Title

Reflections on autonomous systems using a case study

Author Manuel Rodriguez

Reference A-2007-009
Release 0.1 Draft
Date July 16th, 2007

Address
Autonomous Systems Laboratory !
UPM - ETS Ingenieros Industriales
José Gutierrez Abascal 2
28006 Madrid
SPAIN

Case study: Room heating system

Goal: Keep the room at a determined temperature

1.First case. The system is already designed.

Questions to answer: is it autonomous? Can it be explained using the OASys descriptions?

System description

The system, represented in figure 1, is composed of the (main) following elements:

- Boiler: The boiler heats water through combustion. Air and fuel are mixed and the heat of reaction is used to heat the water.
- Pump: This elements provides the energy to make the water flow through the circuit.
- Radiator: This elements releases the heat of the water and makes the room warmer
- Other elements: pump lubricating system, pipes, expansion tank, expansion valve. Water feed (to compensate for leaks)
- The fluid (water in this case) should be considered as another element.
- The room itself is another element of the system

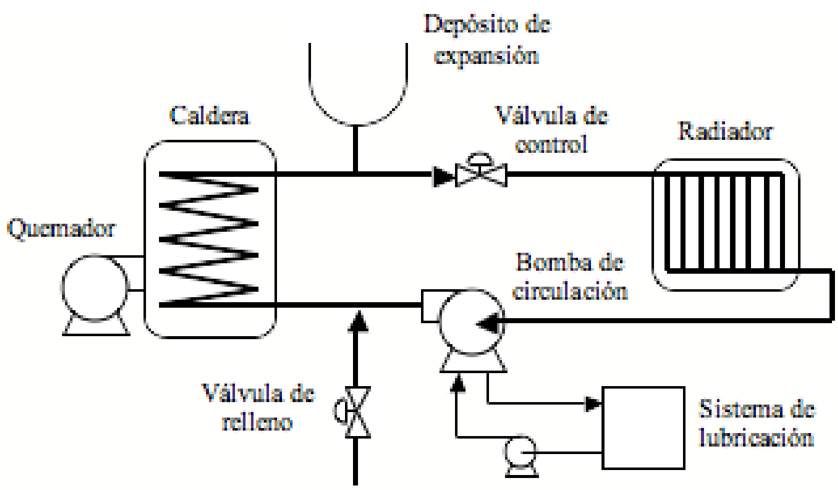

Figure 1: Heating system

Necessary condition for autonomous systems

The system with just the described elements cannot achieve the goal or doesn't know if it has been reached. So for any autonomous system the following elements seem neccessary:

- Sensor:A part of the system that allows to know the state (part of it) of the system. It provides awareness.
- Controller: A part of the system that can "reason" if the detected state is the desired goal and how to proceed to go in the goal direction.
- Actuator: A part of the system that changes the state of the system to make it closer to the goal state.

The three mentioned elements constitute the control system. So the first conclusion for ***a system to be autonomous is that it has to have a control system.***

Relation to OASys concepts:

Agent: Currently defined as entity that sense, reason and is intended to act. It seems that the agent is the control system, I would remove this word. I would use control system.

Regarding the relations...

An autonomous system IS A system and it is COMPOSED of a control system AND a self (descriptive/ proper/ behavioural/ inner...) system. Besides a system HAS elements and relations (or couplings).

Any element HAS a behaviour that REALIZES a function. In this example, the boiler behaviour is that it gives heat to the water, heating it. The function realized is "to heat". This function could have been realized by another element (if so designed).

The behaviours and related functions of the elements of this system are:

Pump: Behaviour gives mechanical energy to a fluid, changes pressure of the fluid. Function: Circulate water

Boiler: Already commented

Radiator: Behaviour, gives heat to the room. Function: Heat

Analysing the system, is it autonomous?

If we have this system with a control structure (a temperature sensor, a controller, and a valve regulating the flow of fuel) we can analyse it to see if it can be considered an autonomous system. In order to be considered autonomous it has to have the necessary elements (control system and inner system) which now it has. The second step is to see the functions it provides and try to see if those functions allows to reach the goal.

First of all we see what function achieves the goal. Function: Change room temperature.

Now an analysis of the functions provided by the system is presented:

Function: Heat the room (provided by the radiator). This function ”changes” the room temperature, so it can achieve the goal. to have this function available, the radiator needs: hot water. Water flow is provided by another function realized by the pump, and ”hot” is provided by the boiler element. We reach the elements that depend on the inputs to system. As far as the fuel and air are available to the boiler and energy is available to the pump the system can (in normal operation) provide their functions and the goal reach.

There are some considerations to be made. The function that achieves the goal, change room temperature, can be decomposed in two functions: heat the room, cool the room. The existing system ONLY can provide one of them so the goal will be achieved if the conditions make that heat the room is the needed function. Another consideration is that the behaviour of the elements realizes a function but only between some limits (mechanical limits, structural limits). These limits indicate the magnitude of the disturbances that the system can reject and still reach its goal.

Comment: Would it be interesting to distinguish between full and limited autonomy? The first case would be when all the functions that characterize a goal are provide and the second case when only some of them can be provided.

Relation to OASys concepts:

It seems that concepts like limit and constraint are relevant to the autonomy domain. It is related to the state transition structure of the OASys metamodel.

The aforementioned behaviour and element correspond in some cases to the algorithm and grounded function. I.e. a physical object is the implementation of the algorithm (behaviour) that realizes a function. Clear distinction has to be made if we talk about the control system or not.

