Interval Computation for Water distribution system

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Résumé

Ce rapport est un condensé de stage d'assistant ingénieur à Barcelone à l'IRI (Institut de Robòtica i Informàtica industrial) , mon travail était d'appliquer mes connaissances en analyse d'intervalles à un projet mené par un doctorant : La mise en place d'un système de distribution d'eau assurant à la fois la façon la plus économique de gérer le système sans mettre en danger le système. Ce rapport inclut mon travail plus une partie sur la détection de faute que j'ai crée pour ce projet.

J'y explique aussi ce que ce stage m'a apporté en tant qu'expérience professionnelle , internationale et humaine et ce que cela signifie pour ma future carrière.

Abstract

During my Internship in a Spanish research center, I had to find a way to use Interval computation to add robustness to an economical control system, a vital quality that assure us that a system is safe to use.. The solution was to use Interval to work a safe zone for our possible instance of our system. Furthermore is was my first international experience and I add to adapt to an other way of working and more than that to an other language : This constitute a vital part of my professional experience and I discuss about how this stage orient my career project.

Chapter 1

Introduction

To end The 4th Year of our engineering studies, we are required to do a nine week internship as an assistant engineer, this internship follow the formation's logic in following the laborer internship who ended the 4rd year. It is followed by the engineer internship who conclude our studies. This work experience take place at a turning point in our formation because after 4 years of advanced studies in the STEM (Science, Technology, Engineering, and Mathematics), we now have the skills to have a real place in our working place. More than with our precedent internship, we can discover what will be our future work and what will be asked of us .

Furthermore as we are expected to be able to work within a global world, we are required to do a part of our formation outside of France. For the 2017 promotion the requirements is 12 weeks. This time allow us to experience other way of working in our domain and have an opportunity to test our foreign language capacity in a real situation. We follow English classes since more than twelve years and have pass the TOEFL test that should prove our skill in English but between a two hours test and a three month journey , the needed skill are very much different. Working in English, we, non-native speaker with other non-native speaker is very contrasting to speaking with our teacher as most of them are completely bilingual or native speaker themselves.

My internship was in Barcelona, in the IRI. My work was to incorporate Interval Analysis method in one of their project, an automatic control project. During my work , I was the one knowing about the possibility of the Interval methods and I had to explain what was possible and what was not. A situation out of my comfort zone as this responsibility was on our teachers shoulders not ours.

Finally, this internship was a challenge on three fronts : The International challenge : More than just working, I had to being able to live in English for three months. The Technical challenge of the work itself : incorporate the interval in the control method of the project and finally the Professional challenge, the first responsibility that came with the advancement of our studies and being closer to our diploma.

Chapter 2

Context

2.1 IRI (Institut de Robòtica i Informàtica industrial)

The IRI is a Spanish research center whose main domain are Automatic control and Robotic, the institute is part of the UPC (technical University of Catalonia) and the CSIC, the Spanish equivalent of the CNRS. Their laboratory is in the same building as the Faculty of Mathematics in Barcelona.

Most of their projects are technologies transfers with the goal to find way to improve existing system with current scientific progress. For example AutomaticTV, a program in collaboration with Mediaproduction S.L.U with the goal to develop algorithms for the control of camera during sports events or SITEL, the adaptation of a existing method to manage medium power network to include a simulator for demonstration. The IRI serves as the link between pure research and the industry. A capital role in science as it provide the advance in science for the public

my internship came perfectly with the methods of the IRI, The goal of the project I work with was to develop new algorithm for water network system using the last advancement in Automatic. My work was to use interval method to add robustness to the new algorithm.

The research center is young : their first publication was in 2008 and Robotic is also a young domain with a great future, it was apparent in the building as most of their staff is under 30 years old. Furthermore his localization in The UPC (Polytechnic University of Catalonia) complex make the link between the student and the researcher easy . During my stay, I have seen several visit of student from near university and we were many student from other university in internship : some from Spain, some from Europe and even several from other part of the world. I personally work close handed with a Chinese Phd student. Every one had a working english and most of the staff could hold long and precise conversation without any problem. That's why I had the feeling that the IRI, although small have a great future in robotic research.

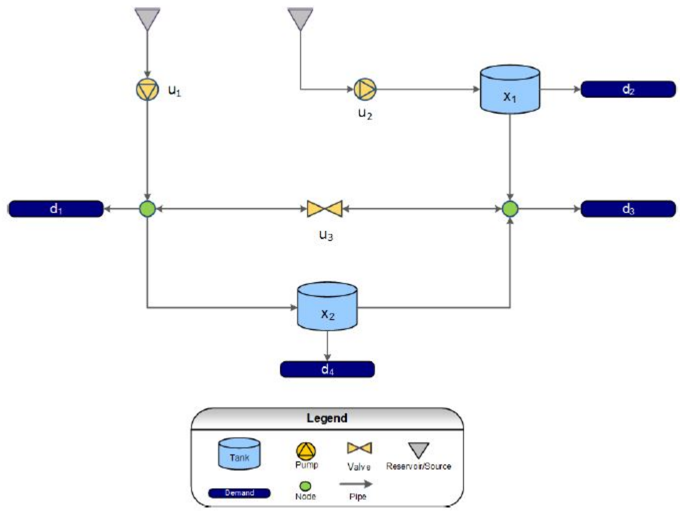


Figure 2.1: System's Diagram

2.2 The system

2.2.1 Overview

The chosen systems is a Water distribution system. it is a very simple system with equation that stay linear. We can see 2 water tanks, 2 water pomps and 4 distribution points.Voir :2.1. This system is non symmetrical as the equation for the evolution of x2 is not the same as the evolution's equation for x1

