Suspension system in a spray boom using a fractional PID controller

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Abstract: - This work investigates, by means of numerical simulations, a suspension system in a spray boom using a fractional PID controller. In recent years, an increase in global demand for food has required a major usage of fertilizers and pesticides. However, their applications in agriculture should be as uniform as possible, reducing waste, production losses, economic consequences and environmental contamination. In general, it has been given greater importance to the active ingredient used like poison over application of techniques and equipment. That means that there is a decrease incontrol, leading to an increase in recommended doses for application. In order to decrease the scroll of the spray boom and thus ensure more uniform application, the modern sprayers are equipped with a suspension that has the function of keeping the spray boom parallel to the ground. This suspension requires a control system that optimizes its stabilization function. In this study, a fractional controller is applied to sprayer when it is in operation. Simulated and experimental data are considered. The experimental data of acceleration caused by vibration in the spray bar are obtained with the use of sensors installed on the bar. The main and preliminary results show a better performance of the fractional P$I^{\lambda}D^{\mu}$ controller when compared to a classical PID. Therefore, such controllers can contribute to the development of more efficient systems involving applying pesticides and fertilizers in agriculture.

Key-Words: Control in Complex Systems; Modeling, Simulation and Optimization; Nonlinear Fractional Dynamics and Applications.

1 Introduction

With the increase in agricultural production in the world, seeking to meet the increase in food consumption caused both by increasing population rate in some regions, but also due to greater access to certain foods by the population, was increased also the need to utilize defensives and fertilizers. For a more efficient use, reducing waste and environmental pollution, good uniformity of application is needed [1]. During the treatment, it is essential to evenly apply the required dose of agrochemicals over the field. An application of less than the amount required is not entirely effective, while excessive application leads to environmental pollution, excessive waste and other damage. A poor application also brings economic consequences, as poor control of pests and weeds can result in production losses, affecting the producer's earnings. In addition, the over-application results in economic losses beyond what is necessary for the use of products that do not require being bought.

According to Rodrigues et. al [2] the herbicide, for example, must exercise its action on the body to be controlled; so any amount of chemical that does not reach the target will have no effect and will represent a form of loss. However, what we see in the field is the lack of information on the technology of application. In general, it has been given great importance to the active ingredient used and little application of techniques and equipment. This causes less effective control and induces to application doses above the recommendations required, increasing the cost of production.

Studies indicate that the roll motion of a vehicle is responsible for variations in the volume of distribution in between 0-1000%, a range of up to 100% would be common due to field variations. To decrease the scroll of the spray boom and thereby ensure better application uniformity for the sprayers they are equipped with a suspension that has the function of keeping the spray boom parallel to the ground [3]. This suspension requires a control system that improves upon its stabilizing function. For this there is the need to developing systems that meet the variations, both in the field and in other aspects that influence stability of the spray boom and thus ensure a correct application.

One of the control systems that can be used is the PID (Proportional, Integrative, Derivative). In the case of this controller design, the earnings of each driver component are calculated. Considering this controller, it is also worth noting that it can be designed using concepts of fractional calculus. This work is one that involves PID automatic control systems of fractional order (FOPID) [4,5].

Fractional calculus utilizes concepts of non integer order derivatives and integrals in several areas of human knowledge. In some of them, its application has shown promise. At the same time, other as well as in some specific applications has shown to be more effective and / or efficient alternative. The most common way to represent a PID controller of fractional order is designating P $I^{\lambda}D^{\mu}$ as a controller, where λ and μ represent arbitrary parameters hat can be integers (classic case) or not (in the case of fractional calculus) [5] .

The fractional calculus began, according to some authors, in 1695. Since then, several studies in numerous areas have studied the application of fractional calculus. One of the most diverse application areas involves projects related to the control of vibrating systems. These systems include land vehicles, robots, other autonomous systems and even drones. Espíndola et al. proposed to apply the fractional calculus with an objective function defined by Frobenius norm to mitigate vibrations in the door of a car [6].

