ReSecure: A Restart-Based Security Protocol for Tightly Actuated Hard Real-Time Systems

Fardin Abdi, **Monowar Hasan**, Sibin Mohan,
Disha Agarwal and Marco Caccamo

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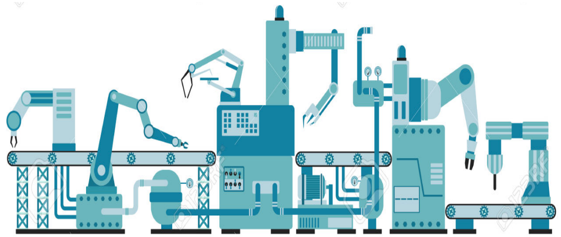
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Embedded Real-Time Systems

- **Time** and **Safety** critical!

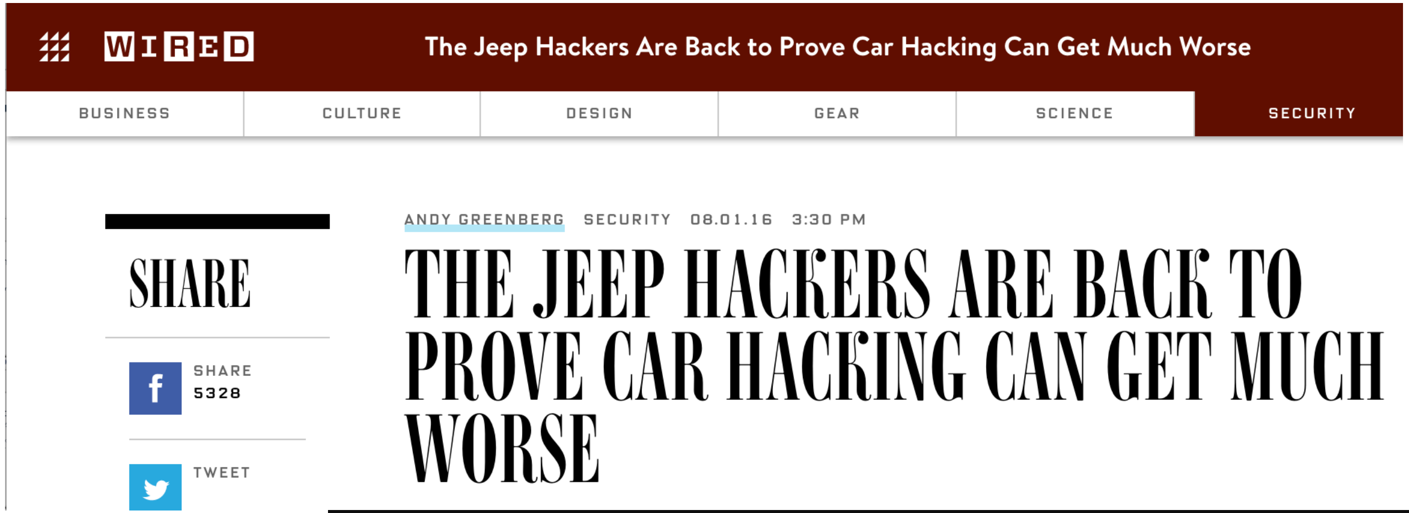


Is Cyber-Security an Issue for RTS Design?

- A decade ago:
  - *Perhaps NO*

Is Cyber-Security an Issue for RTS Design?

- A decade ago:
  - *Perhaps NO*
- Now:
  - ***YES!***



WIRED The Jeep Hackers Are Back to Prove Car Hacking Can Get Much Worse

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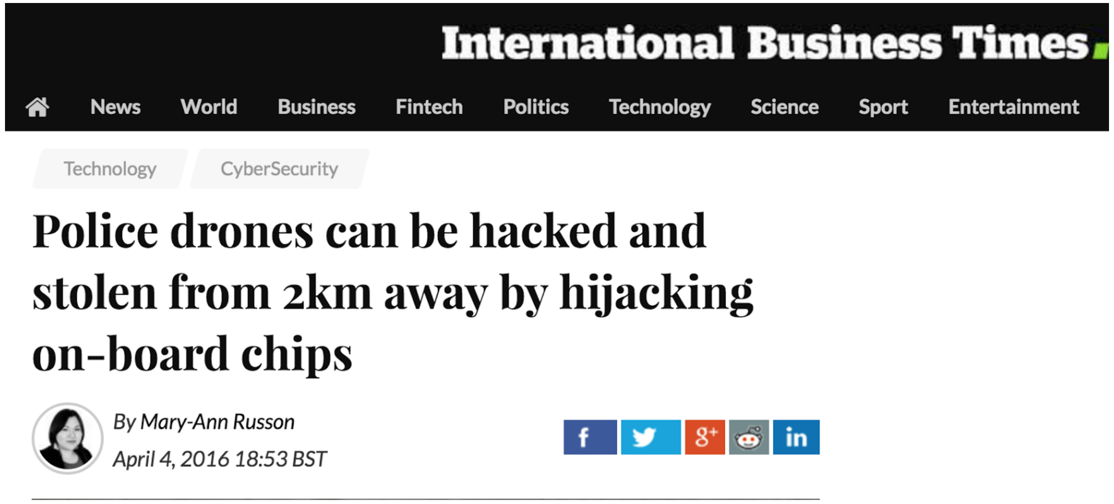
THE JEEP HACKERS ARE BACK TO PROVE CAR HACKING CAN GET MUCH WORSE



