Dynamic resource configuration and control for an autonomous robotic vehicle

Abhishek Kulkarni, Bryce Himebaugh and Steven D Johnson [1]

School of Informatics and Computer Science [1],
Indiana University
Bloomington, 47401

{adkulkar,bhimebau,sjohnson}@cs.indiana.edu

October 23, 2009

Outline

- ERTS robotic vehicle
  - Mission
  - Architecture
- ERTS software requisites
- SyncFS
- Cart component model
- Work in Progress
  - platform heterogeneity
  - reactive programming in limbo
  - 9p on embedded network protocols

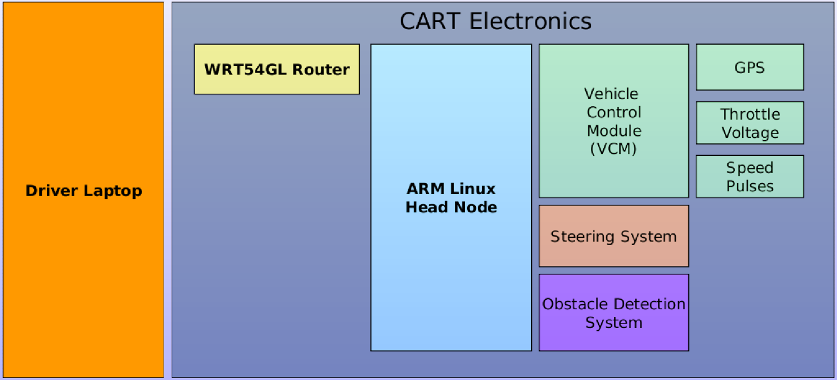
ERTS Mission

- Lessons learned from participation in the Darpa Grand Challenge development effort
- Developed for and by the participants of introductory course on **Embedded and Real-time Systems**
- Explore embedded system design through the control of an autonomous vehicle
- Platform for local experimentation, collaborative research and instruction

ERTS robotic vehicle

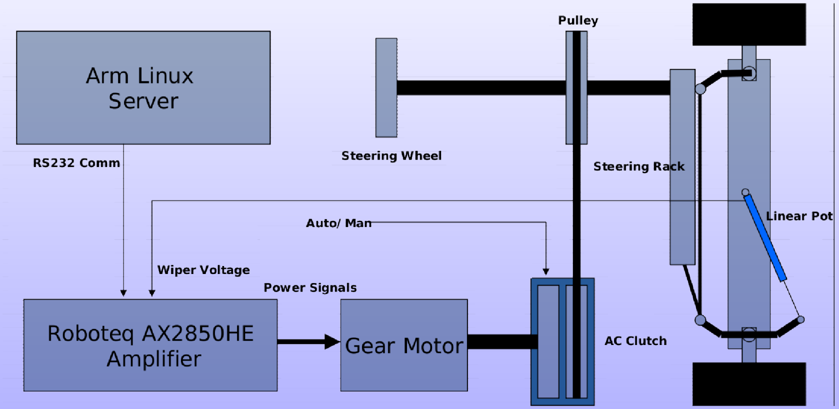
- EZGO® golf cart augmented with controls
- Sensors
  - GPS, compass, IMUs, vision, joystick, laser, IR, . . .
- Actuators
  - VCS, steering control, obstacle avoidance, voltage throttle, . . .
- Onboard LAN of ARM Linux computer nodes (CNODEs)
- Networked navigation system

ERTS architecture



Overview of the cart's electronics

Steering system overview



Cart's steering system architecture

ERTS software requisites

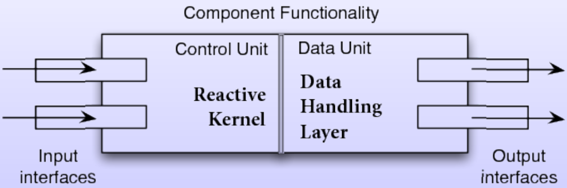
- flexible, modular and composable
- horizontal and vertical configurability
- light-weight with sufficient abstractions
- sensor network architecture
- platform heterogeneity
- implicit/explicit time synchronization

Synchronous reactive systems

`Reactive systems are computer systems that continuously react to their environment at a speed determined by this environment.`

- **ERTS** is essentially a reactive system
- timing behaviour can be formalized trivially
- easier to model, design and verify
- signals change only at the clock edge
- no data races and hazards

Reactive components



- control unit
  - usually implemented as a state machine
- data unit
  - processes, stores or exchanges data
- example
  - in a navigation system: GPS, IMUs, compass ...

