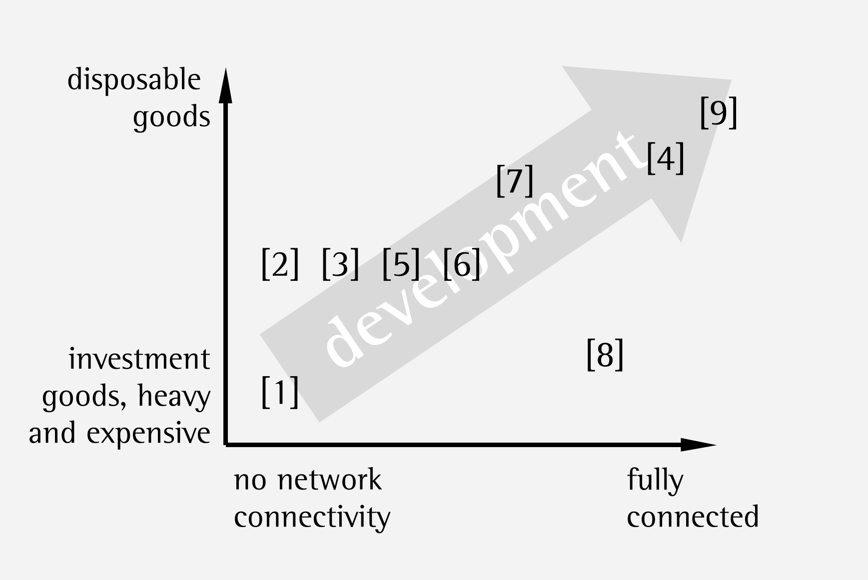
Lecture on Sensor Networks

Sensor networks - motivation

Historical Development
Applications for sensor networks
Introduction to the ESB
Future Batteries
ESB Terminal commands
Energy consumption



Historical Development

[1] IBM S 3/60 (1960)
[2] Apple II (running VisiCalc)/IBM PC/C 64 (1980)
[3] 486er PC, Amiga and modem, acoustic coupler, BTX (minitel in france) (mid 80ies)
[4] Cell phones become bulk article (end of 80ies, beginning of 90ies)
[5] Pentium class PCs, Datex-J, soon replaced by Internet (90ies)
[6] Boring PC-era (getting smaller, faster), increasingly „always-on“ (mid 90ies)
[7] GPRS capable PDAs, vanishing borders between PDA and cell phone (late 90ies)
[8] Connected car
[9] Smart Dust

Sensor networks - motivation

Applications for Sensor Networks

Monitoring the integrity of buildings and building automation

Early detection of changes in the structural integrity, developing over the years or after an earthquake. This could be accomplished by sensors which are built into the walls or the concrete without any power supply or network connection. Sensor nodes would only have to wake up between large intervals like minutes or hours working for years or even decades. The dynamics of collapsing buildings could be analyzed after the event by data that may have been sent during the collapse. In particular our ESB nodes can be woken up by timer events as well as vibration or tilt events.

Each light bulb could be a sensor node. A broken build could e. g., trigger a switched off neighbor to switch its state. No complex and expensive wiring or control wires would be necessary. Bulbs could also be triggered by activity in a room with motion sensors like they are used for the ESB nodes. Furthermore every bulb could be a part of a distributed alarm device measuring movements in a building. Simply unplugging the system would not be trivial anymore as there would be no single point of failure.

Sensor nodes could server thermostats with no wiring overhead. Every room could be controlled independently.

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Applications for Sensor Networks

Early discovery of catastrophes like forest fires

By scattering sensor nodes from an airplane over a forest a so called ad-hoc network is built up autonomously. Heat-sensing nodes can signal events like fires over the network. This enables the early detection of forest fires which is crucial for efficient fire fighting.

Medical surveillance and remote diagnosis

In the future long term measurements of vital function might be possible with the help of tiny sensors which could be implantet under the skin, swallowed etc. Small fully encapsulated and disposable video sensors which can be swallowed do already exist which are able to send images from a persons interior for about 24 hours with no surgery necessary.

Burglary prevention

Safety for buildings and other territory without any installations. Surveillance of railroads in order to prevent crashes with animals and humans may be an application.