In this system we can see that x1 and x2 are the levels quantity of water in the two tanks. Our two pumps are u1 and u2, u3 is a bit particular because it's not a pump but a valve that serve to stop the communication in case of incident but in the normal case the valve is left open. This valve also serve as a point of measurement for the fault detection

This system was thought with the goal to make an example with the maximum of component and difficulties that we could find in real system. With this decision we can expect that if we are able to solve this system, we could solve the large majority of the real water distribution systems.

2.2.2 System's Equations

This are the equations that regulate our system:

$$x_{k+1} = A(\theta_k)x_k + Bu_k + B_d d_k \tag{2.1}$$

$$0 = E_x(\theta_k)x_k + E_u u_k + E_d d_k \tag{2.2}$$

With our matrix:

$$A(\theta_k) = \begin{bmatrix} 1-\theta_{1,k}\Delta t & 0 \\ 0 & 1-\theta_{2,k}\Delta t \end{bmatrix}$$

$$B_d = \begin{bmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & -1 \end{bmatrix} \Delta t$$

$$E_x(\theta_k) = \begin{bmatrix} \theta_{1,k} & \theta_{2,k} \end{bmatrix}, E_u = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}, E_d = \begin{bmatrix} 0 & 0 & -1 & 0 \end{bmatrix}$$

for our linear case, we consider :

$$\theta_k = \begin{bmatrix} \theta_1 & \theta_2 \end{bmatrix}^T = \begin{bmatrix} 0.2/\Delta t & 0.01/\Delta t \end{bmatrix}^T$$

To emulate real system we consider some limits for our system : the capacity of the two tanks , the power of the pump and for the valve the maximal flux possible. Those limits can be any set of values but for our example we will take :

$$x1 \in [0, 170]$$

$$x2 \in [0, 560]$$

$$u1 \in [0, 0.02]$$

$$u2 \in [0, 0.028]$$

$$u3 \in [-0.05, 0.05]$$

Futhermore Δt is here one hour as we change the imput in our system every hours. So we have:

$$\Delta t = 3600$$

2.2.3 Predicted and real Water demands

Modern technologies and statistical analysis allow us to have an estimation of the water demand hour by hour, we have observed a tendencies in the water demand and some periodicity in the trajectory. But our predictions are not 100 % accurate and with the observation of past values we have an error of maximum 10%.

The point of difficulty is that the system must answer an unknown demand, it causes a major difficulties with the robustness of the system. We could have some problem if there is not enough water to fulfill the water request or we could have problem if the demand is lower that we could have expected : we could make the tank overflow.

2.3 Technology

2.3.1 Model Predictive Control

Model predictive control[5] or MPC is a way to control a complex system with an emphasis on the possible future behavior. The concept is to predict more than one step at every moment to compute the best possible trajectory in the long run. The difficulties is he lack of information on the future situation : The controller only have the feedback on the present step so we have to find a way to predict the possible change in our system.

That's why the accuracy of the model is crucial for this methods, every variation can make the whole process void. The choice of the horizon is also an important point for this methods, the horizon is the furthest step the controller must predict. As we lack information on the future step we can have a big propagation on the noise effect and we a bigger horizon we can loose focus with data that don't really help us.

Our chosen system is a good focus for a simple application of this methods because the only non predictable variable is the variation of our water demand between our 10% of our predicted demand.

2.3.2 Economical Model Predictive Control

In our project[2] we have chosen to use an evolved version of the MPC, The economical MPC who try to add a economical notion in the decision of our best possible trajectory[1]. The economical notion in our system come from the cost of the pump, as our pumps use electrical power.

This electricity is cheaper during the night than the day tanks to the off-peak hour policy, this policy is present in a lot of country including Spain and France. As most of the household electricity need decrease, the electricity provider put a discount during the night.

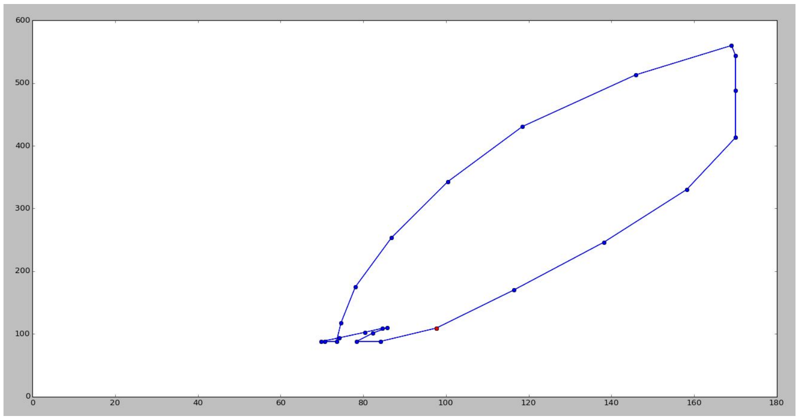


Figure 2.2: Optimal trajectory

For our system it means that it is advantageous to refill the tank during the night and to try to limit the use of the pumps during the day.

