15 Euro for the receiver), low power (17mA for the transmitter and 40mA for the receiver), and easily wearable (the main size constraint are the coils which are about $25mm^3$) system for tracking the relative position and orientation of body parts. We evaluate our system on two recognition tasks. On a set of 6 subtle nutrition related gestures it achieves 99.25% recognition rate compared to 94.1% for a XSense inertial device (operated calibrated, euler angle mode). On the recognition of 8 Tai Chi moves it reaches 94 % compared to 86% of an accelerometer. Combining our sensor with the accelerometer leads to 100% correct recognition (as compared to 90% when combining the accelerometer with a gyro).

1 Introduction

Posture and motion of body parts are well known to be a key component of many human activities. Therefore, a significant proportion of research in activity recognition is based on posture and motion information. However, technology for capturing body motion and posture (often referred to as motion tracking systems) is still far from being perfect. A much cited overview of such technologies ([9]) is titled "No silver bullet but a respectable arsenal". From wearable application point of view the problem is that many of the best technologies in the 'respectable arsenal' require stationary, often bulky infrastructure and are not suitable for wearable use. Today, the core of wearable activity work still relies on accelerometers which capture only a small part of posture and motion information (see Related Work below).

General Idea Existing magnetic field systems (e.g. the "flock of birds" system from ascension: www.ascension-tech.com) require a bulky, power consuming stationary transmitter and cost thousands of dollars. In our system both the transmitter and the receiver consist of a couple of cheap components (price of all components 20 Euro for the transmitter and 15 Euro for the receiver) consume a reasonable amount of power (17mA for the transmitter and 40mA for the receiver), and are easily wearable (the main size constraint are the coils which are around $25mm^3$).

Our work is based on the observation that the requirements the system must fulfill to be a useful tool for activity recognition are very different from the requirements for which stationary magnetic systems have been built. Stationary magnetic systems target sub centimeter precision, high speed tracking over ranges of up to 3 meter. On the other hand, for activity recognition, the system merely needs some sort of relative position related signal over short distances (50 to 80cm). The signals do not have to be the actual position and orientation values expressed in any standard units. They just need to be deterministic and reproducible.

Paper Organization The paper first describes the physical principle behind the system and outlines and justifies the assumptions behind it. It then provides a detailed description of the implemented system including the discussion of different design alternatives and problems. We finish with a three step evaluation of the system. First we conduct an analysis of the signals produced by our system. Second we compare the performance on a simple gesture classification task against the Xsens MT9 inertial tracking sensors. There our systems gets 99.25% recognition rate compared to 94.1% for a single MT9 and 97.28% for a system of 3 MT9 sensors. Finally we demonstrate the benefit of combining our sensor with an accelerometer on a more complex activity recognition task: the classification of Tai Chi moves. Starting with a recognition rate of 86% for the accelerometer, and 94% for our system the combination of the two leads to 100% correct recognition (accelerometer/gyro combination 90%).

Related Work The use of accelerometers for motion based activity recognition is motivated by the availability of cheap, low power, easy to handle sensors. The disadvantage of accelerometers is that they are able to capture only a small part of motion and posture information. On the vertical axis they mix the gravity component (=vertical orientation) with 'true' acceleration. On the horizontal axis they capture only

978-1-4244-2638-6/08/$25.00

speed changes, but no orientation information. Other common sensors are gyroscopes and magnetic field sensors. The former capture rotational motions but give no information about translation and orientation. The later capture the absolute relative orientation with respect to the earth magnetic field. The most advanced wearable motion tracking technology are so called MARG (Magnetic Rotation Gravity e.g. [2]) system that combine 3D acceleration, 3D gyroscope and 3D earth-magnetic field with appropriate algorithms to deliver the absolute orientation of the device. Different commercial MARG systems exist (e.g. Xsens www.xsens.com) and cost in the range of 1000 Euro per unit. They work well for many applications however they are sensitive to disturbance caused by magnetic fields (e.g. caused by 50Hz mains currents). Also they provide no direct relative position information. Instead the information must be derived from several sensors on adjoining body parts through trigonometric calculations. Another technology that gives information about the relative orientation of body parts are elongation or bend sensors integrated in the user's garment (e.g. [7]). It has also been proposed to use capacitive sensors to measure joint angles [1]. A stationary magnetic tracking systems has been used in a large backpack for a wearable application by [5]. A magnetic tags based interface for music has been proposed in [8].