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Technology CyberSecurity

Police drones can be hacked and stolen from 2km away by hijacking on-board chips

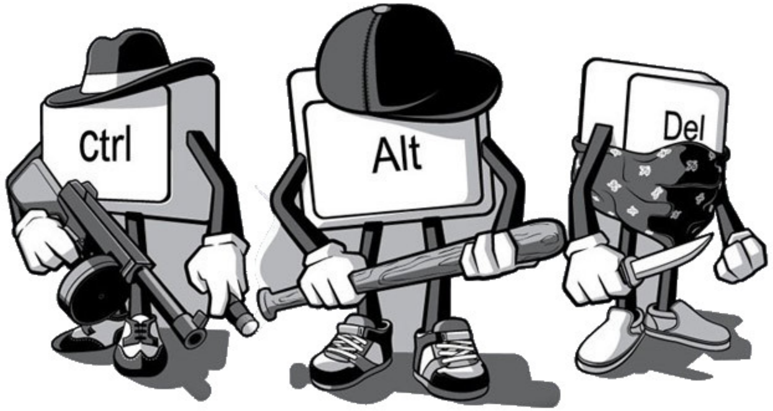
By Mary-Ann Russon

April 4, 2016 18:53 BST

Our Approach

Security through *Restarts*

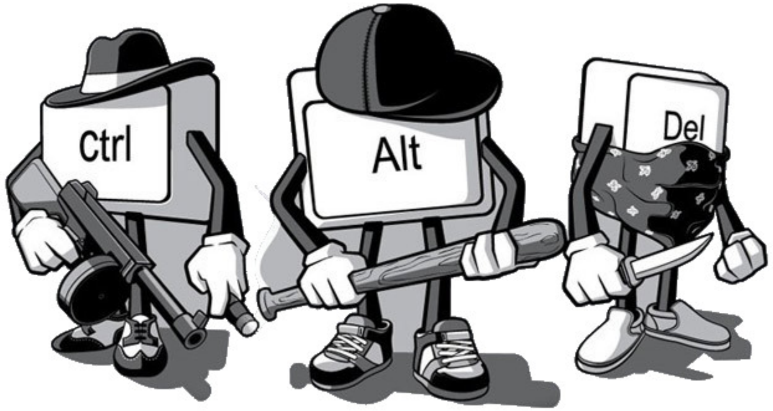
and fresh Reload!



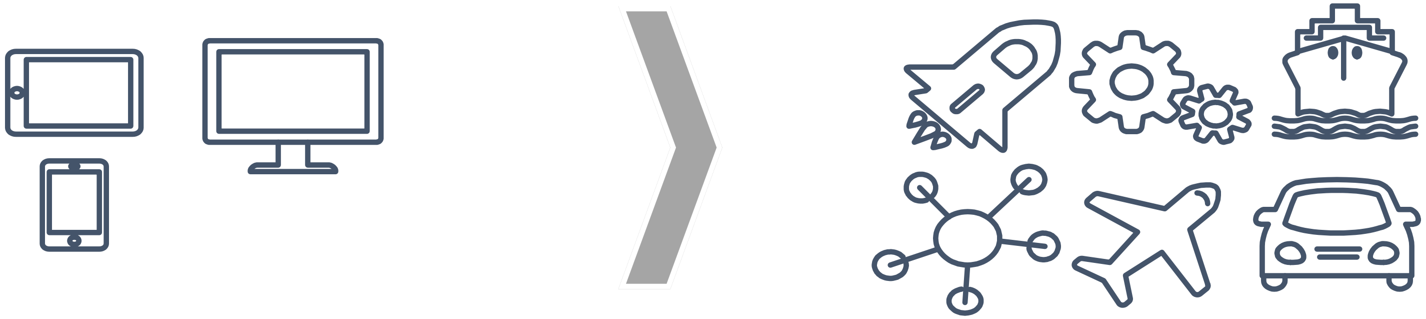
Our Approach : ReSecure

Security through ***Restarts*** and fresh Reload!