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Applications for Sensor Networks

Business applications

Stock-keeping with connected temperature and humidity sensors contained in packages which can signal high humidity or exceeding temperature. Nodes being added to packages could at the same time be used to carry further information like recipes for food, they could be used to track and authenticate goods like it is already done or planed with the help of RF-IDs.

These sensor nodes could also enable the administration of containers in container harbors. Every container would be a node in the sensor network and could remember its content reliably. Communication over longer distances would be done hop-by-hop from one container to the next extending their range significantly.

A collection of containers would be the database itself and thus is would always be consistent. Ships could easily identify their correct load and a container could even report a missing neighbor.

Sensor networks - motivation

Applications for Sensor Networks

Agriculture

Sensor nodes could be added to the seed. By directing a query to the sensor network dry areas could be identified easily. Cattle would also be equipped with sensor nodes in order to track them (that saves on sheep dogs).

Pollution controll

Surveillance of waters: A remote sensor network could be connected via GPSR and a cell-phone with the conventional telephone network and deliver (sparse) data over long distances. Actually the ESB nodes are equipped with a link to a cell-phone. The firmware includes a function to send SMS messages.

Nodes could also be scattered over an industrial site to detect leakages of gas or chemicals and alert in an early state.

Dam protection could be accomplished by including sensors into the dams or between sandbags. Early detection of intruding water could be used to strengthen the dam accordingly.

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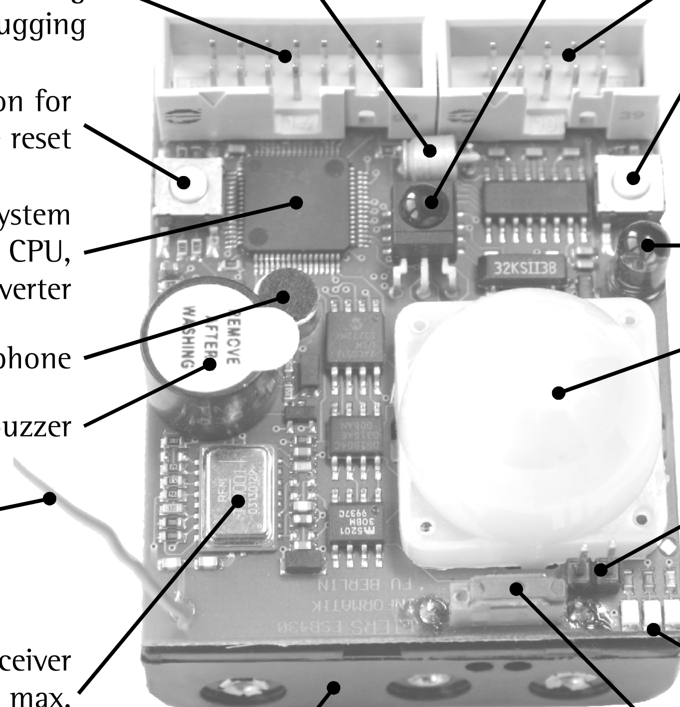
Introduction to the ESB (Electronic Sensor Board)



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Memory Organization

Introduction to the ESB (Electronic Sensor Board)

16 addresses for sub-routines	0xFFE0-0xFFFF	Interrupt Vectors
Is written once prior to initialization, however it can be changed in chunks of 512 bytes during operation	0x1100-0xFFDF	ca. 60 kByte Flash-ROM for firmware, programs, data, tables If there's enough energy left, the application can itself write data here!
two small blocks	0x1000-0x10FF	2x128 Byte Flash-ROM
programmed via scatt.-fl.	0x0A00-0x0FFF	Boot-Loader ROM (fix)
only 2kB fast RAM	0x0200-0x09FF	RAM (for variables, stack)
no real memory behind those addresses, but connected with the "outside world" (memory-mapped)	0x0100-0x01FF	16-Bit periphery (Memory mapped) — only word-wise (16 Bit) reading
	0x0000-0x00FF	8-Bit periphery (Memory mapped) — only byte-wise (8 Bit) reading

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16 Bit Multiplications

Introduction to the ESB (Electronic Sensor Board)

Multiplications are not included into the core of the MSP430. However there is a hardware multiplier, which is addressed via the mapped memory for 16 Bit periphery (0x100-0x1FF) just like every other external device (e.g., the light emitting diodes). TI denotes the four types of multiplications with MPY, MPYS, MAC and MACS.

