Golf Simulator in Scilab:
Capturing a swing and estimating the cary with a tiny low-cost Radar

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ABSTRACT

By using the equations of golf ball flight dynamics, this article demonstrates how to code a swing simulator for a ball in Scilab.

The simulator uses an ODE (ordinary differential equation) solver from Scilab, the fluid dynamics equations on a ball (taking into account gravity, drag forces, and Magnus forces), the restitution of forces from a golf club applied to a ball for launches, its flight, bounce and roll.

In the second part, the article presents a method for capturing the speed of the ball in flight using 2 low-cost radars, coupled with an Arduino Mini and an adapted sound card.

The radar signal is recorded in WAV format and filtered to extract speed and spin information during flight, using power spectral density.

Keywords: *Golf Ball, Simulator, Scilab, Radar, Spectral dentisty.*

Chapter 1

Introduction

After spending a few years playing golf, I wanted to learn more about the dynamics of the interactions between the club, the ball, and the elements.

Of course, the academic literature and publications were quite abundant. But I came accross articles [PWB76] written in 1976 and [SS94] in 1994. The description of the ball's physics pushed me to undertake modeling this system in Scilab (fig 1.1). Subsequently, I did it in Java, C++, and then C# to use it under *Unity game engine®™*.

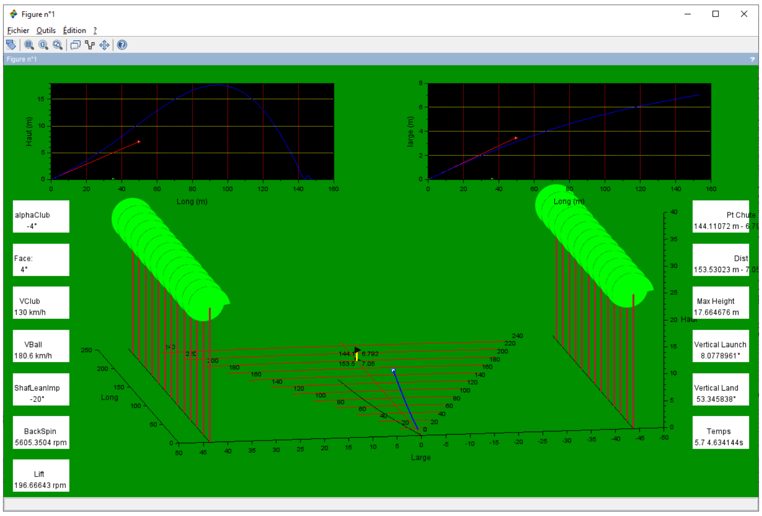

Figure 1.1: HMI Of Simulation

When the results were satisfactory, I thought about capturing the flight of a golf ball with instrumentation. After tests with sonar, which were largely insufficient, I took small presence detection radars for automatic doors.

I didn't know what I was getting into, but after a updating my knowledge on signal filtering and a few lines of programming in Scilab, I found a way to capture the essential data. Namely the speed and backspin of the flight of a golf ball (figure 5.4).

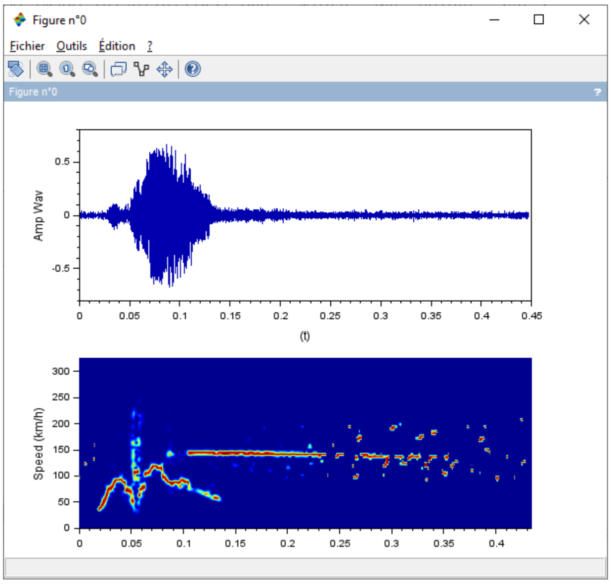

Figure 1.2: Radar Captures

This article describes all items I found, and how I set all them together. Equations, programs, filtering, estimators and electronics compounents to make a Virtual Golf Simulation.

All the equations presented in this article are derived from public publications or books, with references listed in the bibliography. I will not revisit the demonstrations and physical explanations, as they are not the focus of these pages. What matters to me is the relationship between this information and how I have used or adapted it.