- Why Restart?
  - *Reliably remove malicious components*



Restarting in RTS Domain



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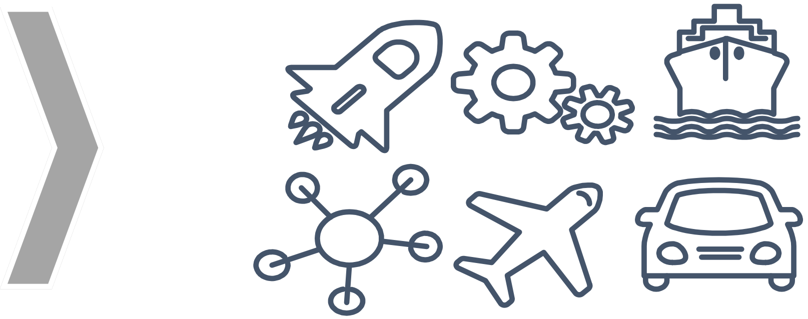
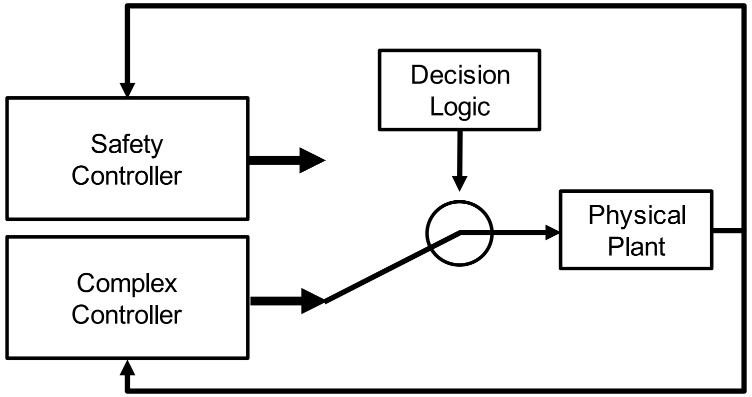


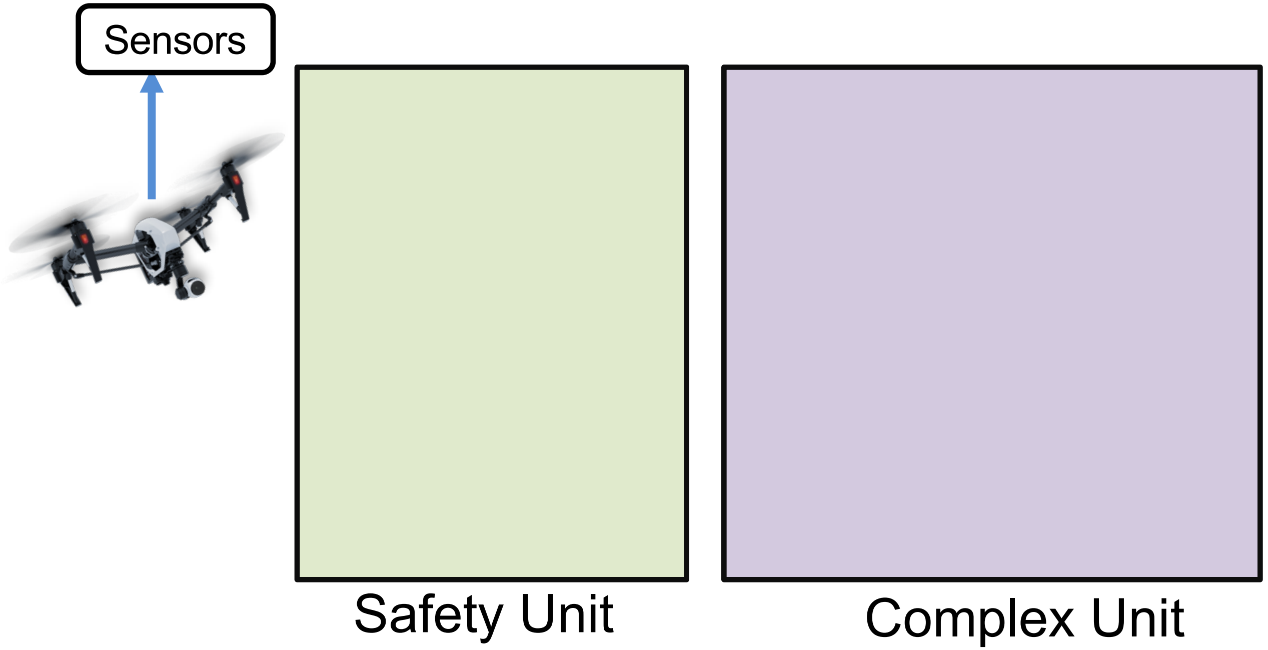
- How to enable Restart in RTS?
  - *Use Simplex! [Sha01]*