In previous work [3] our group has already demonstrated a simple onbody measurement using the magnetic resonant coupling principle (measurement of elbow angle). However this was done with a 1D system ignoring orientation. We had also not done an evaluation on a recognition task. Finally, the system was a simple first prototype with none of the hardware optimizations described in the paper.

Paper Contributions As described above the general principle on which this work is based is not new and even has been initially demonstrated for simple on body measurements before. The contribution of the paper is to demonstrate that (and how) a system based on this principle can be built that is suitable for wearable use and useful for activity recognition. By useful we mean that the system leads to better recognition rates than comparable wearable sensors (accelerometers or MARG), which we demonstrate empirically. While the system is simple in terms of the numbers of components, it involves a number of non trivial design issues. These are discussed and the resulting solution described.

2 System Concept

2.1 Physical Principle

The principle behind our sensor is that of 'resonant magnetic coupling'. The sender generates a magnetic field that oscillates with certain well defined, narrow frequency. This can be achieved by driving an appropriate coil/capacitor combination with a sinusoidal current of the desired frequency. This field carries energy which falls with rising distance. The receiver contains an LC oscillator circuit (in essence a coil and capacitor) tuned to precisely the same frequency. As a consequence the oscillating magnetic field induces a voltage in the receiver coil. The magnitude of this voltage depends on the relative orientation of the sender and receiver coils and the distance between them. Thus, it can be used in principle as a relative positioning system.

Compared with other positioning systems resonant magnetic coupling has a number of interesting properties:

1. The attenuation of an oscillating magnetic field is reasonably independent of the environment. The main loss mechanisms are so called 'eddy currents'. These are circular currents induced in conductors exposed to changing magnetic field. The amount of energy loss depends among others on the volume of the material so that small volume metallic objects cause only little disturbance. There is no need for line of sight between receiver and the sender. Human body causes virtually no disturbance.
2. Since the receiver is resonant circuit tuned to a narrow frequency environmental, magnetic fields (e.g. caused by the AC current of household installation) and stationary magnets do not disturb it. This is in contrast to sensors utilizing the earth magnetic field (like most MARG trackers) that are highly sensitive to the described disturbances.
3. Unlike a radio frequency (RF) based system, a magnetic resonant coupling system does not radiate energy. In our system there is no antenna and thus no RF transmission [1]. The magnetic field build up by the coils is fully 'retracted' as the energy flows back into the electric field of the capacitor during the next oscillation cycle. Apart from the damping losses, the only energy that is extracted from the system is the energy needed to induce the voltage in the receiver's coil and any energy lost due to eddy currents as described above. Thus relatively strong signals can be generated without excessive cost in terms of energy consumption.
4. The energy in the magnetic field attenuates with distance r as $1/r^6$. At first this appears to be disadvantage, as the range of the system is obviously limited. However, we need to remember that for on body applications we hardly need ranges of more than 1m (a sender placed in the body center) and in many cases around 50cm is enough. At the same time the strong dependence on distance means that other disturbance have less effect on the measurement result. There are also no problems with reflections and multi-path propagation.

In summary resonant magnetic coupling is an attractive, robust technology for on body relative positioning.

2.2 Relative Positioning Principle

The down side of resonant magnetic coupling is the complex relation between signal strength and the relative position

[1] In reality cables and data lines act as parasitic antennas and some energy is indeed radiated.

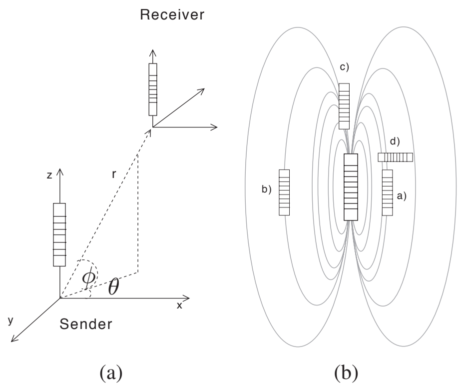


Figure 1. (a) Orientation and Distance overview. (b) Schematic Magnetic field with receiver coils.

and orientation of the sender and the receiver (another is the limited range which, however, is not an issue for on body systems). Thus, the main design issue is the ability to deal with such complex dependencies. To understand how this can be achieved we first define the degrees of freedom which we consider the relative orientation and position measurement. We then describe how the intensity of the signal at the receiver depends on this degrees of freedom. Based on this we describe the design of a relative positioning system.

Coordinate System and Degrees of Freedom The coordinate system on which discussion is based is shown in Figure 1(a). We assume the sender to be at the origin with a coil oriented parallel to the z axis. The location of the receiver in this coordinate system can be given spherical coordinates by a distance r from the origin and two angles θ and ϕ. In addition the receiver has its own local coordinates system. Again we assume a coil to be oriented along the z-axis. The orientation of the receiver with respect of the sender is the given by 3 angles α, β, γ that describe the rotation of the local coordinate system with respect to the global one.