MPY: 1. Operand unsigned Multiplication	0x130
MPYS: 1. Operand signed Multiplication	0x132
MAC: 1. Operand unsigned Mult. a. Add.	0x134
MACS: 1. Operand signed Mult. a. Add.	0x136
2. Operand signed/unsigned	0x138

RESLO: 16 LSW of the result	0x13A
RESHI: 16 MSW of the result	0x13C
SUMMEXT: Sum Extension	0x13E

Sensor networks - motivation

Future Batteries

Energy measured in watt hours / gram

```
Lithium-Ions in chemical batteries:      0,3
Methanol in fuel cells                   3,0
Tritium in nuclear batteries           850,0
Polonium-210 in nuclear batteries    57000,0
```

We assume a degree of efficiency of about 50% for the fuel cell and only about 8% for all radio active isotopes. It still holds true that 0,08 x 57000 > 0,5 x 0,3. Today, a problem with the nuclear batteries is that they deliver too small amounts of energy over a period of several years.

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Connect ESB <-> PC

Change to console 1-4 using Alt+F1-F4

login: sensor <RETURN>
password: . <RETURN>

Console 4: Connect the parallel port with the PC's local IP-network

```
msp430-gdbproxy msp430
```

Console 3: Open a serial terminal for entering commands and reading the ESB's output

```
minicom
```

Console 2: Console needed for programming

```
cd tmp/msp430/userapp
nano src/userapp.c
```
(advanced users may use emacs)

Console 1: console for compiling and flashing programs

```
cd tmp/msp430/userapp
make
make flash
```

`make` compile application and firmware
`make flash` automatically flash binary via gdbproxy (does not work the first time – repeat as necessary)

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ESB terminal commands

Some of the basic features of the ESB node can be used with a simple terminal application which allows to enter commands for the nodes that are transmitted over the serial connection. These commands are executed by the ESB immediately or return values are sent back as ASCII strings.

Sampled values or those which have to be entered (e. g., for defining thesholds) usually range from 0-4095 as 12 Bits are provided by the AD/DA-converter.

LED commands

`rlr/rlg/rly`	read state of LED red/green/yellow 0=OFF / 1=ON
`slr/slg/sly x`	set state of LED red/green/yellow x=0 (OFF) / x=1 (ON)
`swr/swg/swy`	toggle state of LED red, green or yellow

beeper commands

`rbp/sbp`	read/set beeper state 0=OFF / 1=ON
`sbp`	set beeper state 0=OFF / 1=ON

Sensor networks - motivation

ESB terminal commands

energy control

rvb/rve	read voltage battery/extern
rbl/rel	read threshold for battery/extern voltage
sbl/sel	set threshold for battery/extern voltage

microphone readings

rmc	read current value of microphone voltage
rmm	read counter for microphone voltage
rma	read average value of microphone voltage
rmi/smi	read/set sensitivity of microphone (noise is below 60)

temperature readings

rtt	read temperature value
rtl/rth	read low/high temperature threshold
stl/sth	set low/high temperature threshold
rte/ste	read/set temperature alarm enable bit the alarm wakes up the ESB based on the predefined theshold (stl/sth) 0=ALARM OFF / 1=ON

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ESB terminal commands

vibration and tilt sensor

`rms`	`read counter for vibration sensor (accumulated value)`
`rvs`	`read both counter and tilt sensor value`

light sensor

`rls`	`read counter for light sensor`
`rll/rul`	`read lower/upper threshold for “light-alarm”`
`sll/sul`	`set lower/upper threshold for “light-alarm” - this wakes the ESB up if the sampled brightness is in the interval`

radio transceiver

`rrp`	`read current AD value of the transceiver (is never zero - why?)`
`rtp/stp xx`	`read/set transceiver transmission power range for x within [00,99]`
`rfr/sfr xxxx (xxxx < 4096)`	`read/set transceiver reception theshold (since the transceiver always samples value, e.g., noise, signal must be above the thresh.`