[Sha01] Lui Sha, Using Simplicity to Control Complexity, *IEEE Software*, 2001

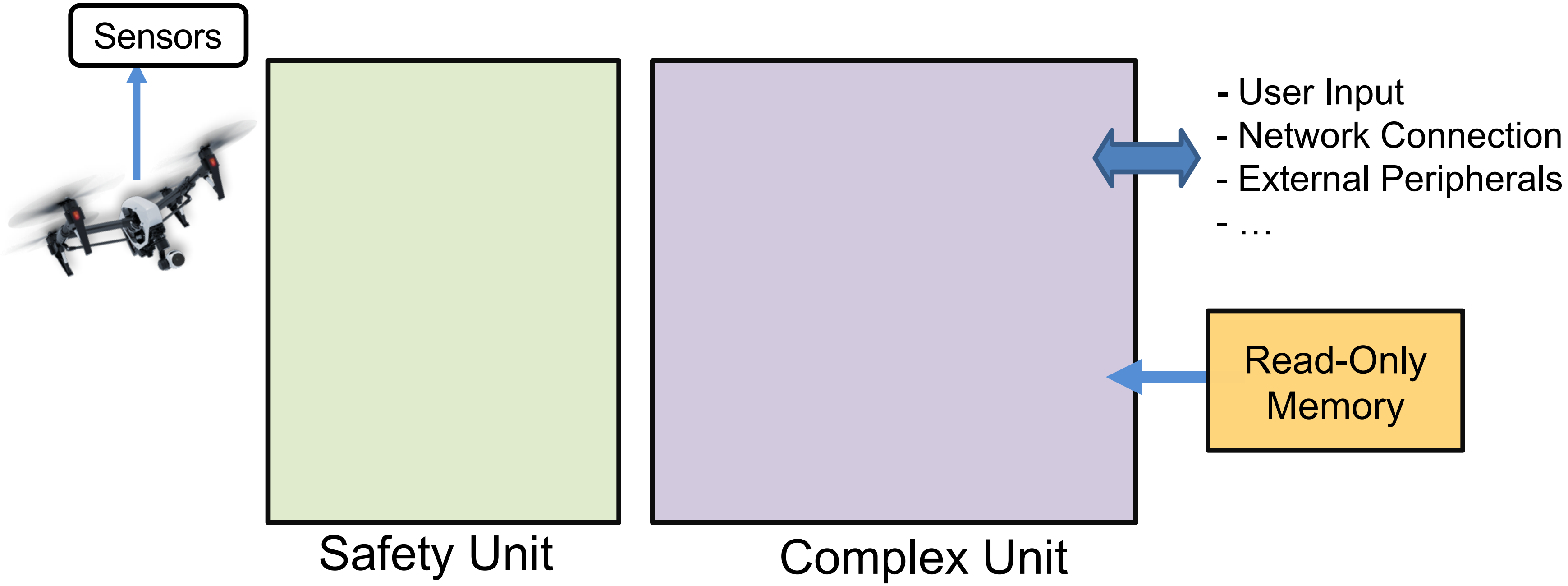
ReSecure

Architecture



ReSecure

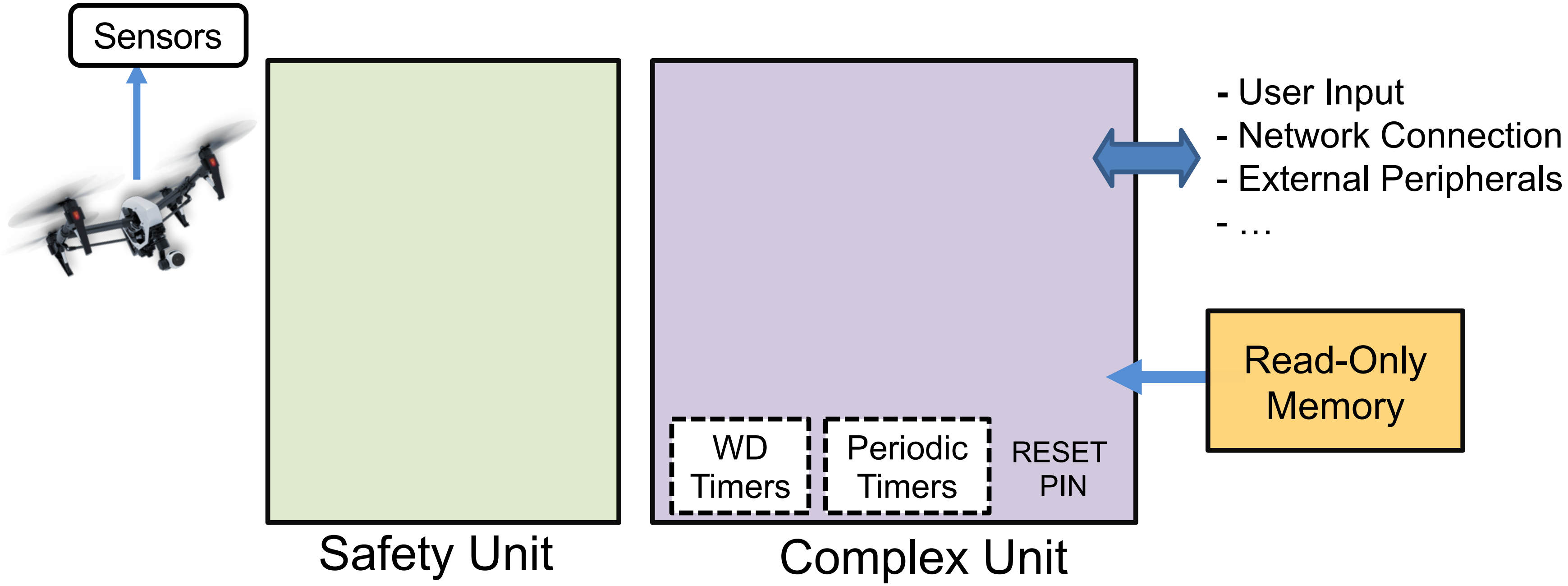
Architecture



- Safety Unit: Bare-metal, verified
- Complex Unit: OS/Firmwire can fail