Position and Orientation Dependence Given a specific coil and a fixed oscillation frequency the voltage induced in the coil is related to the number of magnetic field lines passing through the coil. Figure 1(b) shows the field line structure of a typical coil and illustrates the sources of signal strength variation. First, the density of the magnetic field lines decreases with increasing distance. Thus, everything else being identical, the voltage in a further away coil will be smaller (coil b compared to coil a). This is the $1/r^6$ dependence. Second, rotating a receiver coil in relation to the field lines reduces the effective area through which the field lines can pass and with it the induced voltage. Thus the highest voltage is induced in a coil parallel to the field lines while a coil perpendicular to the field lines has zero voltage (see coil d). Note, that rotations around the axis passing through the coil are not relevant. In our coordinate systems these are rotations around the z-axis of the local coordinate system (γ). Finally, the heterogenity of the field means that for a given distance and fixed orientation of the receiver with respect to the field lines the induced voltage depends on the location of the receiver around the sender (see coils a and c). The field is symmetric with respect to rotation around the axis parallel to the coil which is the z-axis of the sender coordinate system in Figure 1(a). Thus the location around the coil is determined by the angle θ in our coordinate system.

In summary the intensity of the voltage induced at the receiver depends on r, ϕ, α, β. An important thing to note is that the dependence is subject to symmetries with respect to 180 degree rotations in the x-y plane. Thus, for example, the field strength in coil a in figure 1(b) will not change if it is moved horizontally to the other side of the sender coil. This means that the relative position measurement is likely to contain ambiguities with respect to such 180 degree rotations.

Resulting Sensing System From the above it is clear that a system with a single sender and receiver coil will not be able to yield all six degrees of freedom the define the spatial relationship between the sender and the receiver. The most obvious solution is to use three perpendicular sender and receiver coils. The sender has to pulse the three coils sequentially. Each pulse induces voltage in all three receiver coils. A single measurement therefore results in a 3x3 matrix of signal strength values: three receiver coil values for every one of the three sender coil pulses.

$$\mathcal{M}_i = \begin{pmatrix} x_x & y_x & z_x \\ x_y & y_y & z_y \\ x_z & y_z & z_z \end{pmatrix} \tag{1}$$

In the above equation the suffixes refer to the sender axis that was pulsed and the 'normal' letters to the receiver axis on which the field strength was measured. Thus x_y denotes the strengths of the voltage induced in the x coil of the receiver by pulsing the y coil of the sender. The elements of the measurement matrix can in principle be used to derive all six degrees of freedom of the relative position.

Implementation Consideration In general there is no closed analytical expression that describes the relation between $\mathcal{M}$ and those degrees of freedom. In real systems the field structure is also likely to significantly deviate from the ideal shown in Figure 1(b). It is usually determined using complex numerical simulations. The results of such simulations can be used to build lookup tables or piecewise approximations for the relative position computations. In addition, the field would in general be 'shaped' through appropriate coil design that can make the computation easier and more exact.

Beyond such fundamental considerations there are a number of practical issues that make exact reliable distance measurement difficult. For one the $1/r^6$ attenuation means that the receiver side must support a huge dynamic range. While the signals for small distances are in the range of a Volt, the largest distance will results in sub μV values. The need to amplify such low voltage means that the system must be very carefully designed to avoid picking up noise from the environment. The stronger the signals that one tries to generate the more difficult it is to keep a clean signal shape. There are also a number of issues involved in the coils selection as the size of the coil is related to inductance which in turn determines the capacitor needed to achieve certain eigenfreqeuncy. Finally the need to pulse the sender coils can lead to crosstalk with inactive coils. It also require fast switching times between the amplification circuits to allow fast sampling rates.

Overall it can be said that building a sender/receiver pair that leads to some sort of relative position related voltage being induced in the receiver over short distances is easy. Turning such a pair into an exact distance and orientation measurement system working over larger distances is an entirely different type of problem, which explains the size, price and complexity of existing, stationary systems.

