EU PROJECT RESOLUTION
Reconfigurable Systems for Mobile Local Communication and Positioning

Frank Ellinger*, Jörg Carls*, Silvan Wehrli, Heinz Jäckel, Christian Kromer
Electronics Laboratory, Swiss Federal Institute of Technology (ETH) Zürich, Switzerland
**Will be with the Chair for Circuit Design and Network Theory, Dresden University of Technology, Helmholzstrasse 10, Dresden, Germany,*

Leif Wiebking, Alexander Dabek, Jörg Hüttner, Richard Roskosch, Roland Gierlich, Claus Seisenberger
Power & Sensor Systems, Siemens, Munich, Germany

Mario Huemer, Ralf Mosshammer, Thomas Uβmüller, Robert Weigel
Institute of Electronics Engineering, Friedrich Alexander University of Erlangen-Nuremburg, Erlangen, Germany

Viswanathan Subramanian, Marko Krcmar, Georg Böck
Microwave Engineering Group, Technical University of Berlin, Germany

Demosthenes Doumenis, Anastasis Kounoudes
SignalGeneriX Ltd, Limassol, Cyprus

Krzysztof Kurek, Yevhen Yashchyshyn, Rafal Szumny
Warsaw University of Technology, Poland

Antonis Kalis
Research and Education Society in Information Technologies, Athens, Greece

Elena Avatagelou, Anastasia Garbi
Exodus, Athens, Greece

Solon Spiegel
RIO Systems, Tel Aviv, Israel

Keywords: Local positioning, FMCW radar, RF, WLAN, integrated circuits, CMOS, BiCMOS.

Abstract: This conference paper gives a brief overview of the EU project RESOLUTION started in Feb. 2006. The goal is the development of a wireless three-dimensional (3-D) local positioning system with measurement accuracy in the centimeter regime. A novel frequency modulated continuous wave (FMCW) radar principle with active sensors is employed. This advanced local position radar will be co-designed together with common WLAN systems operating around 5 GHz. Because of the high positioning accuracy, real-time ability, and robustness against multipath effects and fading, novel applications will be feasible including smart factories, robotics, interactive guiding, object tracking and augmented reality.

1 INTRODUCTION

Since more than 50 years, radar based on the transmission and detection of RF waves is employed to locate plains, ships and submarines (James, 1989). Today, positioning services have been expanded and enhanced for guiding of cars and pedestrians, interactive maps, automated factories, robotics, augmented reality, etc. The following positioning methods are commonly used:

Ellinger F., Carls J., Wehrli S., Jäckel H., Kromer C., Wiebking L., Dabek A., Hüttner J., Roskosch R., Gierlich R., Seisenberger C., Huemer M., Mosshammer R., Ußmüller T., Weigel R., Subramanian V., Krcmar M., Böck G., Doumenis D., Kounoudes A., Kurek K., Yashchyshyn Y., Szumny R., Kalis A., Avatagelou E., Garbi A. and Spiegel S. (2006).
EU PROJECT RESOLUTION - Reconfigurable Systems for Mobile Local Communication and Positioning.
In *Proceedings of the International Conference on Wireless Information Networks and Systems*, pages 362-367
DOI: 10.5220/0002094203620367

- GPS (Global Positioning System) based on trilateralisation methods associated with satellites acting as reference transmitters.
- Cell-ID (Identification): position is estimated by means of the closest basestation.
- RSS (Received Signal Strength): distance d between reference transmitter and object is determined by the propagation loss being proportional to $\frac{1}{d^n}$ with n as channel-specific parameter.
- TOA (Time of Arrival): with given signal velocity c, d is measured with respect to the time difference Δt between transmitted and reflected signal:

$$d = \frac{1}{2} \cdot c \cdot \Delta t \,. \qquad (1)$$

- AOA (Angle of Arrival) by means of goniometry considering the angles of the signals.

Detailed information about positioning principles can be found in [Vos03, Sko90, Ell06].

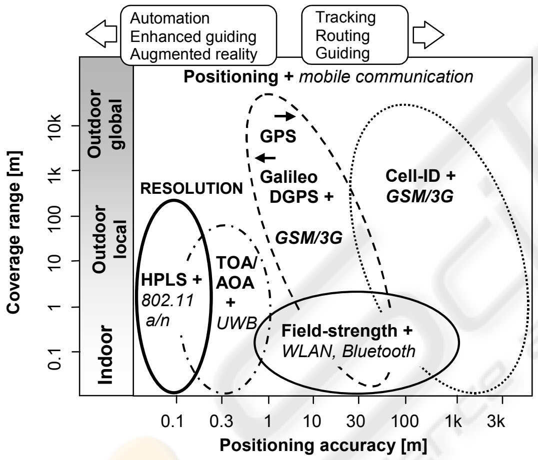

Figure 1: Positioning accuracy and coverage range of systems merging mobile communication and positioning, AOA: angle of arrival, HPLS: high precision localization system based on FMCW.

