HOCHSCHULE RAVENSBURG-WEINGARTEN UNIVERSITY OF APPLIED SCIENCES

Implementation of a GPS and GSM module into a Zynq Z7 SoC based emulator tracking system

Gregor Benz, Andreas Siggelkow

***Abstract*—As part of an ever-increasing fleet management system, the location information of the various vehicles is playing an increasingly popular role. For this purpose, an emulator of an outdoor localization system is to be presented as part of this work, which uses a Zynq SoC, a GSM and a GPS module to carry out the satellite time, the longitude, the latitude and a signal strength determination of the adjacent radio masts. The determined data can then be sent to a central evaluation unit as an SMS, via the GSM module.**

***Index Terms*—Automotive fleet localization, outdoor navigation, GPS, GSM, Zynq SoC, IoT**

I. Introduction

A. Motivation

Localization is an increasingly popular application of vehicle fleet mangement [1]. This can result in various advantages, such as increased security or simplified administration. Further savings in operating resources are possible because, among other things, fuel savings and automatic creation of the logbook are possible [2].

GPS-based outdoor localization systems are a suitable solution for this [2]. These systems provide a localization accuracy of up to 2 m and form an economically scalable system [3]. Since GPS-based localization systems are subject to interference such as jamming and spoofing, the implementation of a further satellite-independent approach is recommended [4]. In [5] various technologies, such as mobile radio, interactive sensors or radio-frequency identification (RFID)-based systems, are presented, which allow satellite-independent positioning in the outdoor area. Among other things, each system has a specific accuracy and infrastructure density. The emulator presented here pursues the approach of using a GSM-based position determination in addition to GPS-based localization.

In addition to commercially available GPS-based localization systems [2], [6], there are numerous publications such as [7]–[9] on this topic. Analogously, localization systems [10], [11] present a localization purely based on the use of GSM.

In addition to all of the publications mentioned above, this publication is intended to implement both positioning approaches in a Zynq SoC emulator. For this purpose, a GPS module should determine the time stamp of the satellite that is to be used as the reference time stamp, as well as the longitude and latitude. In contrast to this, the hard-wired GSM module is to carry out a signal strength measurement (RSSI) of the closest radio station and all adjacent radio stations. The measured coordinates, the signal strength and the time stamp are to be stored in a ring buffer arrangement in the DRAM. The measurement data should be passed on to a central evaluation unit by means of a GSM module. An evaluation to localize the emulator on the central evaluation unit is not part of this work.

B. Structure of this publication

The remainder of this paper is structured as follows: Section II gives an overview of the localization system that is to used maintain the functions of the emulator. Section III outlines the hard wiring and the implementation of the required functionality modules on the emulator SoC. The functionality of the emulator is also demonstrated here. Finally, Section IV concludes the work and gives perspectives on future topics.

II. Localization system overview

Almost all digital systems have a debug interface [12] with different possibilities to attack the system [13]. This debug logic connects all sub-blocks in the system by means of a shadow bus system in order to test or debug it. This could act as a back door which is not secured. To equip this back door and all connection points of the debug bus with a lock, is the focus of the demonstrator system introduced in the following. The lock can be a cypher system. Parallel to the debug problem is the update over the air possibility in such systems, especially modern cars (Jeep Cherokee, Heise 2015) and IoT. Also this door can be secured by cyphering.

To enable research in this fields, an application needs to be modeled first on a high abstraction level, SystemC is used, second, an emulator can be used, described in this paper and as a last step, the system can be implemented as a chip with a surrounding environment.

The demonstrator which has been chosen is a tracker system for a car fleet, e.g. Uber cars. The idea of the whole tracking system is shown in figure 1. Here we have the tracker consisting of a GPS receiver, a microcontroller, a power supply and a GSM transceiver. The GPS module receives the data from the satellites and forwards the position data and the time stamp to a memory location. The GSM module is requested to collect the power data and the corresponding base station IDs, which will be also stored in a memory. If a complete set of data has been collected, it will be send by means of the GSM transceiver to a server. The server stores everything in a database. Before storing the data, the server can calculate the position on base of the GSM data by means of triangulation. This position is not as accurate as the position got by the GPS system, but the signal is more reliable in case of GPS signal loss. The position of any car can be requested by any mobile device. Figure 3 shows the