Regarding the resources, all the parts of the system must be dedicated to achieve the goal, if not, the system is bad (over) designed. The best design is the minimal structure that achieves the goal, i.e., everything of the system is necessary. However, superstructures (overdesigned systems) may be useful as they can provide additional robustness, and therefore additional autonomy.

2. Second case. We can design a system to be autonomous for a specific goal.

Following with the same example

GOAL: Keep the temperature of a room at a determined value.

Now we proceed decomposing the goal into functions and subfunctions until an element (”usually physical”) has reached. This element will realise the lower function.

Functions that characterize the goal: change room temperature (the function that changes the variable that determines the state of the goal). These can be subdivided into COOL and HEAT. Now we need a system that realizes both functions. Different design solutions exist (now the domain knowledge should take over and design the best system. In this case we can have a heating system and an air conditioning or we can have a ”hot pump”, ...). The design should take into consideration the expected range of values for the goals, and the expected disturbances (if known). Depending on these values the system designed will provide according structural limits.

If a system is correctly designed (i.e. the structural directiveness allows to reach the goal), the key factor for autonomy is the control system. In fact, autonomy is the capacity of controlling (sensing, reasoning, and acting) the system (even in some way we could identify autonomous system=controlled system).

Summarizing the presented ideas:

1. An autonomous system is a system that is composed of the system itself and a control system.
2. The self-system has a set of elements and couplings (relations between elements).
3. These elements have a behaviour which has several limits.
4. The elements (physical objects) and their behaviour realize functions.
5. All the functions define the structural directiveness of the system.
6. The structural directiveness is compared with the goal, if it characterizes the goal completely the system has full autonomy, otherwise limited autonomy.
7. The control system is in charge of sensing the actual system state, decide the action to take, and act modifying some element behaviour.In some cases (to keep the full autonomy) the control system may modify the system structure (through the purposive directiveness).

These are graphycally represented in the following class diagram, figure 2.

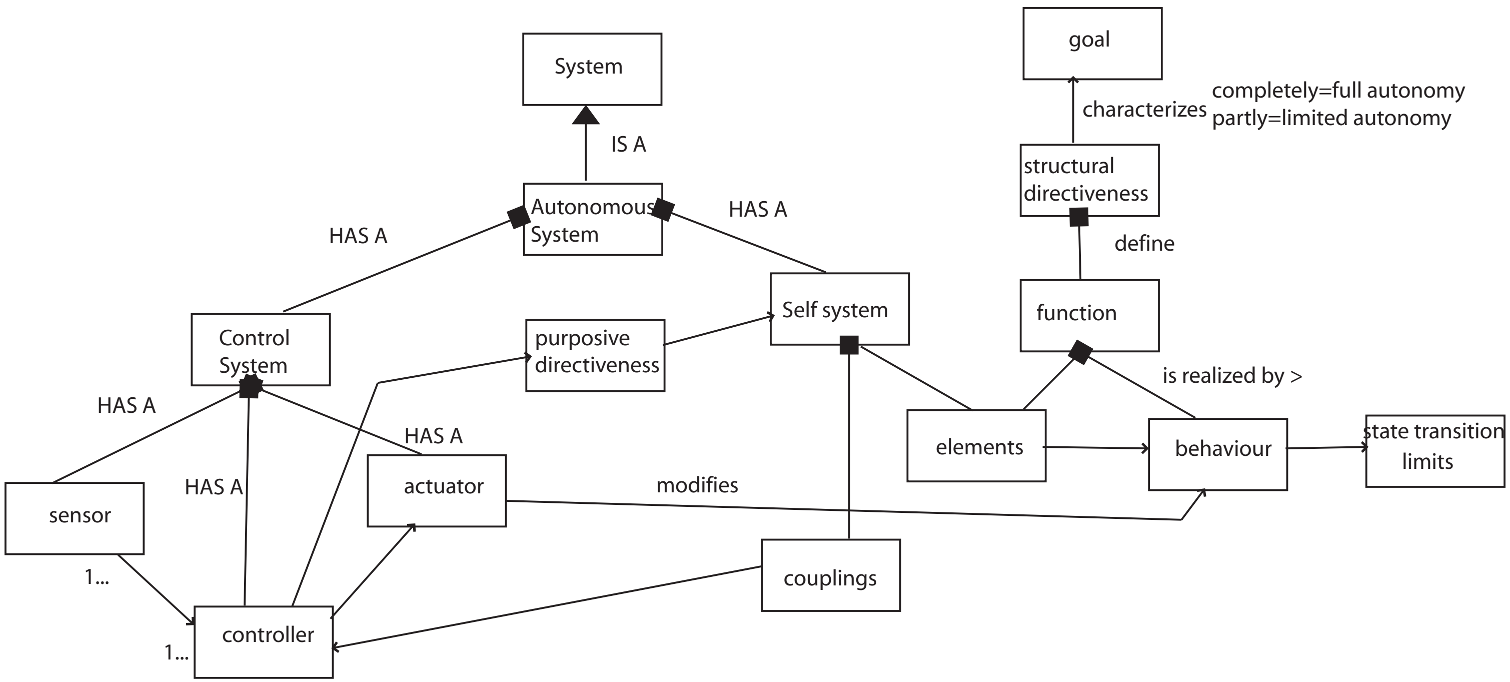

Figure 2: OASys model

Title: Reflections on autonomous systems using a case study
Subtitle:
Author: Manuel Rodriguez

Date: July 16th, 2007
Reference: A-2007-009 v 0.1 Draft

URL:

Autonomous Systems Laboratory

UNIVERSIDAD POLITÉCNICA DE MADRID
C/JOSÉ GUTIÉRREZ ABASCAL, 2
MADRID 28006 (SPAIN)