2.3 System Concept

The basic idea behind this work is that for a sensor to be a useful activity recognition tool it does not have to be much more then an *"sender/receiver pair that leads to some sort of relative position related voltage being induced in the receiver over short distances"*. The main considerations that lead to this assumption can be summarized as follows:

Range Many activities are determined by hand actions performed somewhere in front of the body. With an average male arm span of about 170cm (arms spread from fingertip to fingertip) for most such activities we can assume a distance between chest and the wrist (where the sender and receiver would likely be placed) to be in the range of 50 to 80cm. In many applications (e.g. nutrition monitoring) the hand comes into the immediate proximity of certain body parts, so that even smaller ranges (20 to 30 cm) would be sufficient. For leg related applications we may fix the sender on the belt and the receivers somewhere below the knee so that 50 to 80 cm range would also be enough.

System Output The fact that an activity is determined by the relative position and orientation of two body parts does not mean that the recognition system must know the actual distance and angle values in any standard units. In fact, in many systems the distances would be combined with other signals to define a lower dimensional, abstract feature space. What is needed is a signal that is (1) different for different relative positions and orientations and (2) reproducibly the same for the same positions and orientations. Thus in principle the elements of the measurement matrix $\mathcal{M}$ could be used as input to the recognition system. However it is well known that training a classifier on such 'raw data' that has a complex relation to the factors that actually separate the classes requires a large amount of training data and often produces poor results. As a consequence we define a set of values that are a clear indication of the magnitude of the 6 degrees of freedom, without actually providing a measurement in any standard unit (see section 3.3).

Accuracy The most common sensor location in wearable activity recognition applications are wrist, torso, arms and upper and lower legs. For routine a activities none of the above is moved with sub centimeter accuracies. In fact, for many activities, trajectories will vary by up to a few centimeters between individual executions. As an example consider bringing a bottle to your mouth for drinking and a wrist mounted sensors. Clearly, there will be applications (e.g. in high performance sports) where accuracy within a few centimeters is not enough. Our system does not target such applications.

3 System Implementation

The system consists of a single three coil sender and an arbitrary number of receivers (each also containing three perpendicular coils). As described in the previous section the sender sequentially pulses each coil and the receivers register the signal intensity on each of its coils.

3.1 Sender

The sender holds three orthogonally oriented coils and a signal generator circuit. To avoid interferences and magnetic coupling the coils are split up and spatially separated. The sender amplification board uses a square shaped input signal and transforms it into the 10 mA sine shaped output current applied to the coils. The sender sequentially puts the output signal on the emitter coils for 2.5 ms. As described in the previous section sequential pulses on the 3 sender axis are needed to deal with orientation dependence of the signal strengths.

In an initial version of the sender we used a quartz controlled signal generator to generate a 32 kHz sine shaped output current. Experimental evaluation has shown that high inductivity of the emitter coils lead to small range at this frequency. The maximum range was between 30 and 45 cm depending on the used transmitter coils.

To overcome this problem we moved to the 20 kHz frequency. A microcontroller sequentially puts the square shaped signal on the input channel of the x,y,z axis of the sender for $2.5ms$. To synchronize the receivers, the sender broadcasts a synch packet over an RF channel. Initially we tried to synchronise the receivers by using a synchronisation break after the x, y, z sequence. Unfortunately if the distance between the sender and the receiver is too high the signal-to-noise ratio made this type of synchronisation unreliable.

3.2 Receiver

Each receiver measures the magnetic field strength using three orthogonally orientated coils (Figure 2). Depending on the orientation of the receiver and also depending on the sender side axis which is currently generating a magnetic field three different voltage levels are induced at the three receiver coils. After signal regeneration (hardware filtering,

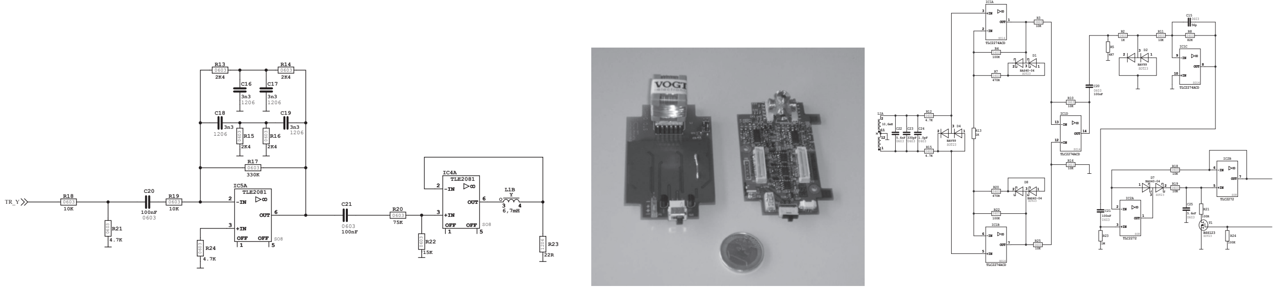


Figure 2. The sender schematics, sender and receiver,receiver schematics

amplification, signal rectification) the signal is presented to a 12 bit ADC of a Microchip DSPIC.