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ESB terminal commands

miscellaneous

```
rcf            read configuration
rid/sid xxxx   read/set ID of ESB with x in [0000,0255]
raf/saf        read/set announce flag (?)
rmr/smr        read/set receiver's phone number for short
               message service
rsm/ssm        read/set sensor mask
dea            erase complete EEPROM
flx            start broadcasting userapp. (binary)
```

timer function

```
rt5               read 5 milliseconds timer
rdd/rct           read date/time of realtime clock
sdd dd-mm-yyyy    set date of realtime clock (sdd 31-12-2005)
sct hh:mm:ss      set time of realtime clock (sct 23:59:30)
sat hh:mm:ss      set alarm time. This is the time when the
                  node should wake up
rce/sce x         read/set alarm time enable bit
                  x=0 (OFF)/ x=1(ON)
```

Sensor networks - motivation

ESB terminal commands

infrared transceiver

```
sir xxyy        send RC-5 code via the IR sensor diode
                xx (hex) is the MSB (most significant bit)
                yy (hex) is the LSB (least significant bit)
                Bit 11  :    toggle bit (stable bit=key is
                             kept pressed/changing bit=key
                             was pressed again)
                Bit 6-10:    5 address bit (TV=0)
                Bit 0-5 :    6 code bits   (16=volume++)
                (0 << 11)|(0<<6)|(16)

rir             read last two bytes received by IR diode
```

memory functions

```
reb xxxx        read byte from address xxxx
rer xxxx yyyy   read bytes between xxxx and yyyy
web xxxx yy     write byte yy at xxxx
```

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Energy consumption

Important variables:

```
P_RX     4,5mA          energy consumption receiving
P_TX    12,0mA          energy consumption sending
P_CL    12,0mA          basic consumption w/o radio
P_SL     8uA(0,008mA)   energy needed for sleep mode
```

[capacity (watt) = current (ampere) x voltage (volt)]

Rough estimation for energy consumption and sensor lifetime:

Let's assume that each sensor should wake up once a second, measure a value and transmit it over the network.

a) Calculations needed: 5000 instructions (f. measurement and preparation for sending)
b) Time to send information: 50 Bytes f. sensor's data, another 250 Byte for forwarding foreign data
c) Energy needed to sleep for the rest of the second (Sleep-Modus)

Time for calculations and energy consumption

MSP430 running at 8 Mhz clock rate => one cycle takes 1/(8x10^6) seconds
1 instruction needs an average of 3 cycles => 3/(8x10^6) seconds, 5000 instructions 15/(8x10^3)s.
15/(8x10^3) x 12mA = 180/8000 = 0,0225 mAs (milli Ampere seconds)

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Time for sending data and energy consumption

The radio frequency unit sends with 19.200 baud (here approx. by 19.200 bits/second)
1 bit takes 1/19200 seconds. We have to send 50 bytes (own measurement)
and we have to forward 250 bytes (external data): 250+50=300 which takes takes 300x8/19200s
300x8/19200 x 24 mA (energy basic+sending) = 3 mAs (milli Ampere seconds)

Energy consumed while sleeping

Time for calculations 15/8000 + time for transmission 300x8/19200 = ca. 0,127s
Time for sleep mode = 1s – 0,127 = 0,873s
Energy consumed while sleeping 0,008mA x 0,873s = 0,007 mAs

Total amount of energy per second and resulting lifetime

The ESB is needs to be supplied with 4.5V, so we need 3x1.5V AA batteries.

(0,0225 + 3 + 0,007) x 3 = ca. 3x3,03 mWs (milli Watt seconds)
Energy of 3 AA battery: ca. 3x2300mAh = 3x2300x60x60 mWs
Total lifetime: 3x2300x60x60/3x3,03 = ca. 32 days

Critical review

Battery suffers from leakage current (loosing about 10% energy/year)
small network (forwarding takes only 250 bytes)
most important: Only sending was taken into account, not receiving!
If we listen into the channel rather than sleeping 0,007mA has to be replaced by (12+4,5) mA
which results in a lifetime of 2300x60x60/ = ca. 5 days

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