With the prevision of the demand and the economical timing we can decide of the best trajectory for our system. This optimal trajectory will be noted $Xopt_{x,k}$.

Chapter 3

Controller and Trajectory

3.1 Real and Nominal Demand

As we have seen previously, we have a prediction of the water demand that help us predict our trajectory. Therefore we have for each step two values $d_k$and D_k. The former is the nominal value know by the controller and the latter being the dependant on the first with a random component.

$$D_k = d_k + \alpha w_k$$

with w_k the mean of the 7280 $d_k$created for the project with statistics from real examples, time our uncertainties.

$$w_k = \frac{0.1}{7280} \sum d_k$$

As the uncertainties vary between $-w_k$and $w_k$so we have:

$$\alpha \in [-1, 1]$$

3.2 Controller

3.2.1 Base

As previously said, in a normal utilization we control u3 so the controller must only decide the value of u1 and u2, the two pumps.

To simulate our system, we begin to compute the value of u3, meaning the water going in the central pipe.

$$u_{3,k} = D_{3,k} - (0.2x_{1,k} + 0.01x_{2,k})/3600 \qquad (3.1)$$

Then the program computes the imput of $u1$and $u2$ considering the nominal demand d_k, the precedent step $x_{x,k}$, the optimal next step $Xopt_{x,k+1}$ and

$u_{3,k}$computed with (3). This basic controller will be combined with other methods to

$$u_{1,k} = d_{1,k} + d_{4,k} + u_{3,k} + \frac{1}{3600}(Xopt_{2,k+1} - 0.99x_{2,k}) \tag{3.2}$$

$$u_{2,k} = d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - 0.8x_{1,k}) \tag{3.3}$$

3.2.2 Robustness

Due the inaccurate part of the demand some step can be dangerous. If some demand are greater than expected , we could empty the tank and not fulfill some consumer need and other potential problem is the water going overboard if some demand are lower than expected.

Fortunately we know that the real demand will be contain within a know Interval. As such we can predict a safe interval for the input.

$$Umin_{1,k} = d_{1,k} - w_1 + d_{4,k} - w_4 + u_{3,k} + \frac{1}{3600}(Xopt_{2,k+1} - 0.99x_{2,k})$$

$$Umax_{1,k} = d_{1,k} + w_1 + d_{4,k} + w_4 + u_{3,k} + \frac{1}{3600}(Xopt_{2,k+1} - 0.99x_{2,k})$$

$$Umin_{2,k} = d_{2,k} - w_2 + \frac{1}{3600}(Xopt_{1,k+1} - 0.8x_{1,k})$$

$$Umax_{2,k} = d_{2,k} + w_2 + \frac{1}{3600}(Xopt_{1,k+1} - 0.8x_{1,k})$$

After this computation, we have to compare this limitations to the value previously chosen by the first phase of our controller:

$$Umin_{1,k} \leq u_{1,k} \leq Umax_{1,k} \tag{3.4}$$

$$Umin_{2,k} \leq u_{2,k} \leq Umax_{2,k} \tag{3.5}$$

If our precedent input is not in the border we change it by the closest safe value in our interval.

3.3 Prediction at 24 hours

Our first question is how to compute a safe trajectory if we don't have any access to the sensor information. It is useful as a safeguard : what happen if we loose the connection between the pumping system and the tank : this trajectory is , in this case our insurance.

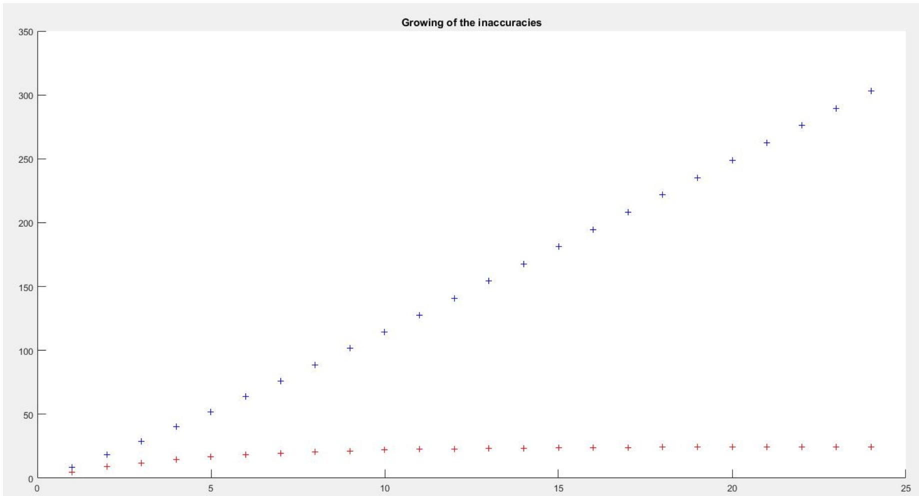


Figure 3.1: The growing Of the inaccuracies

The principal problem in this case is the propagation of our error on the demands but fortunately for us we have know border on our inaccuracies so we can computed the maximum possible error for each step of our process. With this values we can create a sequence.

$$Z_{1,k+1} = 0.8 * Z_{1,k} + w_2$$

$$Z_{2,k+1} = Z_{2,k} + 0.2 * Z_{2,k} + w_1 + w_3 + w_4$$

with:

$$Z_{1,0} = Z_{2,0} = 0$$

With the computation of this value we can assure a safe zone : a zone where we can put our Target value and be sure that the tank will neither overflow or be empty.