The induced voltage is filtered to remove the induced parts which do not lie in the interval of $[19500Hz; 20500Hz]$. A voltage rectifier transforms the ac voltage to a dc voltage. Depending on this input voltage level, the amplification circuit boosts the rectified input voltage. A hardware peakdetector and hold mechanism stores the maximum voltage level. The Microchip DSPIC digitalises the attached voltage and deletes the hold buffer. The microcontroller sequentially samples for each sender axis all 3 receiver axis and transmits the data with a connected bluetooth module to the data recorder. A complete measurement consists of 9 adc values. (Eq.1)

Initial Architecture Initially the receiver was based on a simple magnetic coil. After rectifying the signal, a logarithmic amplifier module rises the input signal for the receiver. This architecture was fine when we were working with just one coil. However for a 3 sender 3 transmitter system it was to slow due to the high saturation and falloff times of the receiver circuit which only led to a sampling rate of 50 Hz and low range performance of 45 to 50 cm at 20 kHz.

Second Receiver Version The second receiver version uses a different coil architecture: each axis consits of a pair of coils with a center tap. This allows us to use an operational amplifier with voltage dependent back coupling. The induced voltage is presented to a signal regeneration circuit which filters, rectifies and amplifies the input signal. The two step amplifier circuit automatically adjusts the amplification multipliers using diodes with different threshold voltages. If the input voltage is high (as it is in near distance measurements), the diodes reduce the amplification at the first and second amplifier to limit the voltage level. If the sender and receiver are far apart, the diodes are non-conductive and the amplifiers both rise the voltage.

After regeneration a hardware peak detector with hold mechanism stores the maximum voltage level. A transistor allows to clean the hold mechanism after reading the voltage level. We estimate the saturation and falloff times of this circuit which lead to a sampling rate of 106 Hz and a maximum range of 65 cm.

3.3 System Output

As described in section 2.3 as system output we do not use the raw measurement matrix but values that are more intuitively connected to the individual degrees of freedom:

1. The sum of all 9 elements of the matrix as indication of the distance.
2. The ratios of signals on pairs of receiver coils from a single sender coil (e.g. $\frac{x_x}{y_x}$) as indication of the angles α, β, γ by which the receiver is turned.
3. The ratios of signals received by a single receiver coil when transmitting with different sender coils (e.g. $\frac{x_x}{y_y}$) as indication of the angles θ, ϕ

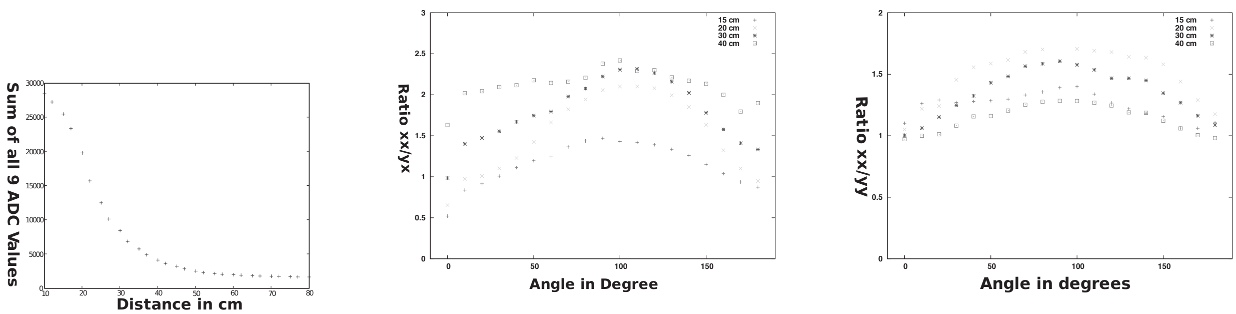
The parameters are based on the observation that when a decrease of the signal in one of the elements of $\mathcal{M}$ is caused not by increase in distance but by a rotation, then it is always accompanied by an increase of a signal on another axis. If the x coil of the receiver is parallel to the field lines and receives maximum signal then the y coil will be perpendicular and receives none. As we rotate the receiver around the z axis the x becomes gradually 'less parallel' while the y coil becomes 'more parallel'.