David and Valentim [7] applied the Euler-Lagrange fractional equations to study the behavior of shaped oscillatory systems. The fractional calculus was also used to explore the dynamic modelling and numerical simulation of a rigid robotic system with two degrees of freedom, as in other work of David et al. [8].

In the case of spray bars, many manufacturers use their own models for passive suspensions. But, the most used are the pendulum model and trapeze style. Such models can be studied with the intention of using active components in such suspensions. Moreover, control of these active components can be evaluated in the context of fractional calculus and may have their performance compared with traditional controllers. This study aims to provide some contribution in this regard.

In this view, this study intends evaluate and compare two control systems (integer and fractional) applied to a spray bar and whether they can meet the requirement to smooth the movement of this scroll bar. Also, calculate the gains of these two systems in conditions of simulating.

2 Problem Formulation

In this model, the bar is attached to the sprayer frame by an arm.In the illustration presented in Figure 1, there are two points of revolution which move according to the movements of the spray bar. The center of mass of the bar is located in the middle and in the case of a tractor without suspension, the scrolling movement is caused by the rotation of the rear axle when one wheel rises more than the other.

To analyze the vibration in this bar, are considered the α angle (angle variation of the sprayer frame) and the β angle (the angle of variation in the spray bar).O'Sullivan [9] studied and made a mathematical model for this type of bar is as follows:

$$\frac{\beta}{\alpha}(s) = \frac{Es^2+\mu s}{Fs^2+us+G} \tag{1}$$

where,

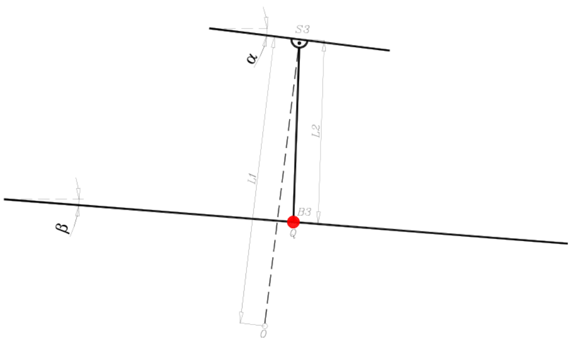
$$\mathrm{E} = \mathrm{Mb} * \mathrm{L2} * \mathrm{L1} \tag{2}$$

$$\mathrm{F} = \mathrm{Ib} + \mathrm{Mb}(\mathrm{L2})^2 \tag{3}$$

$$G = MbacL2 \tag{4}$$

and where beta over alpha is the frequency response relating α to the roll angle of the bar β. *Ib* is the moment of inertia, *L1* and *L2* are the lengths of the bars, *Mb* is the mass of the bar, μ is the rotational damping coefficient and *ac* the acceleration of gravity.

Figure 1. Bar pendulum model .



2.1 Methods

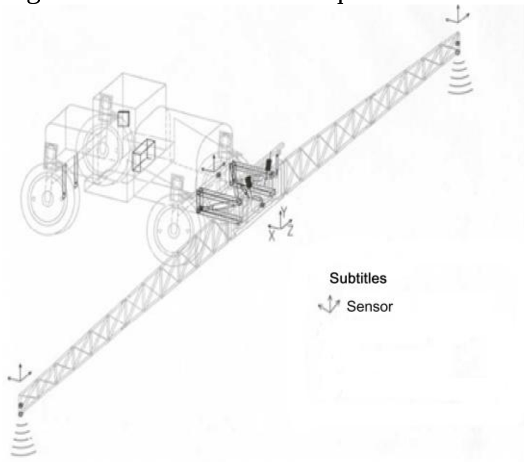
To perform this tests, it was initially used the pendulum model described in the previous section. This model proposed for the system, shown by the equation [1] to [4], was included in Matlab Simulink ® software and calculated the optimal values of PID controller gain (fractional and integer). For this simulation we used a constrained optimization method for finding the best parameters (gains) for the controllers and the best fractional orders to the problem of the controller $PI^{\lambda}D^{\mu}$. The said method is based on the one proposed by Xue et al. [10], which relies on the driving method for fractional derivatives Oustaloup modified.