ReSecure

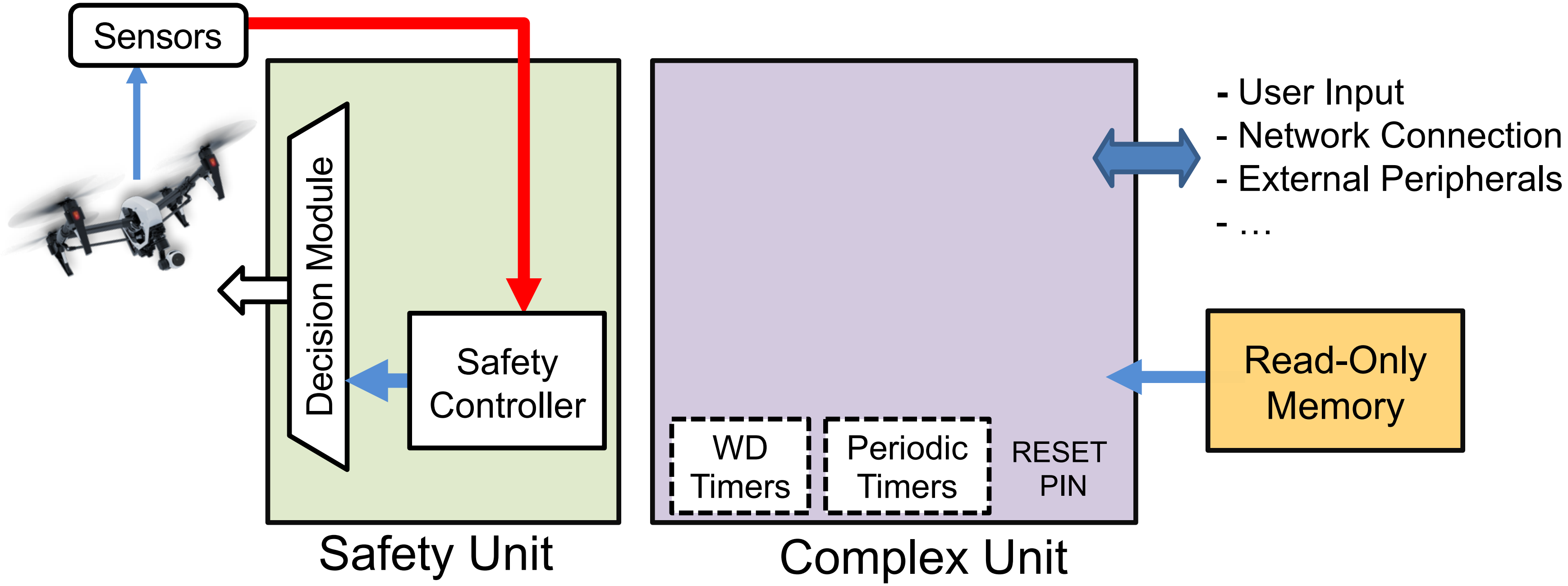
Architecture



- WD times: restart the Complex Unit upon fail-stop

ReSecure

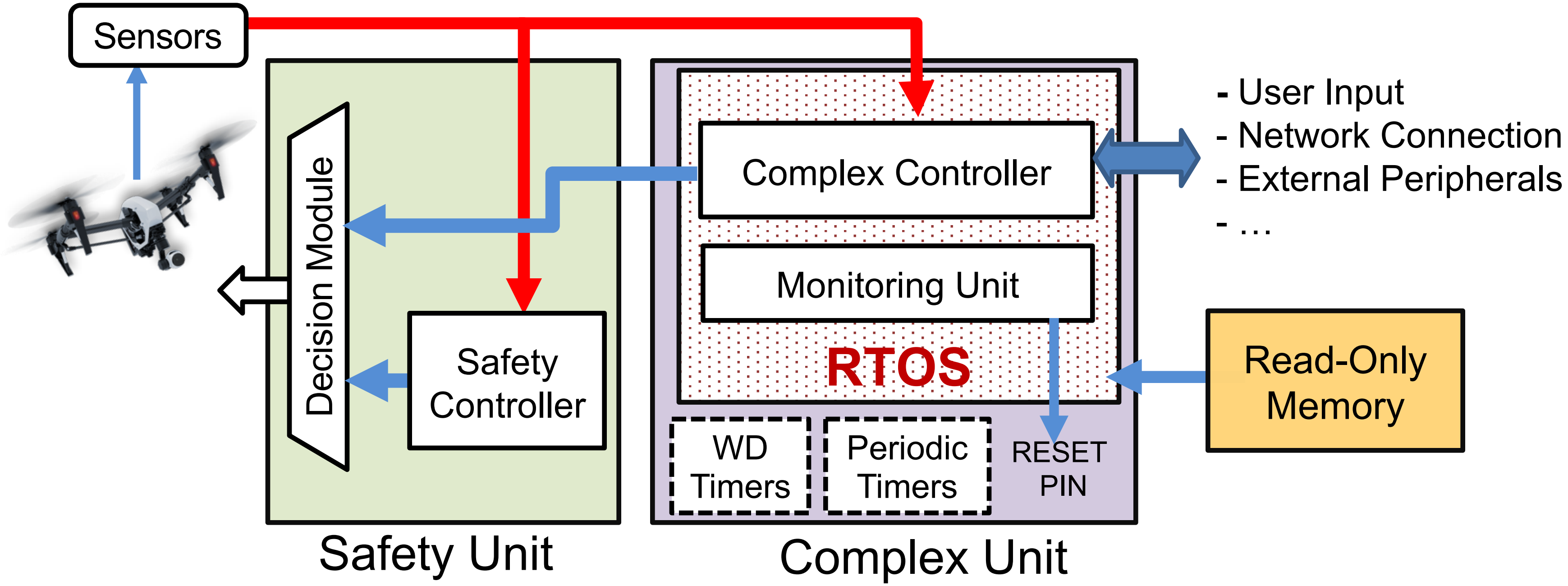
Architecture



- Safety Unit: can always keep the system safe!