4 Experimental Evaluation

We evaluate our system in three steps. First we look at the distance and angle data to verify that the features defined in 3.3 display the desired qualitative correlation with distance and the angles. We also investigate the influence of envi-romental factors on signal quality. Second we compare the performance on a simple gesture classification task against the Xsens MARG sensors (euler angles on three body parts derived from 3D acceleration, 3D gyroscope and 3D earth-magnetic). Finally we demonstrate the benefit of combining our sensor with an accelerometer on a more complex activity recognition task: the classification of Tai Chi moves.

4.1 Signal Level Evaluation

Relation between Distance and Signal We place the receiver at a fixed position (and orientation) and increase the distance between the sender and the receiver in 2.5 cm steps from 10cm to a maximum of 80 cm along one reception axis. The orientations of both sensors are fixed.



(a) (b) (c)

Figure 3. (a) Low pass filtered sum adc value against distance, (b) Ratio $\frac{x_x}{y_y}$ at different distances, (c) Ratio $\frac{x_x}{y_x}$ at different distances.

After adding all 9 ADC values, we smooth the complete measurement set using a low pass filter and calculate the mean sum for each reference point.

The results are shown in figure 3(a). Between $[10cm; 40cm]$ the system shows a high resolution which flattens with increased distance. The gradient especially in $[10cm, 40cm]$ is adjustable by changing the hardware amplification multipliers. The signal to noise ratio in $[65cm; 80cm]$ is near one and therefore the maximum distance is about 65 cm.

The deviations between the 9 value sum approximation and

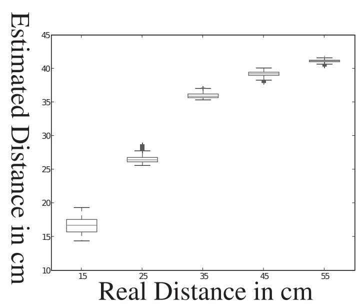


Figure 4. Influence of angle on distance approximation

true distance illustrated in figure 4. The y-axis shows a piecwise linear approximation based computation of the distance trained on the sum of the 9 values. To generate the figure we have placed the receiver at 15,25,35,45,and 55 cm and rotated it by 720° and compared the predictions of the piecwise linear approximation to the true distance.

Relation between Receiver Angle and the Signal We use a fixed sender position and orientation. The receiver is moved along a circle always pointing towards the sender. We record the adc values at discrete 10° steps around the receiver from 0° to 180° compute the signal ratios on the two relevant axes. The result is shown in Figure 3(b)

Relation between Sender Angle and the Signal In this experiment the receiver is centrally positioned, the sender is placed at the circle and moved along the circle around the receiver. As before, we record the adc values in 10° steps from 0° to 180° and compute the signal ratios on the two relevant axes (see 2). Figure 3(c) presents the results.

Sensibility to Disturbances Having attached the sender to the wrist and the receiver to the shoulder, we place different objects between the magnetic measurement system. The distance between the receiver and the sender is 23 cm. We label the measurements while the object is ”disturbing” the system. Reference value is the mean value of the undisturbed measurements. Table 1 presents the objects which have been tested how they influence the measurements.

Object	Δs
Arm	1.3%
Alu. angle bracket	3.9%
Screwdriver	−0.3%
Notebook	5.0%
metal plate	9.5%

Table 1. These objects have been tested how they influence the measurements.

Conclusion The analysis shows the expected performance: our values clearly depend on the respective degrees of freedom although they do not give exact measures with for example the ratios that we use for angle estimation varying with distance. Most important, the curves indicate that different positions and orientations will in most cases produce different values, as required for activity recognition.

4.2 Comparison to XSENS Systems

We compare the usefulness of our sensor for a simple gesture classification task to the Xsens MARG system. The Xsens system is among the most advanced wearable motion and posture tracking systems (cost around 1000 Euro per sensor) and is widely used in activity recognition research.

The selected set of gestures is motivated by our previous work on nutrition monitoring. It contains taking a piece of food to the mouth (Fig. 5(a)), drinking from a cup (b) and four gestures that are similar, yet nutrition unrelated: touching the chin (e), raking the nose (c), touching the earlap (d) and touching the forehead (f). All gestures involve a similar hand posture and differ in the wrist placement by less than 10cm. Thus the recognition problem is non trivial and tests assumption that although our system does not explicitly compute relative positions, it is able to separate subtle, spatial position related actions.

