Smart Communication in a Wired Sensor- and Actuator-Network of a Modular Robot Actuator System Using a Hop-Protocol with Delta-Routing

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Communication in Sensor Networks

- Communication gains impact with increasing **miniaturization** and densities in sensor- and actuator networks, especially in the context of **robotics** and **sensorial materials - they require basically wired networks**
- The **network topology** of sensor- and actuator networks is in generally **distributed and decentralised**, and nodes of such a network have different computing power and storage, resulting in the following constraints and **requierements** for protocol design:
  1. **message-based point-to-point communication**,
  2. application-specific **scalable protocol** regarding network and data sizes to satisfy A. low-power design, and B. reducing computing and storage requirements,
  3. **no** unique node **addressing** (not usable in high density sensor networks),
  4. **simple routing** strategies, and finally
  5. **reliability** and **robustness** against link failures, requires alternative path finding.
- **Development of a Scalable Communication Protocol SLIP satisfying low-resource and low-power demands featuring implementation both in hardware (ASIC/FPGA technology) and software.**
- **System-On-Chip design** on Register-Transfer-Logic (RTL) level using FPGA and ASIC technologies enables
  1. small-sized integration of sensors and data processing units (DPU) scaled down to one-chip designs using ASIC- and MEMS technology, and
  2. low-power design, required especially for high-density sensor networks sourced by environmental energy (energy harvesting).

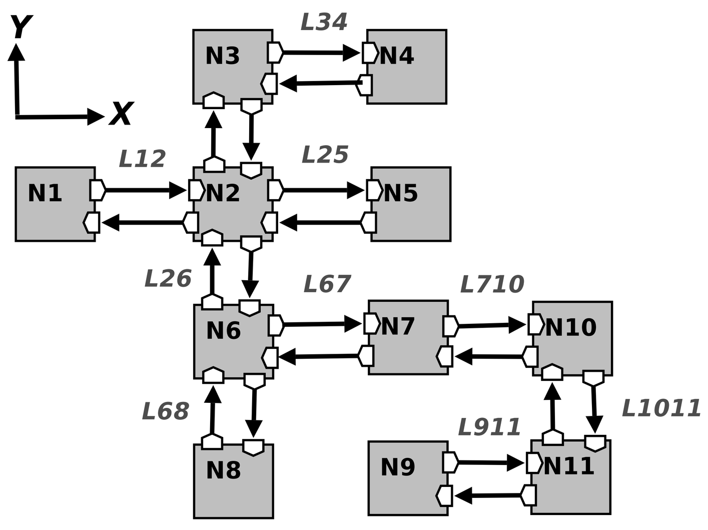

FIGURE 1: **An example network (ADC=2) with an irregular topology connected by bidirectional point-to-point links.**

ModuACT: a Modular Robot Actuator with Integrated Sensorial Materials

- The design of the modular robot actuator (figure **2**) is based on previous projects designing bio-inspired multi-legged autonomous (walking) robots [**1**], and it is used for a **demonstrator** of new **sensorial materials, technologies, and sensor data processing**.
- The **robot actuator** consists of a rotational joint drive, control and data processing electronics using a FPGA, four **bidirectional communication links** (physical layer: LVDS).
- The control and data processing system is implemented entirely in digital logic and RTL as a **SoC-design** using a communicating sequential multi-process programming model and the **ConPro high-level synthesis framework** [**2**] on behavioural level.
  - Highlevel-synthesis: 4000 lines ConPro source code, synthesized to 40000 lines VHDL,
  - Gatelevel-synthesis: about 300k gates with LSI_10k ASIC library, 15000 LUTs in Xilinx Spartan III FPGA.
- There are sensors inside the actuator (position, current, temperature) and outside distributed around interconnection elements (strain gauge sensors).

Several actuators and sensor units can be connected in a network building a robot manipulator arm or a leg of a walking robot [**1**].

- **Array of strain gauge sensors printed on interconnection elements** using functional printing process technology [**3**], see figure **2**.
- One or more sensors are connected to a Digital Processing Unit (DPU). Each DPU implements data processing and communication using the SLIP protocol.

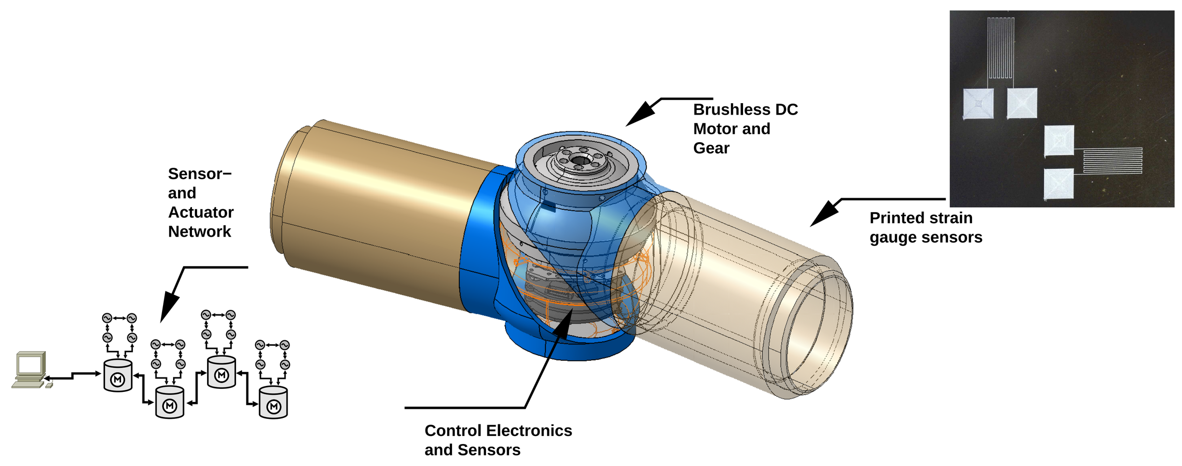

FIGURE 2: **The Modular Robot Actuator Joint with internal and external sensors forming a sensor- and actuator network. Strain gauge sensors can be printed on a film using silver-ink and aerosol techniques [3].**