- Decision Module: predicts if the future states are safe

ReSecure

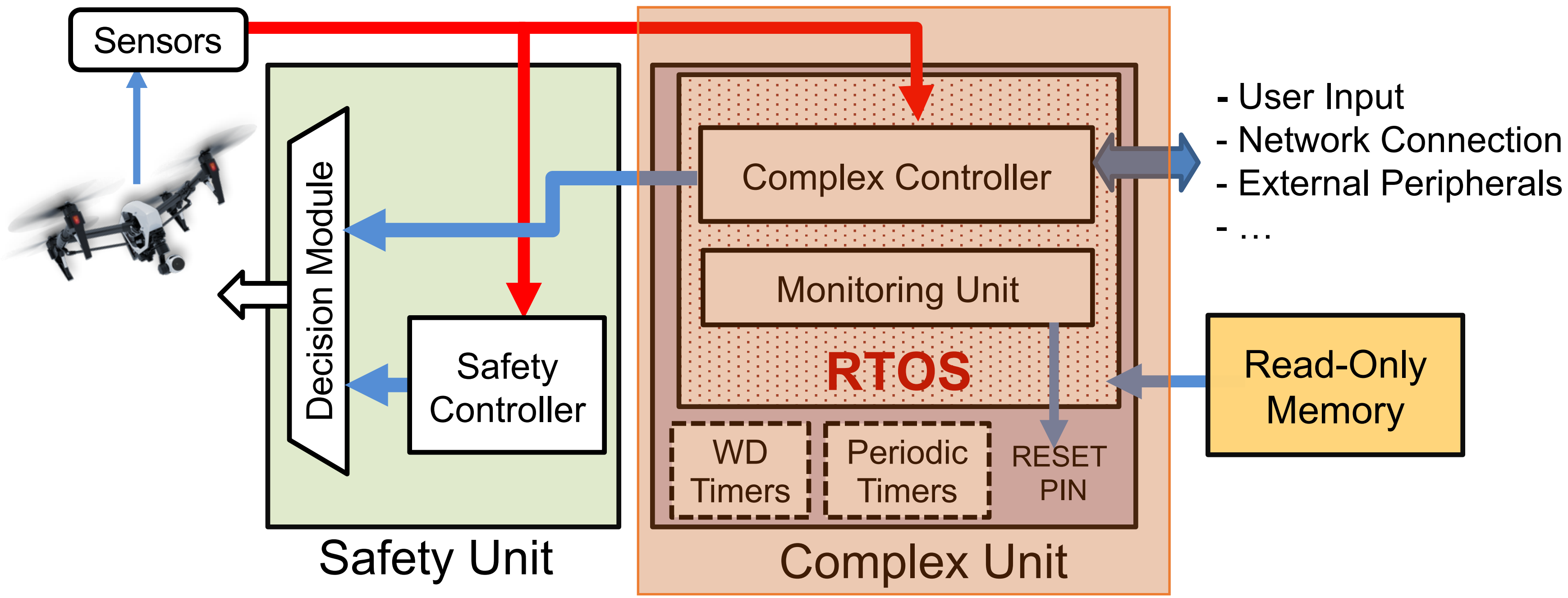
Architecture



- Complex Controller: not verified, can create unsafe command!

ReSecure

Architecture

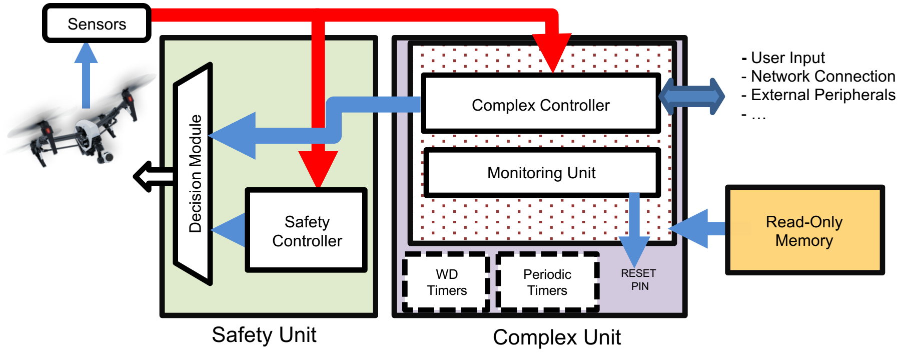


Complex Unit may get compromised!