In order of bringing this work closer to a real situation, vibration data were obtained in a sprayer at FZEA/USP campus, Brazil. The tests were performed on an area in the University itself following the speed and path patterns that would take place at a pesticide application.

In this study we used the data obtained when the machinery was being operated at 7 km/h and the tank containing 500 liters (about 20% of total) and 2500 liters (about 80%) of the total capacity. These data were chosen because they are commonly used in operation and in order to evaluate the vibration on a full tank and on a tank during the final moments of application.

Figure 2 shows a schematic diagram for obtaining the vibration data.

Figure 2. Scheme of data acquisition.



The values of the following parameters were used in the numerical simulations:

Mb = 200 kg;
Ib = 2400 kg.m²;
L1 = 1.4m;
L2 = 0.45 m;
μ_r = 400N.m.s/rad;
ac = 9.8 m/s²;

3 Problem Solution

Initially they were calculated in MatLab® the values of the gains (Kp, Ki and Kd) for fractional and integer models. These data were obtained using a step function with an input value in the system, a final step of 0.1, zero initial value and by starting at time zero. With this simulation, the gains are listed in Table 1:

Table 1.Gains

	Kp	**Ki**	**Kd**
FOPID Gains values x 10^7	6,0818	6,0818	6,0818
PID Gains values x 10^3	6,0299	5,7478	0,2553

The value of μ is 0.7, and the value found for λ, which is the fractional value of the derivative gain was calculated 0.1. The output obtained in this case for two systems are shown in Figures 3 and 4 as follows:

Figure 3. Output to input step in the PID system

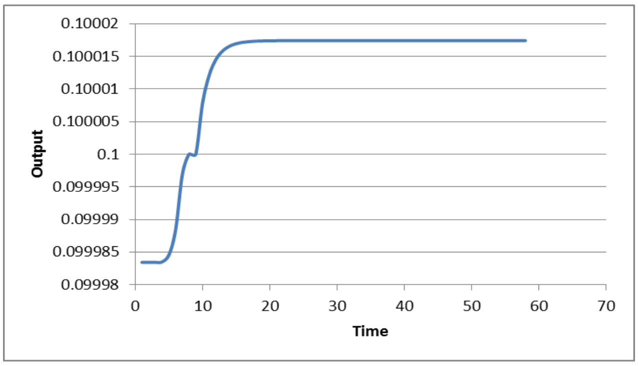
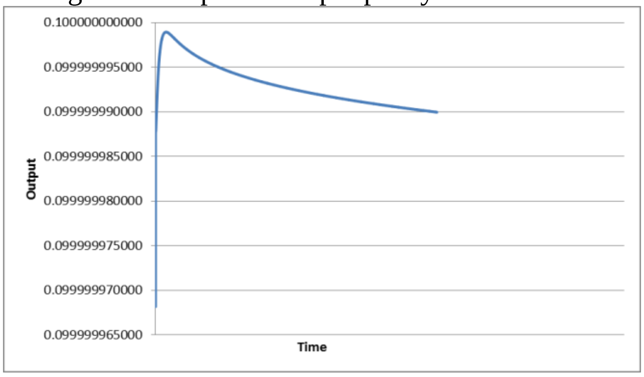


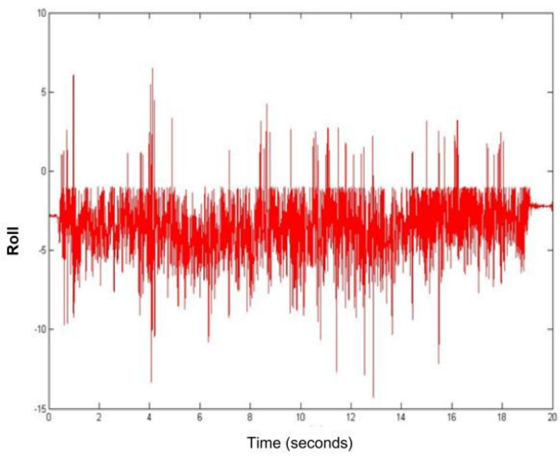
Figure 4. Output for step input system FOPID



From both graphs, we can see that the two systems did not stabilize at the desired value 01. The PID system stabilizes above this value and the FOPID slightly below. The FOPID system has a peak time (time to obtain the value of 0.1) of 10 seconds, while the PID system achieves this peak in 12 seconds.