Chapter 2

Golf Ball Flight

The main equation is the ball's flight. The equation accounts 3 forces : Magnus Force, Air Drag Force and gravity, such as :

$$\sum \overrightarrow{F} = \overrightarrow{F_m} + \overrightarrow{F_d} + \overrightarrow{F_g} \tag{2.1}$$

2.1 Drag Force

2.1.1 Air characteristics

Definition 1: The Air Drag Force	*The Air Drag Force is the resitance exposed on the cross-sectional area of an object, orthogonal to the displacement, determined by the relation given by [BR] as 2.2*

:

$$F_d(V) = -\frac{1}{2}.\rho(T).C_d.S.V^2(t) \tag{2.2}$$

where:

$$\begin{aligned}
\rho(T) &= 1,292 * \frac{273,15}{273,15+T} \\
\rho(T) &= Air\ density\ Rho\ depending\ on\ temperature\ T \\
T &= Temperature \\
C_d &= Drag\ Coefficient,\ depending\ on\ the\ object \\
V &= Object's\ Velocity \\
F_d(V) &= Drag\ Force\ due\ to\ Air\ Resistance\ depending\ on\ velocity\ V \\
S &= The\ cross-sectional\ area\ exposed,\ orthogonal\ to\ the\ displacement.
\end{aligned}$$

2.1.2 Ball's characteristics in the air

Considering those characteristics of a dimpled ball model,

$$\begin{aligned}
mass\ m &= 0,04593\ g \\
Dynamic\ viscosity\ \mu &= 1,5.10^{-6} m^2/s \\
Diameter\ D &= 0,04267\ m \\
Radius\ r &= \frac{D}{2} \\
Inertia\ I &= \frac{2}{5}.m.R^2 \\
Cross-section\ S &= \pi.R^2 \\
Ball\ Velocity &= V
\end{aligned}$$

We have an estimated models,

$$Re = \frac{\rho(T).V.D}{\mu} \tag{2.3}$$

$$C_d = 0,36 + \frac{24}{Re} + \frac{6}{1+\sqrt{Re}} \tag{2.4}$$

$$\overrightarrow{F_d} = -\frac{1}{2}.\rho(T).C_d.S.\sqrt{(V(x)^2 + V(y)^2 + V(z)^2)}.\widehat{V} \tag{2.5}$$

where,

$$\begin{aligned}
\widehat{V} &= Unit\ vector\ of\ the\ velocity \\
Re &= Reynolds\ Number\ estimator \\
C_d &= Drag\ Coefficient\ White's\ relation \\
\overrightarrow{F_d} &= Drag\ Force
\end{aligned}$$

***Remark 1:** Finally, the equation of the drag Force along the 3-axes becomes 2.6*

$$\overrightarrow{F_d} = \begin{pmatrix} -\frac{1}{2}.\rho(T).C_d.S.v_i^2 \\ -\frac{1}{2}.\rho(T).C_d.S.v_j^2 \\ -\frac{1}{2}.\rho(T).C_d.S.v_k^2 \end{pmatrix} \tag{2.6}$$

2.2 Magnus Effect

***Definition 2:** The Magnus Effect* — *The Magnus [Mag53] effect is due to the spin of a cylindrical object, moving in a fluid (air). It is called the Robin effect for a ball.*

But by generalization, the Magnus effect name is applied to any type of object subjected to this suction force. This lift force occurs, altering the ballistic trajectory of the golf ball. The Force depends on the Lift coefficient (C_l), that is associated with the object, according to its shape, nature and texture. So that the force is written as a composant of Object Velocity, SpinRate and a coefficient of Magnus effect C_m (2.7),

$$\overrightarrow{F_m} = C_m.(\overrightarrow{\omega} \times \overrightarrow{V}) \tag{2.7}$$

where,

$$\begin{aligned}\omega &= spin\ in\ rad/s\\ V_p &= r\omega\ periferal\ velocity\\ V &= Ball\ Velocity\\ C_m &= Coefficient\ of\ Magnus\ effect\end{aligned}$$

The main bibliography for golf ball I used, is [PAL05] and [SS94]. I have found several ways to calculate the C_m, given in expressions bellow. The first simple aproximation is given by 2.8, and the Coefficient of Magnus effect can be given by the first two estimators bellow 2.9, 2.10 ([PAL05]). But I kept this one 2.11 ([SS94], [Ala98]).

$$F_m = \frac{1}{2}.C_m.\rho.\mu^2 \tag{2.8}$$

$$C_m = \frac{r\omega}{V} \tag{2.9}$$

$$C_m = -0,05+\sqrt{0,0025+0,36\left(\frac{r\omega}{V}\right)} \tag{2.10}$$

$$C_m = 0,5.\rho(T).S.R^2.C_l.\mid\frac{\omega}{V}\mid^{0,4}.V \tag{2.11}$$

$$C_l = \frac{1}{2+(V/R\omega)*sin(\zeta)} \tag{2.12}$$

[GAS] gives a correction or adjustment coefficient C_l (2.12) to (2.11), where ζ in Lift Coefficient, is the angle between the axis of rotation and the direction of motion. If R$\omega \ll$ V, then $C_l \simeq R\omega\frac{sin\zeta}{V}$. Certainly more appropriate than (2.9) to take into account an effect of side spin and backspin.

$$sin\zeta = \frac{\parallel\overrightarrow{\omega}\times\overrightarrow{V}\parallel}{\omega.V} = \frac{1}{\omega.V}.\sqrt{((\omega_j.V_k-\omega_k.V_j)^2+(\omega_k.V_i-\omega_i.V_k)^2+(\omega_i.V_j-\omega_j.V_i)^2)} \tag{2.13}$$

In order to meet my needs, I have choosen to provide my adapted C_l values to (2.11) instead of (2.12), from tests with my own balls (texture and number of dipples impact Reynolds number (2.3) as shown in [ASC+11]). These data are recorded in a Scilab table C_{l1}. C_m becomes (2.14).

$$C_m = 0,5.\rho(T).S.R^2.C_{l1}.\mid\frac{\omega}{V}\mid^{0,4}.V \tag{2.14}$$

My own C_{l1} from Club Mizuno JPX and Decathlon's ball are given as example in Table 2.1.