There is the trend to combine radio-location and mobile communications yielding enhanced and novel services. Examples of such systems are:

- GPS and GSM/3G
- Cell-ID and GSM/3G
- RSS and WLAN
- TOA/AOA and UWB

In Figure 1, the positioning accuracies and coverage ranges of these approaches are illustrated.

A novel positioning system based on FMCW radar is developed in the framework of RESOLUTION. First feasibility studies have indicated 3-D positioning accuracies in the centimeter regime. This would significantly enhance the state-of-the-art in terms of local positioning accuracy. Further advantages are real-time ability and self-sustaining operation independent on any external operator.

2 FMCW RADAR

Different FMCW systems will be considered in the RESOLUTION project. Potential approaches are discussed in the next paragraphs. The final choice of the architecture will be chosen with respect to market specifications.

2.1 Functionality

In Figure 2, a basic approach of a FMCW positioning radar is illustrated. An oscillator is modulated by a ramp generator yielding a reference signal, which is transmitted and reflected back. The transmitted and reflected signals are denoted by LO and RF, respectively.

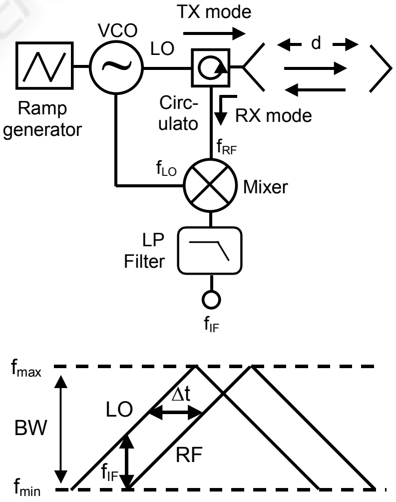

Figure 2: Functional principle of FMCW radar for positioning, TX: transmitter, RX: receiver.

Due to the time delay Δt, the two signals have a frequency offset f_{IF}, which can be extracted by mixing. Suppose that the mixer acts as frequency subtractor yielding

$$f_{IF} = f_{LO} - f_{RF} \,. \qquad (2)$$

Attributed to the linear dependence between d, Δt and f_{IF}, the distance can be determined by

$$d \sim f_{IF} \, . \tag{3}$$

According to Figure 3 we can identify three types of reflections. First, the desired one carrying the distance information. Second, unwanted multipath reflections. In the FMCW based approach, a major part of the mutipath components can be suppressed by lowpass filters, since the delayed multipath components have a higher IF frequency than the target object. Third, we have to consider reflections at undesired objects not hitting the target object. Approaches solving the latter problem are proposed in the next sections.

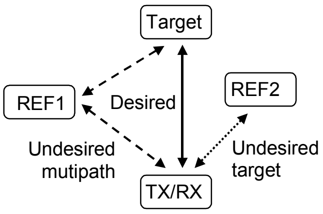

Figure 3: Types of reflections.

2.2 Basestations with Active Reflectors

This system consists of a basesation acting as transmitter and a compact and low-power consuming active sensor serving as reflector. In Figure 4, the schematic of the reflector is illustrated.

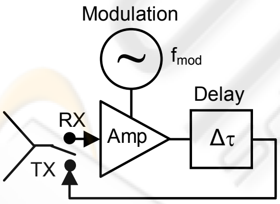

Figure 4: Active reflector with modulated signal.

The feedback amplifier acts as oscillator excited with the frequency of the input signal. By modulating the reflector, the reflected signal is associated with a specified modulation frequency f_{mod}. After filtering, the distance can be extracted on basis of the spacing between the two remaining frequency components located around f_{mod}. The corresponding relation yields (Wiebking, 2003)

$$d = \frac{\Delta f \cdot c}{f_{mod} \cdot 8BW} \tag{4}$$

with Δf being the frequency offset of the frequency components located around f_{mod}, and the bandwidth BW. Multiple objects can be detected by choosing different modulation frequencies.

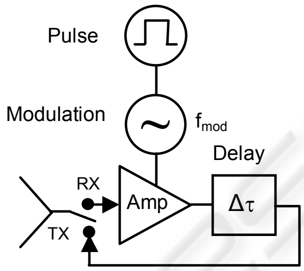

Figure 5: Active reflector with modulated and pulsed signal.

Active sensor topologies allow amplitude recovery of the signal resulting in enhanced coverage range. However, the measurement accuracy is limited by the jitter inherent in the reflector. By pulsing the modulated reflector, this jitter can be reduced. The corresponding circuit schematic is outlined in Figure 5. Note that at every switch-on, the oscillator frequency is coherent with respect to the input frequency. Consequently, the signal frequency is recovered at every pulse cycle.