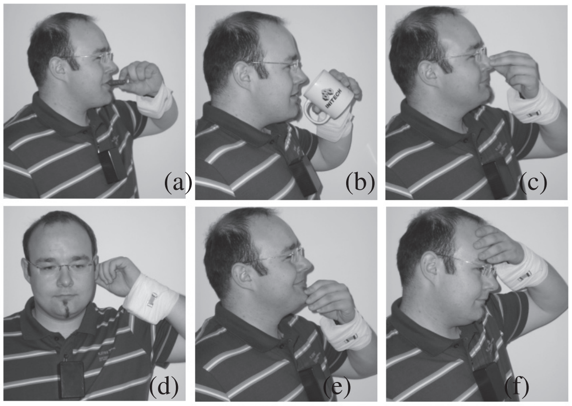


Figure 5. Gestures to be classified.

Experimental Setup The magnetic receiver is placed at the chest of the test person, the magnetic emitter at the forearm. The Xsens sensors are attached to the forearm, the upper arm and the torso. The use of three Xsens sensors is motivated by the fact, that the gestures are determined not by the wrist orientation alone, but by the relative position and orientation of the wrist to the body. Such a relative position and orientation is the information that our sensor captures. The three Xsens together capture the posture of the shoulder and the elbow which determine the relative position of the wrist with respect to the torso. During the recordings the test person keeps the arm at the same level. Each gesture is repeated 30 times. We only record data while the hand is at the current wished position and we do not record the way to the position and back to the start position of the hand.

Recognition Approach We train the Weka J48 Decision tree algorithm on the following features:

- Magnetic sensors: sum of all 9 adc values as rough distance estimation and $\frac{x_x}{x_y}, \frac{y_y}{y_z}, \frac{z_z}{z_x}$ as relative angle values, i_j is the adc value measured at receiver coil i while sender coil j is emitting the magnetic field. All these magnetic sensor values have been low passed filtered.
- XSens: Euler angles (roll,pitch and yaw) computed by the sensor from the 3D accelerometer, gyroscope, and magnetic field signals. The proprietary algorithm includes complex filtering to stabilize the signal.

Results We present the data on a frame by frame (framesize 1 - one measurement) to the decision tree. It has been trained with 50 percent of the collected data, the rest has been used for testing (test set 6500 Instances, overall recorded set: 13000 instances). The classification results for our sensor tracking the forearm, a single Xsens placed on the wrist, a single Xsens on the upper arm, a combination of an Xsens on the upper arm and the forearm, and all three Xsens is shown in the table below.

Sensor	Recognition rate
Magnetic sensor	99.3%
Xsens (all 3 sensors)	97.3%
Xsens (Forearm only)	94.1%
Xsens (Upper arm only)	93.7 %
Xsens (upper and lower arm)	96.9%

It can be seen that our sensors tracking the forearm outperforms a forearm mounted XSens by over 5% (99.3 % recognition rate to 94.1%). As expected all three XSens together perform best of all the XSens based configuration. However they are still 2% behind our sensor (97.3%).

4.3 Comaprison to and Combination with Accelerometers

Our next experiment focuses on a comparison with an accelerometer and more important on the evaluation of the usefulness of combining our sensor with an accelerometer. The investigation is motivated by the fact that in terms of sensor system complexity and price our sensor is more comparable with an accelerometer then with a 1000 Euro MARG unit. In addition, accelerometers are the most widely used activity recognition on body sensors and are increasing integrated.

As case study we take the recognition Tai Chi gestures. The choice is motivated by previous work ([6]) that has shown that Tai Chi and in general Kung Fu recognition using wearable motion sensors is feasible. At the same time we have seen that recognition is non trivial and far from perfect. Unlike the experiments in the previous section, the Tai Chi case study targets not static gestures but motions.

Experimental Setup The magnetic field sender is mounted on the wrist, the receiver mounted in the middle of the torso. One accelerometer sensor is mounted behind the sender on the forearm. The accelerometer was sampled with 50 Hz.

Our test subject is a relative novice to Tai Chi having around 5 years background in other kinds of Kung Fu. As we do not really want to access quality and are focusing on Tai Chi beginner form movements, this presents no problem. We recorded gestures from the beginner form of the Yang Tai Chi style. The Yang style focuses on health benefits. The effectiveness has been proven in several medical studies (see [4]).

The gestures recorded are: opening form, parting wild horse mane, single wip, grasping sparrow's tail, waving arms like clouds, high pat on horse back, brush knee, appear to close crossed hands. Each gesture was recorded 10 times.