3.4 Sensors

One of my responsibility was to introduce sensors in our system. Previously we considered that the controller had total knowledge of the state of our system, it made a easy controller but not a very realistic one . Every machine has to relly on sensor to be aware of reality. So my goal was to introduce sensor for the variable $x_1$and $x_2$and transform our system model to take care of them

In our algorithm , it's translated in the division in two part : The reality part and the sensor part. The problem with sensors is that they introduce themselves

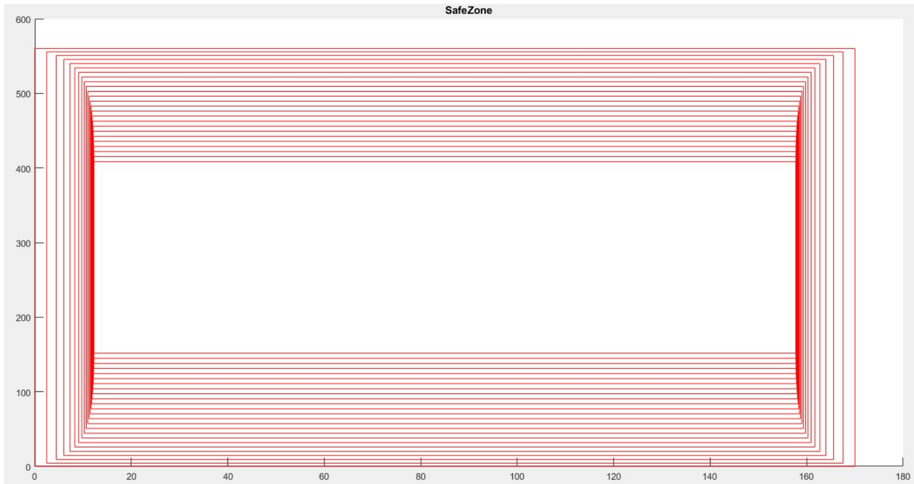


Figure 3.2: The Safe Zone

some inaccuracies as no sensor is perfect. For my work I have decided to willingly overestimate the sensor to make the problem they could bring : I have decided on 5% of the maximum of each tank.

$$x_{1,k}sensor = x_{1,k} + \alpha * 0.05 * 170 \tag{3.6}$$

$$x_{2,k}sensor = x_{2,k} + \alpha * 0.05 * 560 \tag{3.7}$$

It brings little change to our controller : the vale of u_3, is not determined with computer but with natural flow in the pipe. So the equation of u_3, does not change and is still the (4). However, the equation of $u_1$and $u_2$can't relly on $x_1$and x_2 and now must work with $x_1 sensor$ and $x_2 sensor$.

$$u_{1,k} = d_{1,k} + d_{4,k} + u_{3,k} + \frac{1}{3600}(Xopt_{2,k+1} - 0.99x_{2,k}sensor) \tag{3.8}$$

$$u_{2,k} = d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - 0.8x_{1,k}sensor) \tag{3.9}$$

The application of this command still are still the same as the one without sensor with the equation (1).