2.3 Synchronized Frequency Ramps

The latter approach applies a compact, light-weight and low-cost sensor, which is advantageous. However, this sensor is not capable to act as transmitter. A solution with equal transceiver stations allowing for both transmit (master) and reflect (slave) function may be favourable for many applications. Efficient signal recovery can be performed in the reflector station. To enhance the performance, the incoming and outgoing signals are synchronized in the reflector. As for the latter approach, the distinction with respect to other objects may be performed by signal modulation or adding of an identification signal.

2.4 Conclusions

We can conclude that FMCW based positioning approaches with active sensors are capable to provide the following advantages:

- High measurement accuracy due to extraction in the frequency domain.
- We can clearly distinguish between target and arbitrary objects.
- Detection of multiple objects is possible.
- Efficient rejection of multipath effects by means of lowpass filtering in the frequency domain.
- Enlargement of coverage range by signal recovery.

However, we also have to mention the following disadvantages compared to approaches with passive reflectors:

- Active sensors consume dc power and require a battery.
- The complexity and costs are higher.

For many applications such as smart factories and interactive guiding, the latter properties are not a problem.

3 PARTNERS AND TASKS

The consortium combines multidisciplinary competences and resources from academia and industry including market-oriented service providers. It consists of 1 large enterprise, 3 small/medium size enterprises, 1 research institute and 5 universities, from 4 EU countries (2 of them new EU countries) and one associated EU country. Details including the key tasks of each partner are outlined in Table 1.

4 APPLICATIONS

The developed positioning system does not require any external service provider and can be applied for various applications. Two examples are smart factories and interactive guiding.

4.1 Smart Factories

A smart factory is based on knowing the position of every workpiece, fabrication tool, transport machinery or maintenance worker at any time and everywhere. Position tracking performed by a host enables several exciting new features:

- Complete overview over the location and amount of all supplies and tools included in the manufacturing process.
- By virtue of wireless networks, real-time data access is possible anywhere and anytime.
- Due to information transfer enhanced global management and product state monitoring is possible.
- The level of automated fabrication can be increased.
- Optimization of material flow and resource delivery.
- Less storage area and material consumption.
- Reduced fabrication time.
- Efficient use of fabrication tools and machines.
- Collision avoidance and increased security.

Table 1: Partners and tasks.

Partner	**Core Role and Competence**
1a. Swiss Federal Institute of Technology (ETH) Zürich, Switzerland, *U*	Preparations/proposal writing CMOS RF reflector design
1b. Dresden University of Technology*	Coordination CMOS RF transmitter design
2. Siemens AG, Germany, *LE*	Economic exploitation smart factories Demonstrator design Associate and market relevant project management
3. Technical University of Berlin, Germany, *U*	CMOS RF receiver design Experience with reconfigurable systems
4. University of Erlangen-Nuremberg, Germany, *U*	System engineering and simulations CMOS fractional-n synthesizers
5. RIO System, Israel, *SME*	Linearization and smart power control of power amplifiers
6. Signal Generix, Cyprus, *SME*	Signal processing, FPGA and baseband implementations
7. Warsaw University of Technology, Poland, *U*	Antennas Basic channel characterization and modeling
8. EXODUS S.A., Greece, *SME*	Economic exploitation cultural and interactive guiding
9. Research and Educational Society in Information Technology, *RI*	Algorithms for adaptive antenna combining including implementations

LE: large enterprise, *SME*: small and medium size enterprise, *U*: university, *RI*: research institute
*Participation is planned in Aug. 2006, meanwhile tasks are performed by ETH Zürich

4.2 Interactive Guiding

Real-time based active mapping, e.g. for advanced sightseeing, in museums, shopping malls and amusement parks are useful for guiding of pedestrians. The positioning is marked in a PDA based map and can be transferred to a server. Location dependent actions can be applied to increase the amusement and information quality. The services can be combined with location-aware billing, which decreases personnel costs and improves the billing system.

5 FIRST RESULTS

The project has just started. However, first experiments with the master/slave approach employing synchronized frequency ramps according to Section 2.3 have already been performed. A 1-D positioning accuracy of 20 cm at a coverage range of up to 20 m is demonstrated.

6 CONCLUSIONS

A brief presentation of the EU project RESOLUTION has been given, which aims to develop a localization system with 3D accuracy in the centimeter range on basis of FMCW radar.

REFERENCES

F. Ellinger, *Radio Frequency Integrated Circuits and Technologies*, Springer, to be published 2006.

R. J. James, “A history of radar“, *IEE Review*, Vol. 35, No. 9, pp. 343-349, 1989.

M. Skolnik, *Radar Handbook*, McGraw-Hill, 1990.

M. Vossiek, L. Wiebking, P. Gulden, J. Wieghardt, C. Hoffmann, P. Heide, “Wireless local positioning”, *IEEE Microwave Magazine*, Vol. 4, No. 4, pp. 77-86, Dec. 2003.

L. Wiebking, *Entwicklung eines zentimetergenauen mehrdimensionalen Nahbereichs-Navigations-Systems*, VDI Verlag, 2003.