

Measurement-based real-time analysis of robotic software architectures

Nicolas Gobillot, Fabrice Guet, David Doose, Charles Lesire, Christophe Grand, Luca Santinelli firstame.lastname@onera.fr

IROS 2016



return on innovation

Introduction •0000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis 00	
Introdu	iction	Robots	as autonomous	systems	

- Autonomous Robots
 - Not supervised by a human operator
 - $\rightarrow~$ need for safety guarantees
- Modular robots
 - DIY systems
 - World-wide software contributions
- $\mapsto\,$ need for a versatile and cheap analysis process



Introduction 00000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis	
Introdu	ction	Robo	ts as real-time s	ystems	

a real-time system is a computer system that has to respond to externally generated events or inputs within a finite and specified time period





Introduction 000●0	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis	
Introdu	ction		Task model		





Introduction 0000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis	
Introdu	iction		Contribution		

- Objectives:
 - evaluate the Worst Case Response Time (WCRT) of the software components of my robot
- Current Limitations:
 - ► WCRT analysis uses too simple task models → Component- and StateMachine- based WCRT analysis
 - ► WCET estimation is either empirical or hard to obtain → Measurement-based WCET estimation



 Component-based approach a well-established practice in robotics software development (Quigley et al. 2009; Soetens et al. 2005; Mallet et al. 2010; Schlegel et al. 2010)





- Component-based approach a well-established practice in robotics software development (Quigley et al. 2009; Soetens et al. 2005; Mallet et al. 2010; Schlegel et al. 2010)
- Classical schedulability theory uses monolithic task models (Klein et al. 1993)





- Component-based approach a well-established practice in robotics software development (Quigley et al. 2009; Soetens et al. 2005; Mallet et al. 2010; Schlegel et al. 2010)
- Classical schedulability theory uses monolithic task models (Klein et al. 1993)
- Recent approaches can take profit of a precise component model (Baruah 2003; Stigge et al. 2011; Gobillot et al. 2015)





N. Gobillot et al. (2015). "Periodic state-machine aware real-time analysis". In: ETFA 2015. Luxemburg



- One State Machine per component/task
- Periodic task triggering



- Component-based approach a well-established practice in robotics software development (Quigley et al. 2009; Soetens et al. 2005; Mallet et al. 2010; Schlegel et al. 2010)
- State-Machine-based modeling of component behavior
- \rightarrow the MAUVE DSL (Gobillot et al. 2014)



ONER

 Introduction
 WCRT Analysis
 Component-based Models
 WCET Estimation
 Schedulability Analysis
 Conclusion

 00000
 000
 000
 000
 000
 000
 000
 000

 Component-based Models
 MAUVE

 shell PathPlanningShell {

 property resolution:
 double = 0.3

 input port map:
 DocuparcyGrid

 input port pose:
 PoseStamped

 input port goal:
 PoseStamped

 output port path:
 Path

codel astar(in p: PoseStamped, in goal: PoseStamped, in map: OccupancyGrid): Path core PathPlanningCore (PathPlanningShell) { var pose_: PoseStamped var goal_: PoseStamped var map_: OccupancyGrid var path_: Path var new_goal: bool = false statemachine { initial state Idle { run = fif (read(goal, goal_) == NewData) then { new_goal = new_plan(goal, pose); 3 3 transition if (new_goal) select Planning 3 state Planning { entry { read(pose, pose_); read(map, map_); path_ = astar(pose_, goal_, map_); write(path, path_); transition select Idle

}}}







Introduction WCRT Analysis Component-based Models		WCET Estimation	Schedulability Analysis		
Compo	nent-base	d Models	Ca	ase study	







12 Measurement-based real-time analysis of robotic software architectures – Charles Lesire – IROS 20



automatic generation of PSM from MAUVE models



- but transition execution time are still missing!
- $\rightarrow\,$ we need the WCET of each component function



- The WCET is obtained using two different methods:
 - Static analysis: the executable code is used on a model of the hardware target
 - Measurement-Based Probabilistic Timing Analysis
 - no need for a specific hardware with models
 - based on measurements only
 - ▶ probabilistic estimates \rightarrow confidence indices
 - F. Guet et al. (2016). "On the Reliability of Probabilistic Worst-Case Execution Time Estimates". In: ERTS 2016. Toulouse, France



Introduction 00000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis	
WCET	Estimatio	on	Process	5	

- Timed traces are generated for every architecture element
- Execution times are gathered from the traces and the architecture specification
- Extreme Value Theory is applied to the time distributions
 - The resulting pWCET is cut at 10^{-x} to obtain the WCET.
 - Metrics are used to check EVT applicability.
 - The time spent in the middleware is also determined.













Introduction 00000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis ●○	
Schedu	ılability aı	nalysis	Deployment	specification	

component	period (ms)	deadline (ms)	priority	affinity
p3dx_driver	100	100	10	1
hokuyo	100	100	9	1
safety_switch	100	100	8	1
pose	100	100	7	1
guidance	100	100	6	1
control	100	100	5	1
teleop	100	100	2	4
navigation	1000	1000	2	1
gmapping	1000	1000	3	2



Introduction 00000	WCRT Analysis	Component-based Models	WCET Estimation	Schedulability Analysis ○●	
Schedu	ılability aı	nalvsis	WCRT	Results	

component	1e-3	1e-4	1e-5	1e-6	1e-7	1e-8	1e-9	
p3dx_driver	8	10	11	13	17	29	55	
hokuyo	28	32	33	36	40	52	78	
safety_switch	31	35	36	41	46	61	90	
pose	32	36	37	42	47	62	91	
guidance	35	39	40	45	50	65	94	
control	38	42	43	48	53	68	98	
teleop	45	49	50	55	60	75	499	
navigation	764	817	841	876	906	984	1146	
		1						
component	1e-3	1e-4	1e-5	1e-6	1e-7	1e-8	1e-9	
gmapping	703	711	715	722	764	994	2258	

Introduction 00000	WCRT Analysis 00	Component-based Models	WCET Estimation	Schedulability Analysis 00	
Conclus	sion				

- a complete toolchain from models to execution traces, executable binaries and analysis processes
- measurment-based approaches applicable whatever the platform/OS
- WCRT results as a design criterion
 - safe (larger) period vs. best-effort aperiodic tasks
 - allocate components to CPU cores

Introduction	
00000	

WCRT Analysis

Component-based Models

WCET Estimation

chedulability Analysi 0 Conclusion

ONER

Future works

- a complete probabilistic WCRT approach to correctly propagate uncertainties (more accurate results)
- conditional representation of pWCET w.r.t. test conditions
- better masterizing the execution (towards MAUVE 2.0 runtime environment)