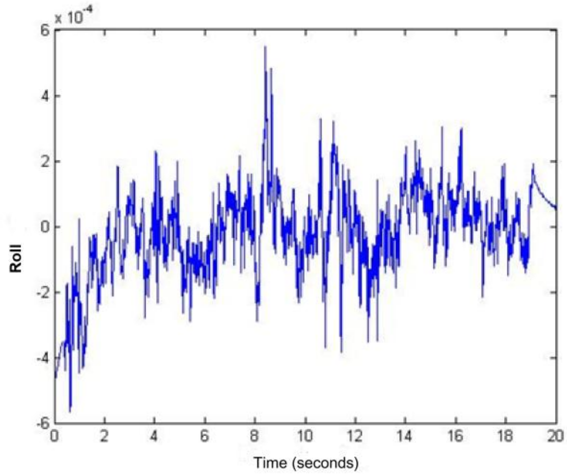
The first test was done with the signal obtained at 7 km / h and the tank filled with 500 liters of water.

Figure 5. Input variation with 500 liters



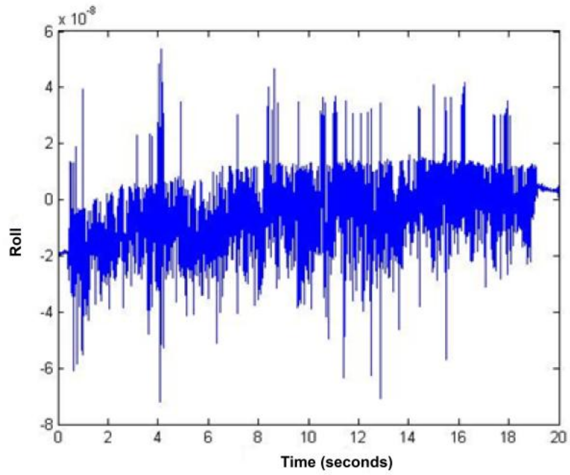
This input signal has small variations that reach an angular displacement of 14º. The average of vibration values was 5 °.

Figure 6.PID output range



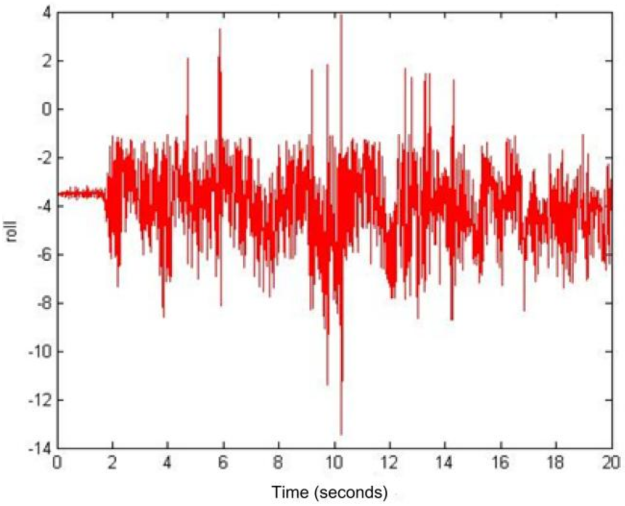
In figure 6, for the PID system is noted that the output variation was very close to zero and a more smoothed graph with less vibration than the input value, which represents the vibration of the soil (uneven terrain, stones, pieces of wood on the way from other obstacles). That is, the system was damped.

Figure 7. FOPID output range



In comparison, the FOPID system gave a response where the vibration frequency was higher, but with a much smaller amplitude values than in the PID system. While in the PID system the amplitudes were in the order of 10^{-4},in the FOPID system the order was ten thousand times smaller, around 10^{-8}.