ERTS software ecosystem

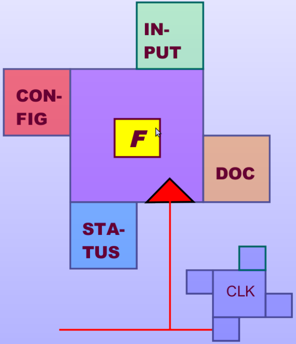
- Operating System
  - Linux, RT-Linux, QNX RTOS, Plan 9, Inferno ...
- CartFS
  - components obeying synchronous access conventions
- SyncFS
  - synchronous file server
- Experiments

SyncFS Overview

- synchronous file server
- modeled after a globally clocked D flip-flop
- defers writes/stats to a simulated "clock edge"
- MRSW model (multiple readers single writer)
- RAM based, w/ double buffering
- system-wide write commits

SyncFS

- facilitates buffer-based inter-component communication
- blocking stat as the synchronization element
- implicit CLK component
- exports elapsed ticks through the `clock` file
- 800 lines of C code, uses npfs



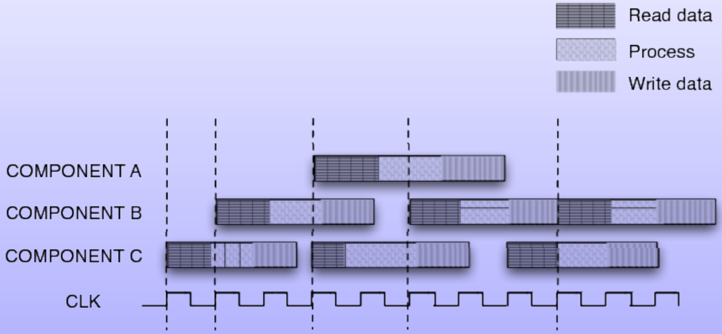
Component Framework (CartFS)

- obeys synchronous access conventions defined by SyncFS
- components communicate with the device or with each other
- exposes files `command`, `status`, ...
- adds itself to the global SyncFS namespace explicitly
- components write only to their own `status` file
- uses JSON for exchanging structured data

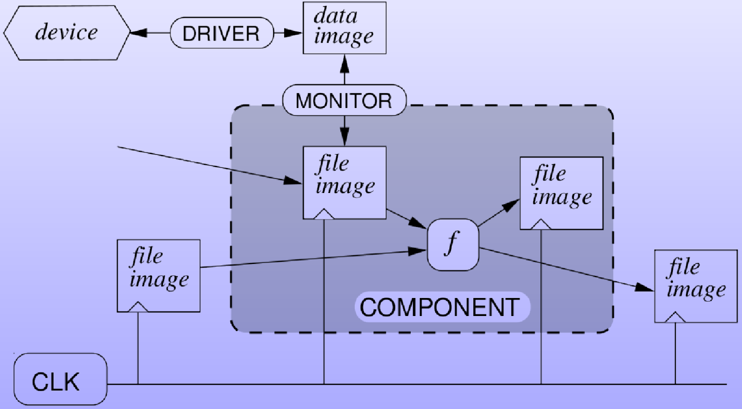
Control Loop Code

```
while True:
    wait_for_clock()
    read_files()
    has_requirements?()
    process()
    write_files()
```

Component access flow



Component Architecture



CartFS overview

- uniform component directory structure
- *status* (_s) - output for the component
- *configuration* (_c) - contains path to the input channels
- *doc* (_d) - contains description of each of the status and configuration variables
  - *log* (_log) - contains diagnostic data
- open close operations minimized to reduce load on SyncFS
- use seek to return to the beginning of a file

Component interface

```
$ cat /tmp/cartfs/config/config_s
{'clock': ['../clock', 'clock', null],
'percent_throttle': ['../jdriver/jdriver_s', 'percent_throttle', 0]}

$ cat /tmp/cartfs/compass/compass_s
{'clock': 1423, 'enable': 'True', 'heading': 124.00}

$ cat /tmp/cartfs/jdriver/jdriver_c
{'joystick_throttle': -0.69999999999999996, 'joystick_steering': 0.0,
'direction': 'Forward', 'enable': 'True', 'clock': 1538}

$
$ cat /tmp/cartfs/jdriver/jdriver_c_d
{'enable': 'True/False - stops reads on jdriver device',
'clock': 'The clock value on which this data was written.'}

$ cat /tmp/cartfs/jdriver/jdriver_s_d
{'enable': 'True/False - stops reads on jdriver device',
'clock': 'The clock value on which this data was written.'}
```

Work in Progress

- 9P on Windows
  - in user space
  - allows interacting components to be written in Windows
  - facilitates collaborative research
  - makes you unhappy ☹

```
device = CreateFile(DOKAN_GLOBAL_DEVICE_NAME,            // lpFileName
                    GENERIC_READ|GENERIC_WRITE,          // dwDesiredAccess
                    FILE_SHARE_READ|FILE_SHARE_WRITE,    // dwShareMode
                    NULL,                                // lpSecurityAttributes
                    OPEN_EXISTING,                       // dwCreationDistribution
                    0,                                   // dwFlagsAndAttributes
                    NULL                                 // hTemplateFile
                    );
```

Work in Progress

- Rewrite the component framework in Limbo
  - leverage typed channels, ADTs
  - time as a first-class notion
- Port the existing simulator to Inferno
  - graphics is a pleasure to work with

Work in Progress

- Distributed clock synchronization
  - implement IEEE 1588 [1]
- Support 9P over embedded network protocols
  - EtherCAT, Ethernet Powerline, CAN bus ...

[1] Standard for a Precise Clock Synchronization Protocol for Networked Measurement and Control Systems

Finally...

Questions?