Figure 3.3: X1 with and without sensor

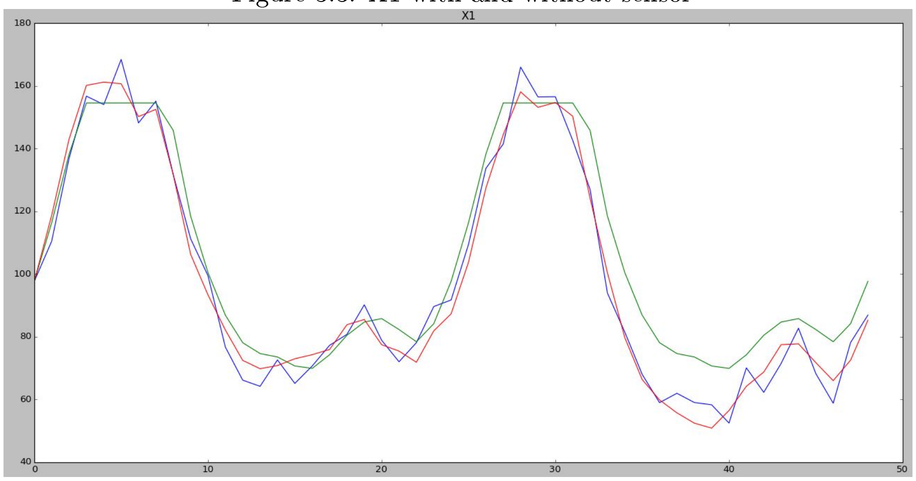
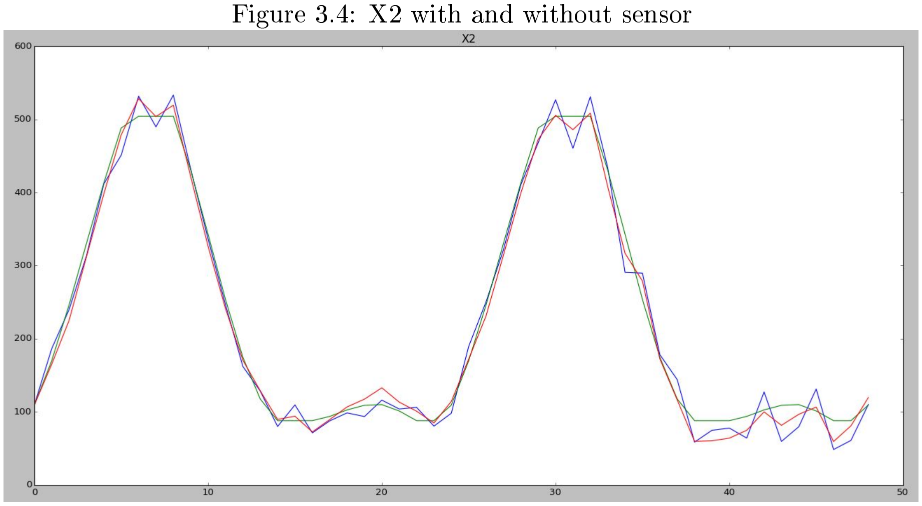


Figure 3.4: X2 with and without sensor



Chapter 4

Fault Detection

After having finished the controller part , I explain to my tutor that what I was working one could be use as a basis for a fault detection system : The basis is that as we have an interval where all our point have to be if our model is true, it means that if we have an instance where one of the point is not in our interval then our model is false : we have a fault somewhere.

4.1 Theories

Fault Detection is a crucial domain in automatic, as the system become more and more complex , the number of components grow exponentially and one little fault can make the whole system conduct itself erratically. For example in our simple system a non managed fault can make the tank overflow or can induce water shortage in a neighborhood. In more complex system, it could provoke material or human loss.Thankfully, it's one the more studied subject in automatics and a great number of work have been published.

As we can see in the literature[3], the domain has to components : proper fault detection and fault masking. The goal of Fault Detection is to watches the system for inappropriate behavior and analyses the data to found the faulty part of our system. Fault masking is a next step as it's goal is to correct the error to allow a correct use for the user.

In precedent work[3] we can see that any fault can be sorted in four categories:

- Non-observable faults : The invisible mistake that we can't see and therefore can't handle.
- Ambiguous faults : Some error can be the consequence of two different problem : in most case the cure to those two problems are different so can be unsolvable complication.
- Omission faults : This categories concern the case where an information

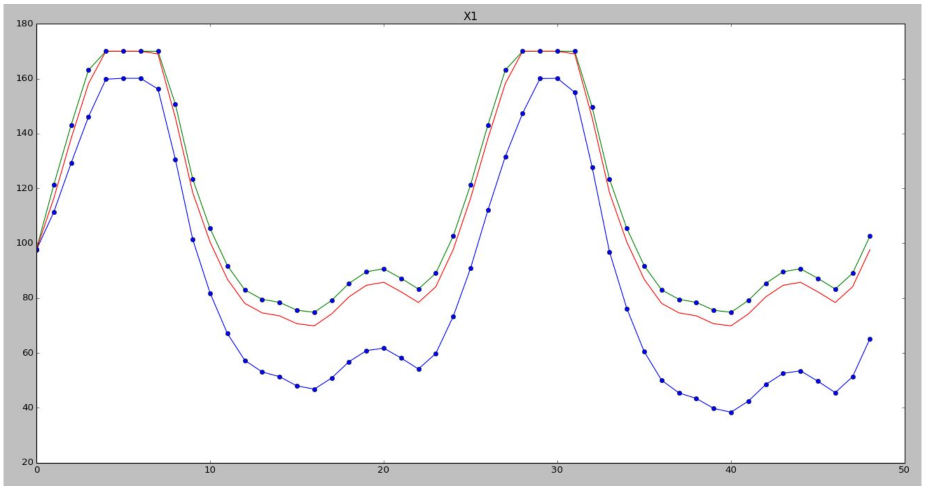


Figure 4.1: Calculated Interval X1

is not sent or received like the case where a sensor stop sending is value to the controller.

- Commission faults: Where a message is transmitted but its information is declared incorrect by the verification process.

We can only solve the Detection of the last two categories and the first one can not be seen at all by definition.