Physical System remains safe!

Adversary Model

- Can compromise entire Complex Unit
  - *Includes real-time OS (RTOS) and the real-time applications*
- Denial of Service (DoS) attacks
  - *System and Network-level resource exhaustion*
- Information leakage through side-channels



Triggering Restart

1) Monitoring Unit
2) Watchdog Timers

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   - *Any technique can be implemented*
   - *Not 100% reliable!*

Triggering Restart

1) Monitoring Unit
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2) Watchdog Timers
   - *Can recover the system when the monitoring unit is compromised*

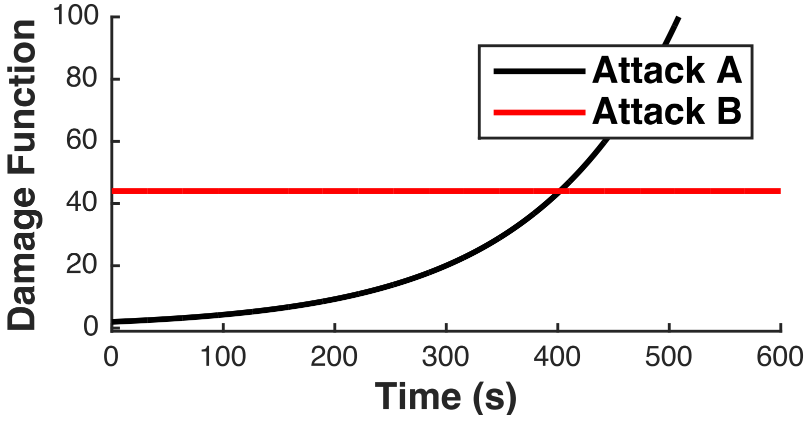
Restart timer frequency

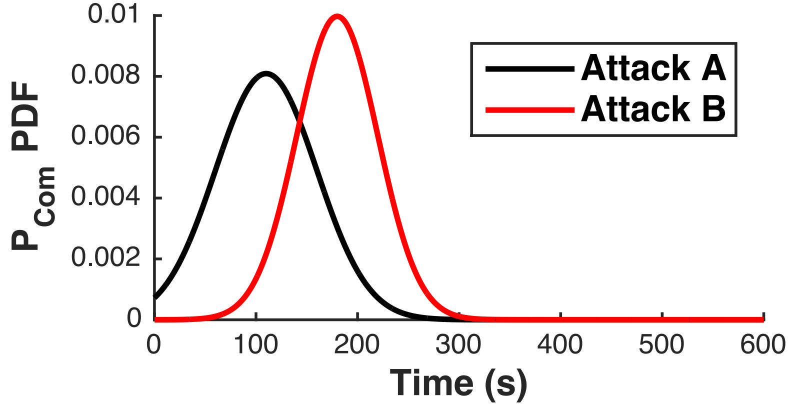
Lower Security
Higher Performance

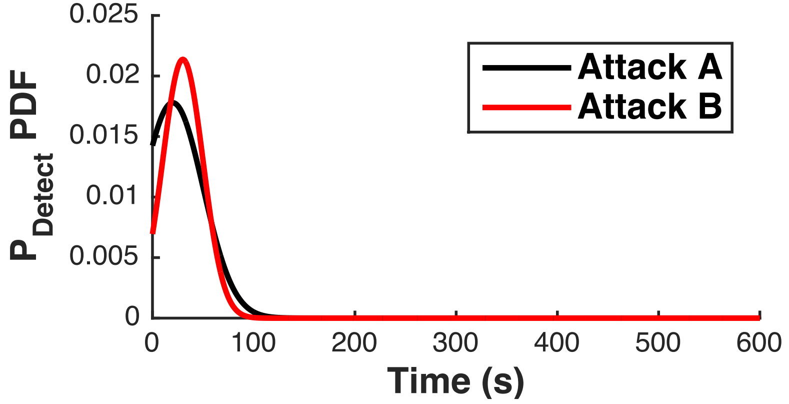
Higher Security
Lower Performance

Impact of Restart

Properties of Attacks



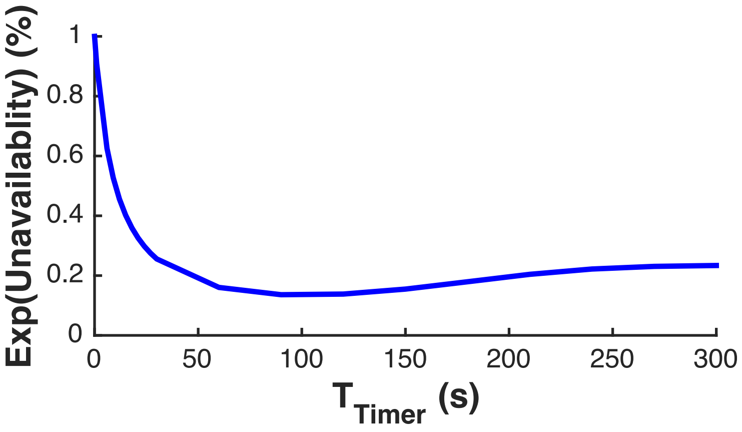


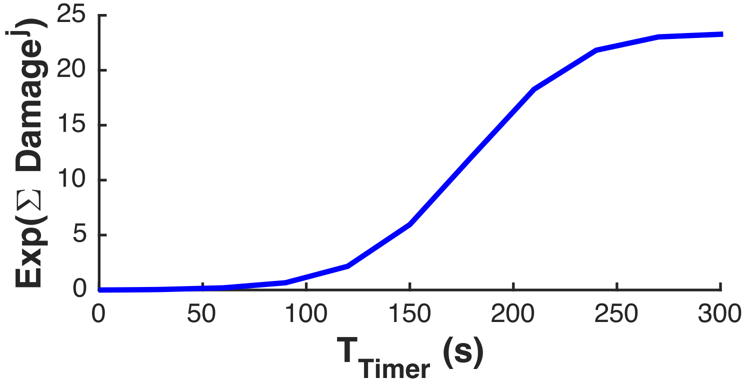


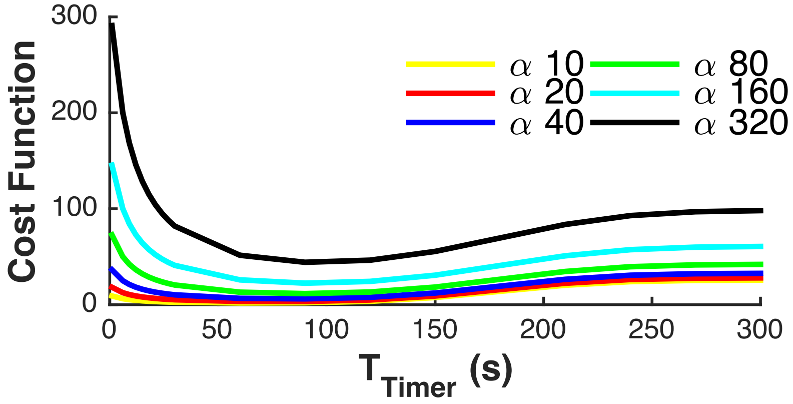
Impact of Restart

Performance-Security Tradeoff

$$Cost(T_{Timer}) = Exp(\text{Total Damage}) + \alpha \cdot Exp(\text{Unavailability}).$$

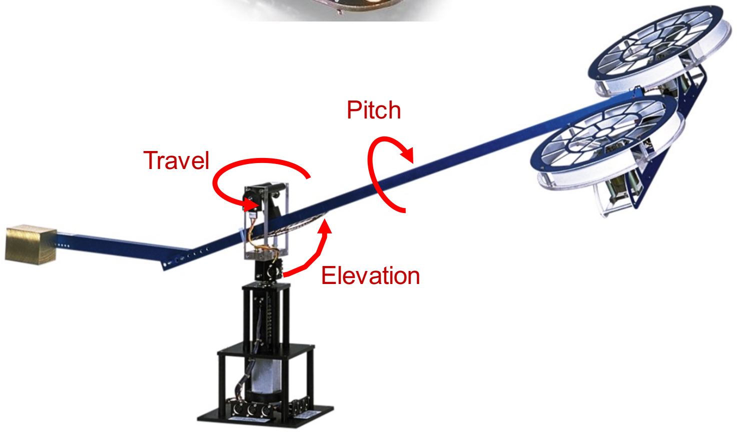






Implementation

- **Complex Unit:**
