Towards Automatic Migration of ROS Components from Software to Hardware

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Introduction

• Embedded Systems group
• What we do
  – Experimental & Modular robotics
  – Field Robotics
  – Cyber Physical Systems
    • Especially for welfare technology
Modular Robotics
Cyber Physical Systems and Welfare technology

Welfare Technology projects

• RoBlood
• RoboTrainer
• RoboTrainer-Light
• Elastic/Exercise-band sensor
• And much much more..
Why FPGA’s

• We primarily use FPGA and Hybrid FPGA<>MCU SoCs (like the Xilinx Zynq) because they:
  – Reduces our need for multiple hardware platforms
    • i.e. we use a single generic FPGA node.
  – Enables flexible and rapid development of custom interfaces and controllers for virtually any application.
  – Performance and timing is easy to handle, as synchronous logic is clock cycle predictable.

• The problems
  – FPGA development is often much more complicated and tedious than software development partly due to a lack of good, open-source, vendor independent component libraries.
  – Even though vendor tools are becoming MUCH better... there is still the issue of many quality IP/components only being available for a steep price...
The Unity Framework

• The Unity-Library
  – A set of support libraries and configurable components
  – Sensor and Actuator interfaces
  – Communication interfaces
  – Real-Time Network(s) and a Real-Time Operating System
  – Signal processing component (e.g. image processing)

• The Unity-Component architecture
  – Enable construction of a complete system based on a simple specification (textual DSL) and using prebuilt/library subcomponent.
  – Mimic ROS’ communication and processing paradigm in embedded Software and Gateware (FPGA logic)
    • Publish/Subscribe (Topic based) & Services (RPC)
    • Nodes (Software as well Gateware based, i.e. SW-eNode and GW-eNode)
  – Migration/easy-reimplementation of e.g. timing critical ROS nodes from a PC to an Embedded Hard Real-Time capable MCU in an FPGA or even directly into logic.
The Unity-Component architecture

- **Unity Component Architecture**
  - SW-eNodes will execute on one or more FPGA embedded MCU’s
    - HartOS (Hardware RTOS) -> higher performance and improved real-time.
    - API that mimic ROS + a subset of POSIX for simplified kernel interaction.
  - GW based clock-cycle accurate Topic and Service-call infrastructure
  - TosNet for Real-Time networking between FPGA boards
  - Unity-Link as PC interface
    - Flexible interface selection: UART/USB communication, Ethernet, etc.
    - Scalable: can fit in very small FPGAs
    - Hard real-time (clock cycle accurate) GW-Protocol
    - Easy to interface with other high-level frameworks/tools
  - Could also easily use:
    - ROSSerial, uROSnode or ROSC executing on e.g. a softcore MCU, might not be as scaleable though.
The Unity-Component architecture
The Unity-Component architecture
Unity-Comp. Topic Architecture
Unity-Comp. Service Architecture

• FIFO interfaces for each GW Service Provider/Consumer
  – MicroBlaze bridge
  – TosNet bridge
• Unity-Link naturally supports IRQ based publishing from FIFO’s
• Interconnect
  – Wishbone master interfaces on Tx FIFOs
  – Wishbone slave interfaces on Rx FIFOs
  – Multi-master/slave wishbone-bus with round-robin arbitrations for simple applications.
  – Multi-master/slave crossbar-switch for applications requiring low latency.
  – Multiple bus’ for highest performance with sparsely connected nodes
• Not implemented yet...
Unity Component Architecture
Unity Component Architecture

PC (ROS)
- getPosition
- SLAM (C++)
- Navigate (Python)
- subscribe (Unity-Link)
- service (Unity-Link)

FPGA (Unity)
- setTarget
- Softcore CPU with HartOS
  - Maintain Position (C++)
  - Filter (VHDL)
- setGoal
  - PID Controller (VHDL)
  - Motor Interface (VHDL)
  - Sensor Interface (VHDL)
- internal bus
- controlMotor
- sensorValue
- subscribe (shared memory)

Hardware Platform