4.2 Interval analysis

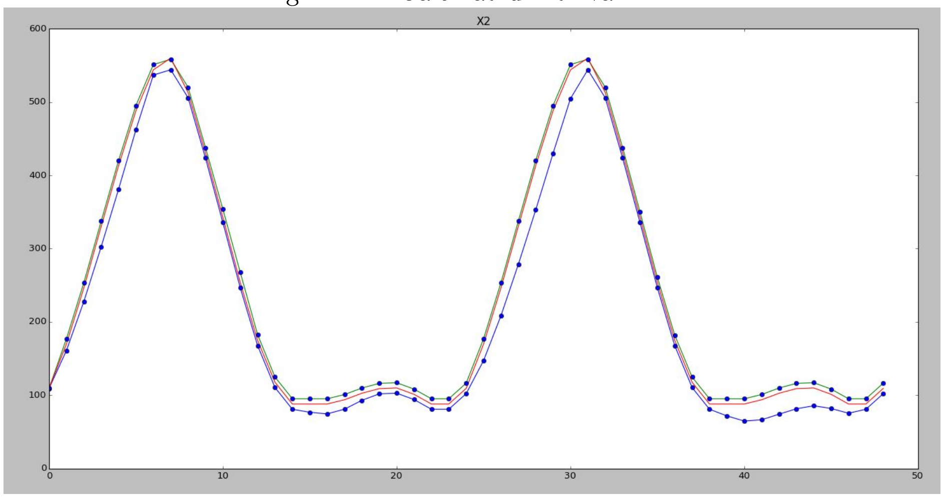
Interval Arithmetic is a simple yet robust tool to put bounds on the error in a system.[7] In our case we can use it to make a projection of all the possible case of our system. If we consider all the possible value of $D_{k,}$We can build all the possible value of our system . These intervals of $X_k$and $u_k$contain all the possible instance of a run of our system. As we consider all the parameters of our water distribution system .So if a step of an instance isn't in our calculated Interval, we can point that this instance presents a problem.

Sadly the inverse isn't true : if all the point stay within our computed interval , it doesn't mean that there was no problem in our instance, it only mean that we don't know if there was an error. It means that in our case, we may have some Non-observable faults.

The equation for this Interval are the following ones:

$$U_{3,k} = \begin{array}{c} d_{3,k} - w_3 - max(0.2X_{1,k} + 0.01X_{2,k})/3600 \\ d_{3,k} + w_3 - min(0.2X_{1,k} + 0.01X_{2,k})/3600 \end{array} \quad (4.1)$$

Figure 4.2: Calculated Interval X2



$$U_{2,k} = \begin{array}{c} d_{1,k} + d_{4,k} + min(U_{3,k}) + \frac{1}{3600}(Xopt_{2,k+1} - max(0.99X_{2,k})) \\ d_{1,k} + d_{4,k} + max(U_{3,k}) + \frac{1}{3600}(Xopt_{2,k+1} - min(0.99X_{2,k})) \end{array} \tag{4.2}$$

$$U_{1,k} = \begin{array}{c} d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - max(0.8X_{1,k})) \\ d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - min(0.8X_{1,k})) \end{array} \tag{4.3}$$

The next step is to apply those interval to the model for X:

$$X_{1,k+1} = \begin{array}{c} 0.8X_{1,k} + U_{2,k} - d_{2,k} - w_2 \\ 0.8X_{1,k} + U_{2,k} - d_{2,k} + w_2 \end{array} \tag{4.4}$$

$$X_{2,k+1} = \begin{array}{c} 0.99X_{2,k} + U_{1,k} - U_{3,k} - d_{1,k} - d_{4,k} - w_1 - w_4 \\ 0.99X_{2,k} + U_{1,k} - U_{3,k} - d_{1,k} - d_{4,k} + w_1 + w_4 \end{array} \tag{4.5}$$

4.3 Sensors

The next step of my work was to add the new model with sensors in our interval computation program. The goal was to build a new algorithm to build this interval without having access to the real value of $x_1$and x_2, as in a real case we would only have access to the sensor value of those variables.

$$Xsensor_{1,k} = \begin{array}{c} X_{1,k} - \alpha * 0.05 * 170 \\ X_{1,k} + \alpha * 0.05 * 170 \end{array} \tag{4.6}$$

$$Xsensor_{2,k} = \begin{array}{c} X_{2,k} - \alpha * 0.05 * 560 \\ X_{2,k} + \alpha * 0.05 * 560 \end{array} \tag{4.7}$$

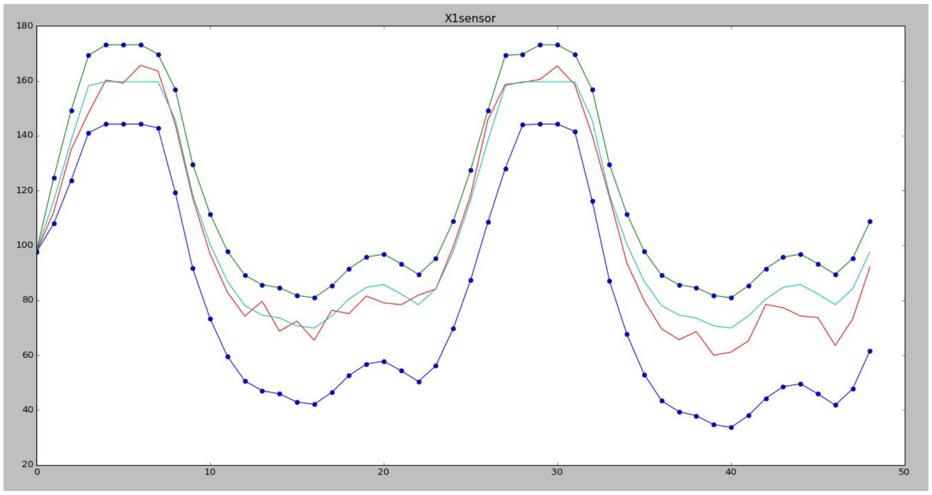


Figure 4.3: Calculated Interval X1 with sensor

We, of course, have to change the decision part of our algorithm:

$$U_{2,k} = \begin{matrix} d_{1,k} + d_{4,k} + min(U_{3,k}) + \frac{1}{3600}(Xopt_{2,k+1} - max(0.99Xsensor_{2,k})) \\ d_{1,k} + d_{4,k} + max(U_{3,k}) + \frac{1}{3600}(Xopt_{2,k+1} - min(0.99Xsensor_{2,k})) \end{matrix} \tag{4.8}$$

$$U_{1,k} = \begin{matrix} d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - max(0.8Xsensor_{1,k})) \\ d_{2,k} + \frac{1}{3600}(Xopt_{1,k+1} - min(0.8Xsensor_{1,k})) \end{matrix} \tag{4.9}$$

With this we obtain an Interval of the correct value for our sensors : like the case without sensor it mean that we can detect some error.

4.4 Upgrading the precision of our sensor:

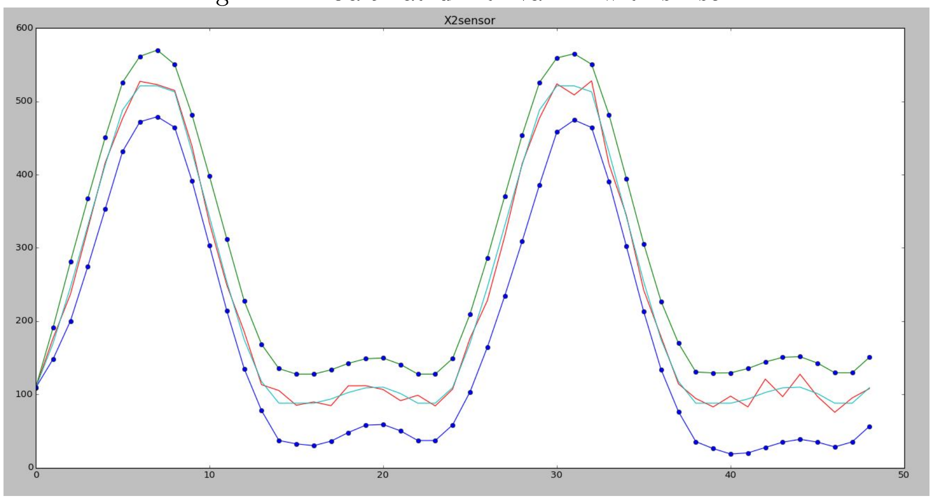
A way to make the precision of our system better and to counter the error of our sensor is to use the fact that we know thank to our computation where can be our real value of our system, so we can correct some of the sensor value that bring us out of this bound .

An other way is to use interval arithmetic on every step to correct the value of our sensor : if two step seem incoherent between each other it mean that our sensor may have overestimated or underestimated the value of our state.

of course the danger is to confuse an imprecision of the sensor with a real error like a leak or a faulty sensor.

My test have shown me small but positive result with our methods we raise the precision by 10.07 % on x2 but only 1.76% on x1