SLIP: a Scalable Local Intranet Network Protocol

- **SLIP** is scalable with respect to network size (**address size class ASC**, ranging from 4 to 16 bit), maximal data payload (**data size class DSC**, ranging from from 4 to 16 bit length) and the network topology dimension size (**address dimension class ADC**, ranging from 1 to 4)
- Network nodes are connected using (serial) point-to-point links, and they are arranged along different metric axes of different geometrical dimensions (ADC=1:chain,ADC=2: meshnet,ADC=3: cube...), see figure **1**.
- Regular and irregular networks (with missing nodes and links) are supported for each dimension, a **node is both a Network Service Endpoint and a router**, using smart routing rules, see figure **3**, to solve for example backend-traps (Path N1-N9 in figure **1**).
- Communication implements message passing, the destination is specified by a relative **Δ-distance vector** (hop-count for each dimension), avoiding unique and absolute node addressing.
- A message packet contains a **header descriptor** HDT specifying the type of the packet and the scalable parameters ASC, DSC and ADC.
- A **packet descriptor** PDT follows the header descriptor, containing: the original and actual Δ-vector modified by routing, a backward-propagation vector Γ, a preferred routing direction ω and the length of the message.
- Implementation of protocol stack in hardware making a **SoC-design** using a communicating sequential multi-process programming model and the **ConPro high-level synthesis framework** [**2**] on behavioural level:
  - Highlevel-synthesis: 3000 lines ConPro source code, synthesized to 30000 lines VHDL,
  - Gatelevel-synthesis: about 100k gates with LSI_10k ASIC library, 9000 LUTs in Xilinx Spartan III FPGA.

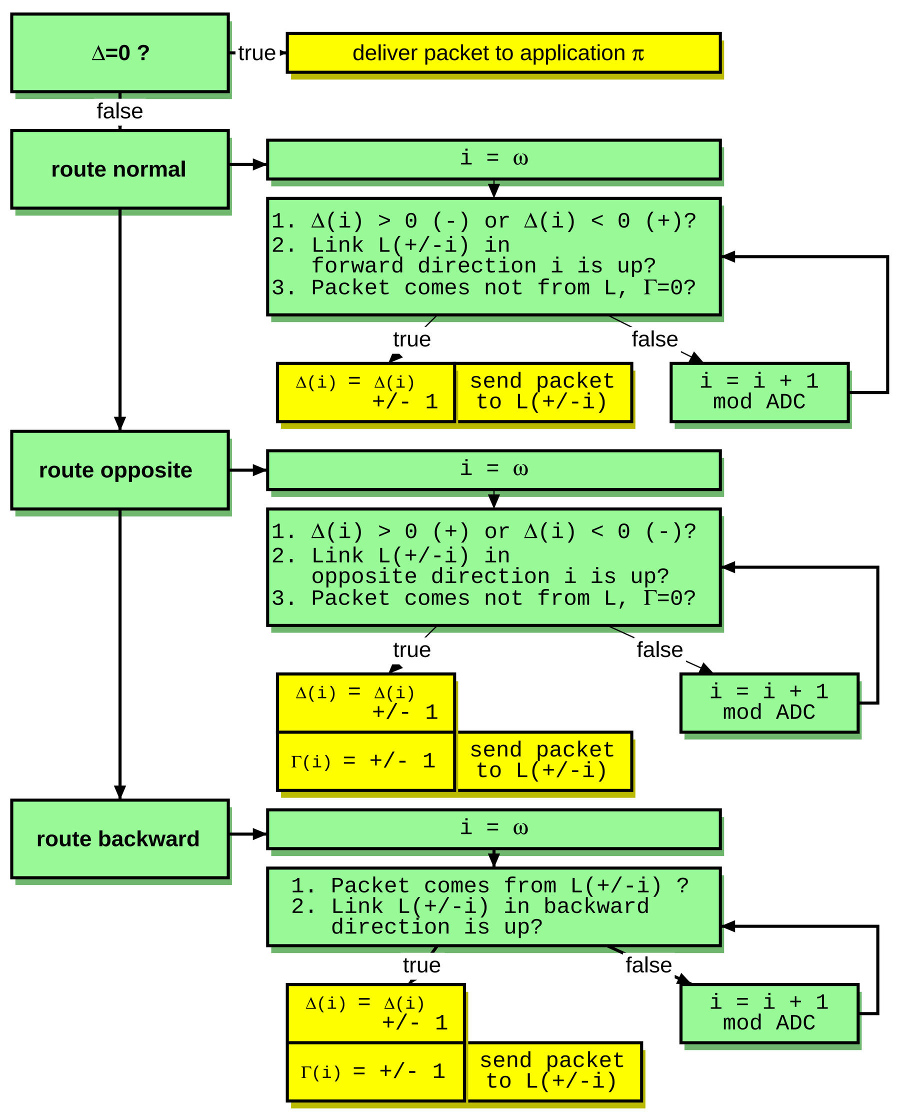

FIGURE 3: **Simplified processing of incoming packets with smart routing using different rules (either from incoming link L or application layer π). Rule selection depends on packet descriptor contents.**

Bibliography

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