  - *BeagleBone Black (ARM Cortex-A8)*
- **OS:**
  - *Linux with RT-PREEMPT patch*
- **Real-time system:**
  - *Hardware-in-Loop simulation of 3-DOF Helicopter*



○ Source-codes: https://github.com/mnwrhsn/restart_n_secure_cps

Experience & Evaluation

- **Recovery by Watchdog Timeout:**
  - *Launch "fork bomb" attack*
  - *Recovered from the attack by ~14 second*
- **Recovery by Monitoring Unit:**
  - *Inject a kernel-level malware*
  - *Intercepts every* `read()` *system call*
  - *Recovers from the intrusion within* $T_R + T_{MU} - t = 13 + 2 - t \approx 15\ sec.$

Conclusion & Future Work

- Illustrate restart as a viable mechanism to ensure security in safety-critical systems
- Designers of the system can now evaluate the necessary trade-offs between control system performance degradation and increased security guarantees
- Future work
  - *Domain Specific Analysis of Attacks*
  - *Randomization and Restarts*

THANK YOU!

Questions?

SUPPLIMENTARY SLIDES

Safety Controller Design

- Goals:
  - *To keep system within the Linear constraints*
  - *To stay within the limits of actuators*
- Strategy:
  - *To find a region where all the above are always satisfied*
  - *To design a state feedback controller that keeps the system within that region*