Figure 4.4: Calculated Interval X2 with sensor



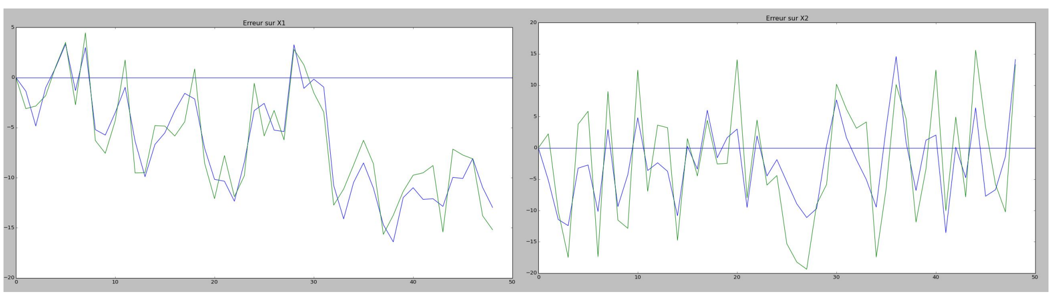


Figure 4.5: Graph of the error without correction

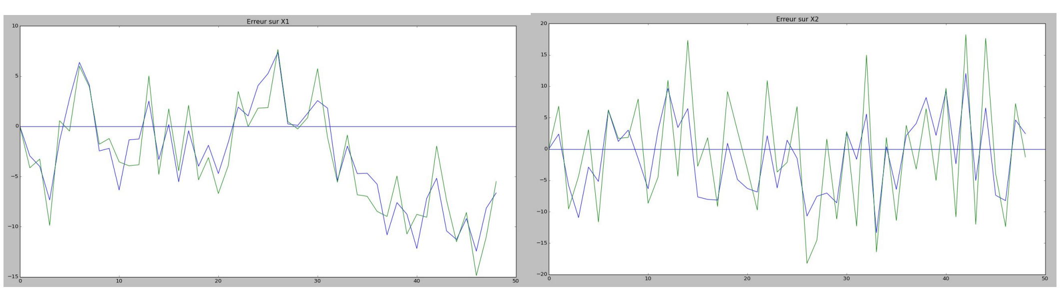


Figure 4.6: Graph of the error with correction

Chapter 5

My professional Project

5.1 Working abroad

This Internship was my first real experience outside of France, it have more than doubled the sum of time I live abroad. I can confess that I was afraid about having to live with my English as I consider myself better with comprehension than with expression. After this three month, I can say if my English is better but it's surely more fluent. I was able to make myself understood In nearly every place : Most of the problem was during my free time with inhabitant with dubious English, In The center everyone was speaking English : even the presentations were in English.

The scenery change was bigger than just the language, I can confess than I was underestimating the difference between Spain and France : The biggest contrast was in the method of communication : From what I have seen the french use a lot more E-mail than the Spanish for communication where the Spanish would prefer a face to face meeting. I have tested working abroad and I have checked the required 3 month in a foreign country of my diploma and for now I thnk I will search for the final 6 months internship in France. I don't feel I need more foreign experience and safe from a wonderful offer, my first job will be in France.

5.2 Industry vs Research

This Internship also allow me to experience working in a research institute which is really different from a company : my first internship was in Thales : a global company. It was really two contrasted world : In the first one their was a bigger presence of the hierarchy . Stress was more present as there was army contract and concrete objective to achieve. The research center in comparison was more relaxed with an invisible management part, we had more place for initiative and the reunion were more brainstorming than work checking.

One thing for sure, I will try to have my last internship in an Industrial company : my first year stage was not really an engineering stage and I need a last test before my first 'real' job. The last question mark is on the size of the company : my conversation with some of the former students , the job of an engineer is very different according to the size of the company. The Start-ups are more demanding but more rewarding, not on the money side but on the fulfilling side.

I have a tendency to become easily bored so a more active job is better for me.

5.3 Interval Computation & Robotic

Interval computation is one of the skill, I learn in second year. We only seen some of the use of this method. But now after three month of work on it, I have enough experience to say that despite the power and usefulness of Interval computation, I found it too far into the mathematics, I prefer the algorithmic part : building the intelligence ' of the system : its adaptability. I acknowledge the utility of interval and would keep in my bag of solutions in the future but I don't think it will become my job in the future.

This internship really help me define my professional project and I will search for a more classical robotic project as my last stage. My second year project was on flying autonomous drone and the experience was really good , my only regret was that we rely heavily on Firmware : time and money was against our dream.

The ideal would be a stage in humanoid robotic or autonomous vehicle but that's not the easiest internship to get.

Chapter 6

Conclusion

This internship allow me to have my first real professional experience as an engineer : my first stage was really just a ' discover the professional ' world stage. So it was the first time I use my engineering skills in a ' real ' context. The result is that I have enjoyed this internship. The structure of the job : discussing the objectives , having a time limit and the liberty to organize my timetable as I want and the liberty to attack the problem as I want is really a way of work I enjoyed.

The Confirmation that what we learn in classes is really useful is nice to have : there is a difference between knowing that what we learn is useful and seeing it in practice. But despite that this internship also confirm something that a lot of the ancient student told me : We may follow a lot of classes , in most of the case the work of an engineer are so specialized and technical that we have to be autodidact and learn by ourselves how to do the task we are asked by reading scientific paper and inspecting documentation. I have made this experience with the Fault Detection I build during the last part of my internship, I had to learn by myself and understand how to do it with the help of paper written by professor and researcher in the domain.

My work on interval was interesting but not something I want to work all my life on. Helping my coworker the Phd Student with its project of Water distribution system was interesting, I had to learn and understand how worked there system, design a robust controller for the system and find how to improve their finding with interval computation. The last part was a project approved by my tutor that I proposed. The fault detection make me explore the possibility of interval computation. The result are not really ground breaking but for the most part we are stuck because of the uncertainties in the demand that bring irreducible randomness in our system. It limit the effect that our methods can have on our system.

The most useful experience I have with this system is the experience in an international context. Even if my internship was not on the other side of the world : only 1 300 kilometer divide Barcelona and Brest. But the fact that none of my coworker was a native English speaker meant that we had to rely on a second language to talk. I really think it help my English : I wasn't bad in English and never had any difficulties to understand English but I wasn't the more fluent speaker of the language of Shakespeare. but having to speak English for more than four hours a day provide an intense training and I'm confident that I could work in an international team now.

Of course there are thing that could have been better on this internship : I could have worked with more complicated system that force me to use more complex tools like vibes . For example the next phase of the project I worked for was on a non linear system : it would have make my work more complex and I wish I had time to make more advance on the fault detection, it was one of my favorite domain of work during this project and I learn a lot with the reading of scientific papers.

In any case this stage provided the obligatory three months of foreign experience for my diploma and was a good human experience, I discovered the world of a research lab and have seen the current progress in robotics

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