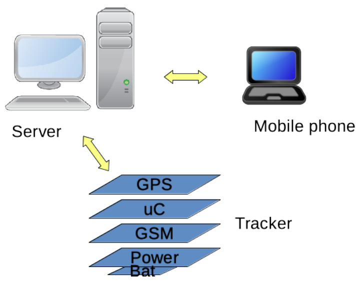

Figure 1. The complete tracking system

idea of the implementation. The microprocessor used in the tracker is equipped with an in-circuit- emulator (ICE) to be able to perform debugging. The memory needs a means to be able to make an SW update over-the-air (OTA). This is also some kind of debugging and a back door. The bus needs a BusWatcher. GPS and modem needs debug capabilities. So, all the blocks indicated with “Dbg”, “OTA” or “ICE” are connected via the debug bus and needs to be secured. The system

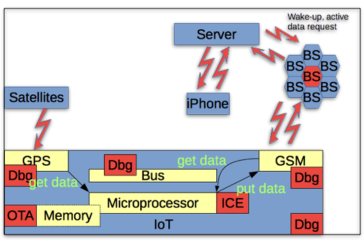

Figure 2. Tracking system with implementation details

emulator has been finished, until now without the debug capabilities, and is shown in figure 3. With the emulator it is possible to implement different debug elements and the corresponding cypher hardware to evaluate the security strategy. Here, only the functional elements have been implemented.

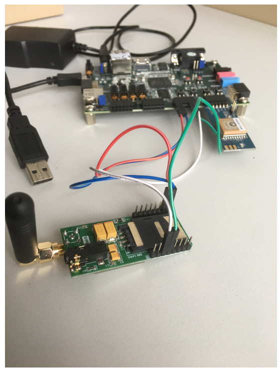

Figure 3. Tracking system on the emulator (Zybo)

III. Implementation and Functionality Test

A. *Zynq SoC*

The emulator presented here uses a Zynq-Z7 SoC from Xilinx [14] as the central processing unit, which is available on a Zybo Z7-20 evaluation board [15]. The architecture of the Zynq-Z7 used consists of a programmable logic (PL) and a processing system (PS), which enable data exchange via an AXI interface bus system [14].

The PL is an Artix-7 FPGA, the PS is an ARM-A9 dual-core microcontroller with separate L1- and L2-cache and a 256k on-chip memory (OCM). Various peripheral interfaces such as GBit-Ethernet, CAN, USB, Quad SPI Flash and GPIO are also provided [14], [16]. The system presented here uses only the GPIO, which are configured as two UART interfaces to read out the two evaluation units GPS and GSM. For each UART interface, 2 data lines are configured as transmitter (TX) or receiver (RX), as well as a 3.3 V supply voltage and GND.

While the PS transfers control commands for the two evaulation units (GPS and GSM) and evaluates the returned information, the PL is only used for signal transmission between the GPS/GSM module and PS.

Another task that the PS performs is storing the measured information (satellite time, longitude, latitude, signal strengths for the individual radio masts) in the DRAM, which is hard-wired from the Zybo Z7-20 [15]. Two ring buffers are configured for this (one for the data from the GPS module, one for the data from the GSM module). As soon as a ring buffer is full, old information is overwritten. Using a button (also GPIO, read from the PS) [14], [15], the last recorded measurement can be transmitted via the GSM module to a central evaluation unit via SMS and saved there. A position determination/evaluation based on the data of the GSM and GPS module takes place in the central evaluation unit, which is not presented as part of this work.

Possible future work may involve the migration of the control of the modules and evaluation of the returned information in the PL itself.

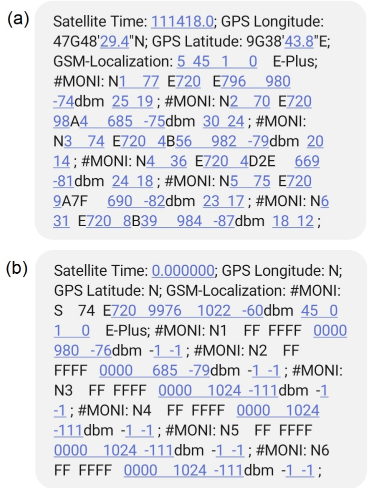

Figure 4. Two transmitted localization data packets after transmission via SMS to the central evaluation unit with detectable gps localization data (a) and non-detectable GPS localization data (b). Note: Each line is separated by a semicolon. The satellite time is preceded by the word *Satellite Time*. First/first two characters indicate the hour, next two characters the minutes, next two characters the second, then a point 0 is connected. If no position information is available, a 0.0 is output. The longitude is preceded by the word GPS Longitude. The letter G is used instead of a degree sign. If there is no position information, an N is output. The latitude behaves analogously to this, which is preceded by the word GPS Latitude. GSM localization is preceded by the word GSM localization. Each line has the following structre: #MONI: Cell BSIC LAC CellId ARFCN Power C1 C2 (Ta RxQual PLMN). The expressions in brackets are only available for Cell S.