Figure 8. Input variation with 2500 liters

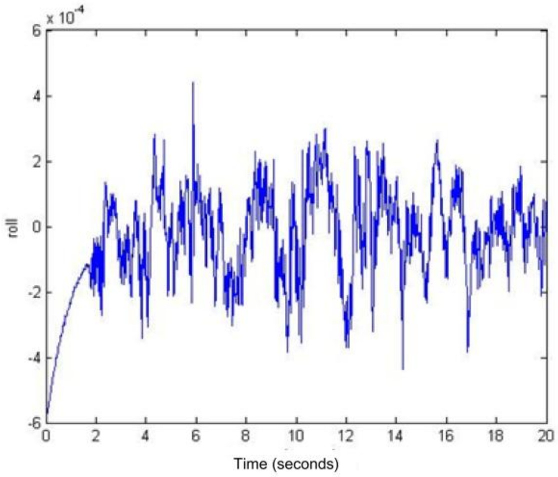


By examining the 2500 liters entry, we can observe that the average change was 4º. With a spray tank fuller, the system becomes more stable and with lower degrees of rolling. This may determine better management in the field and even give voice to a recommendation of decreasing the application speed in order to reduce vibration.

According to Sartori [11], the fluctuations have more intensity with increasing travel speed of the tractor, length of the bar and non-use of damping systems. Therefore, determining the most suitable speed for the amount of liquid application included in the tank helps to decrease the maldistribution in the field.

According to Speelman and Jansen [12], increasing the travel speed of the whole tractor / sprayer, from 6 km / h to 9 km / h increased the value of the liquid distribution variation coefficient.

Figure 9. PID output range

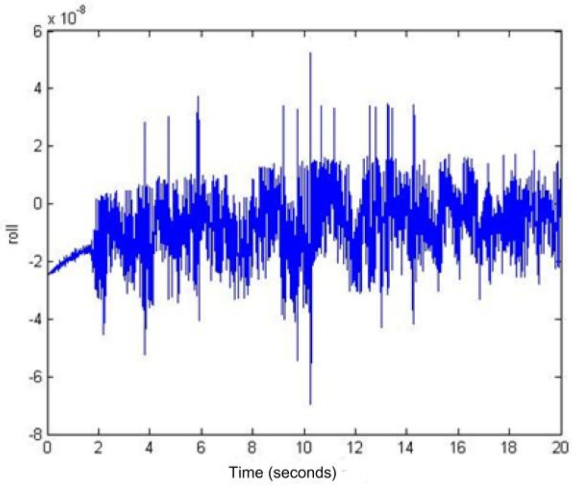


In this system,the traditional PID has damped the vibrations on the order of 10^{-4}, thus having a performance similar to the system containing 500 liters in the spray tank.

In the FOPID system, as seen in Figure 10, again the attenuation was of the order 10^{-8}, with the values being closer to zero, as required in the experiment. The outputs of the fractional systems were more consistent with minor variations of amplitude. However, the outputs in traditional PID has more variation inamplitude. The lower amplitude variation of the FOPID system (ten thousand times smaller in both cases) suggests an advantage to improve application efficiency.

Because, according Speelman and Jansen [12], an increase in the amplitude has a negative effect on the application in all types of used nozzles. The increased vertical bar oscillations caused by irregularities in the terrain affect the distance between each nozzle and the target and distorts the distribution [13]. That is, the application becomes non-uniform, reducing the implementation efficiency or accumulating syrup in places where the application would have a lower necessity. Also, when the amplitudes of variation are excessive, the extremities of the bar may touch the ground, causing damage to the structure. [13]

Figure 10. FOPID output range



Pontelliet. al [3], in a system with speed 5km / h, damping, but without a PID controller, have obtained a variation of 1 ° in an unhindered track. This shows that the simulated control system can further reduce vibration compared to cushioning.

We can notice that the two systems cause reduction of system oscillations, though the fractional system holds greater attenuation, keeping much closer to a zero variation in the case of this study.

4 Conclusion

We can conclude that the two systems may be useful to this type of application, showing a softer vibration of the spray bar.

It is noteworthy, however, that the performance of fractional controller proved to be more efficient, achieving greater smoothing in fluctuations in the simulated bar when compared to the classic controller.

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