Recognition Method For the analysis we calculate the features using a 1 sec. sliding window approach over the data. The features calculated are median, variance, 75% percentile, zero-crossing rate, number of peaks, mean peak hight, FFT

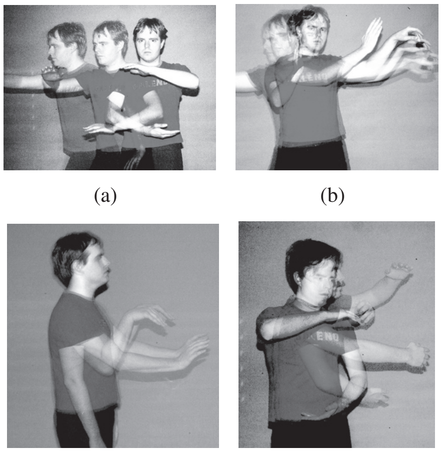

(a) (b) (c) (d)

Figure 6. Four recorded Tai Chi movements: Parting Wild Horse Mane (a), Single Wip (b), the Opening (c) and Moving Hands Like Clouds (d)

center of mass and the root mean square. From the magnetic field sensor we use the ratios between the axis and the sum, as described earlier. Concerning acceleration we use simply the three axis. For the magnetic field we use all features except the median and the zerocrossing rate. For the acceleration we use all features expcept median peak hight and fft center of mass. This leaves us with 6 features per modality. On top of the features calculated with sliding window, we train a KNN classifier with k=3 using a 33% to 66% percentage split for training and test data. The classification results are smoothed using a 10 sec. majority decision sliding window.

Results The results are summarized in the table below:

Sensor	Recognition rate
Gryo	64%
Acceleration	86%
Acceleration and Gyro	90%
Magnetic	94%
Magnetic and Acceleration	100%

As expected from previous experiments, classification just on the accelerometer data brings 86 % correctly classified. The magnetic field sensor is a bit better at 94 %. Combining the two modalities using the method described above, we reach a classification rate of 100 %.

5 Conclusion

The main conclusion of this work is that magnetic resonant coupling relative positioning is a useful activity recognition modality and can significantly improve recognition rates. It can do so in an implementation that is well suited for the wearable environment and in fact not more complex then current inertial sensor based system.

While we obviously do not claim that our system will be beneficial for all problem classes, we believe that there is a broad range of activity recognition task where relative position and orientation of body parts is an important information.

The next steps in our research are to increase system range through higher driving voltages and improve shielding of the circuit against RF noise. We will also apply the system to further recognition tasks.

References

[1] Ryan Aylward and Joseph A. Paradiso. Sensemble: a wireless, compact, multi-user sensor system for interactive dance. In *NIME '06: Proceedings of the 2006 conference on New interfaces for musical expression*, pages 134–139, 2006.

[2] Eric R. Bachmann, Robert B. McGhee, Xiaoping Yun, and Michael J. Zyda. Inertial and magnetic posture tracking for inserting humans into networked virtual environments. In *VRST '01: Proc. of the ACM symposium on Virtual reality software and technology*, pages 9–16, New York, NY, USA, 2001. ACM Press.

[3] M. Barry, A. Grunerbl, and P. Lukowicz. Wearable Joint-Angle Measurement with Modulated Magnetic Field from L/C Oscilators. *4th International Workshop on Wearable and Implantable Body Sensor Networks (Bsn 2007): March 26-28, Aachen,Germany*, 2007.

[4] Wang C., Collet J., and Lau J. The effect of tai chi on health outcomes in patients with chronic conditions: a systematic review. *Arch Intern Med.*, 1:188–189, 2004.

[5] A. Hamaguchi, M. Kanbara, and N. Yokoya. User Localization Using Wearable Electromagnetic Tracker and Orientation Sensor. *Wearable Computers, 2006 10th IEEE International Symposium on*, pages 55–58, 2006.

[6] E.A. Heinz, KS Kunze, M. Gruber, D. Bannach, and P. Lukowicz. Using wearable sensors for real-time recognition tasks in games of martial arts–An initial experiment. *Proc. IEEE CIG 2006*, pages 98–102.

[7] C. Mattmann, O. Amft, H. Harms, G. Troster, and F. Clemens. Recognizing Upper Body Postures using Textile Strain Sensors. *Wearable Computers, 2007 11th IEEE International Symposium on*, pages 1–8, 2007.

[8] Joseph A. Paradiso, Kai yuh Hsiao, and Ari Benbasat. Tangible music interfaces using passive magnetic tags. In *NIME '01: Proceedings of the 2001 conference on New interfaces for musical expression*, pages 1–4, Singapore, 2001. National University of Singapore.

[9] G. Welch and E. Foxlin. Motion tracking: no silver bullet, but a respectable arsenal. *Computer Graphics and Applications, IEEE*, 22(6):24–38, 2002.