B. GPS module

The GPS Pmod module from digilent [17], which communicates with the Zynq-Z7 SoC using the UART interface, is used to determine the GPS-based data. In [7]–[9] a wide variety of approaches are presented that can be used to locate a position using GPS. The difference between GSM position localization as presented below is that GPS performs an absolute position determination. Due to the high sensitivity ($-165\,\mathrm{dBm}$) of the selected receiving chip, an accuracy of up to $3\,\mathrm{m}$ can be achieved with an update rate of $10\,\mathrm{Hz}$ [17]. An update rate of a localiation routine is set to $60\,\mathrm{s}$. The requested information of the GPS location is the satellite time, which is used as a time stamp, and the longitude and latitude.

In the event that GPS is unable to determine the location (e.g. the emulator is located in the interior), which is a valid response from the GPS module, the satellite time is set as *0.0* and the longitude and latitude is set as the letter *N* in the data transmission. (see Fig 4, in the lower message). Otherwise, the values of satellite time, longitude and latitude can be found after the corresponding title (see Fig 4, in the upper message).

After comparing 10 measurements of longitude and latitude by the GPS module with 10 measurements by a reference measurement system, the specified accuracy of the GPS module [17] can be confirmed.

C. GSM module

The GSM module used is the GSM-Click product from microelectronics [18]. UART is used as the bus interface between the module and the Zynq-Z7. They are controlled using the AT command set. Three routines/functionality processes are implemented:

- **Unlock the SIM card and basic configuration**
- **RSSI measurement of the adjacent radio cells:** In [10], [11] the procedure of GSM location using RSSi measurement if 6 adjacent radio cells and the responsible radio cell is briefly described. Using the necessary AT command, the feedback of the GSM module (RSSI measurement) is saved in the DRAM. Using the measured signal strengths, a relative position determination in the room is possible. This should take place on the central evaluation unit, which should not be presented in the context of this publication.
- **Transmission of the determined data via SMS:** For the transmission of the last determined position data (GPS and RSSI measurement), the required information is loaded from the two ring buffers, sent via SMS to the central evaluation unit using the AT command set and the coding form described in the caption of Fig 4. The successful transmission can be verified by feedback from the GSM module.
  This routine is started by pressing a button on the evaluation board, which is queried at a frequency of $8\,\mathrm{Hz}$ (hand movement expected as soon as possible). Otherwise the position is localized with an update rate of $60\,\mathrm{s}$.

More information about the AT command set can be found in [19].

An evaluation of 10 measurement results from GSM location with researched cell information and their strength show plausible values.

IV. Conclusion and further work

In this publication, we have presented an emulator for an outdoor localization system for motor vehicle fleets, which uses GPS and GSM to determine position data and forwards them to a central processing unit via SMS. All the functionalities presented were implemented on a Zynq-Z7 SoC, which was hard-wired with the required components.

The bus system used to control the GPS and GSM peripheral module is UART. Using the AT command set, the signal strength of the adjacent transmitter cells could be measured and the measured data sent. Similarly, a command set was also implemented for the GPS module, which carried out a measurement of the satellite time, the longitude and the latitude. The data determined was then sorted in the DRAM using a ring buffer structure.

As a parallel project, this system will be modeled in SystemC to model the debug and security issues. Later, this models will enhance the presented emulator.

In the future, the functions presented will be integrated on a cheaper hardware platform, such as FPGA. To do this, the peripheral control must be moved from the PS to the PL. Experiments must also be carried out to determine the position information, and the individual functionalities must be transferred from a decentralized circuit board structure to a compact (one circuit board) structure.

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Gregor Benz received his B.Eng. degree in electrical engineering/physics from the Hochschule Ravensburg-Weingarten in 2018. Since 2018, he is pursuing his Master's degree at Educational University Weingarten.

Andreas Siggelkow received the academic degree Dipl.-Ing. degree in 1988 from the University of Karlsruhe. In 1996 he obtained his doctorate at the University of Stuttgart for Dr.Ing. Since 2007 he is professor for ASIC-Design and computer architecture at the Hochschule Ravensburg-Weingarten.