Remark 2: Knowing 2.7 and 2.14 and 2.1, I chose the following Magnus force model	$$\overrightarrow{F_m} = \begin{pmatrix} C_m*(\omega_j*v_k-\omega_k*v_j)\\ C_m*(\omega_k*v_i-\omega_i*v_k)\\ C_m*(\omega_i*v_j-\omega_j*v_i)\end{pmatrix} \tag{2.15}$$

2.3 Gravity Force

Definition 3: The gravity force	*The gravity force is determined by the acceleration g to the ground.*

Club	C_{l1}
D	0.64
W5	0.65
H3	0.54
I5	0.54
I6	0.83
I7	0.42
I8	0.53
I9	0.53
PW	0.52
AW	0.52
SW	0.51
LW	0.51

Table 2.1: Table of my C_{l1}

The gravity Force expression is simply,

Remark 3: The Gravity Force

$$\overrightarrow{F_g} = \begin{pmatrix} 0 \\ -mg \\ 0 \end{pmatrix} \tag{2.16}$$

2.4 Launch Velocity

Due to the impact of the golf club to the ball, it results a ball flight with a launch angle. The club head loft determines the launch angle, the club head speed and the texture of both determine the launch ball speed and ball spin [Pen01].

Due to the texture we have a loss in energy, that can be taken into account throught the Coefficient Of Restitution e (COR [LJ94]).

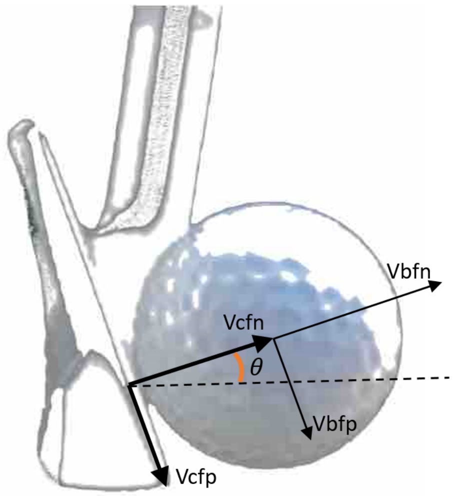

Figure 2.1: Velocity Components

[Pen01] gives an estimation of COR e :

$$\begin{aligned}
e &= 0,86 - 0,0029.V_{ci}.cos(\theta) && (2.17)\\
V_{bfn} &= V_{ci}.cos(\theta).\frac{1+e}{1+\frac{m}{M}} && (2.18)\\
V_{bfp} &= -V_{ci}.\frac{sin(\theta)}{1+\frac{m}{M}+\frac{5}{2}} && (2.19)\\
\psi_{bo} &= \theta+\arctan\left(\frac{V_{bfp}}{V_{bfn}}\right) && (2.20)\\
\omega_{bo} &= \omega_{bf} = -m.V_{bfp}.\frac{R}{I} && (2.21)
\end{aligned}$$

where,

$$\begin{aligned}
V_{ci} &= Initial\ Club\ Velocity,\ parallel\ to\ the\ ground.\\
V_{bfn} &= Final\ Ball\ Velocity\ Orthogonal\ to\ golf\ club\ face\\
V_{bfp} &= Velocity\ of\ the\ golf\ ball,\ parallel\ of\ the\ club\ face\\
\theta &= dynamic\ loft\ (\ club\ loft + Shaft\ Lean\ Impact\ <\ loft)\\
e &= COR,\ e \simeq 0.78\ for\ Irons,\ e \simeq 0.83\ for\ Drives\ and\ Woods\\
\psi_{bo} &= Launch\ Angle\\
\omega_{bo} &= Spin\ of\ the\ golf\ ball\\
I &= Inertia\ (2.3)
\end{aligned}$$

2.5 Balls Velocity with Miss sweet spot

It is difficult to perfectly center the ball and the club. The ball velocity model is modified to include a *Miss* parameter. It is the amount by which the sweet spot is missed, the initial ball velocity in this case is (2.22),

$$V_{bi} = (1 - 35.56 * miss).\sqrt{V_{bfn}^2 + V_{bfp}^2}\ (miss\ mesured\ in\ meter) \qquad (2.22)$$

2.6 Club Face Initial Velocity

Due to the Club Path (α_{cp}) and the Face to Path and Face Angle (γ_{fp}), the initial ball velocity and spin are modified.

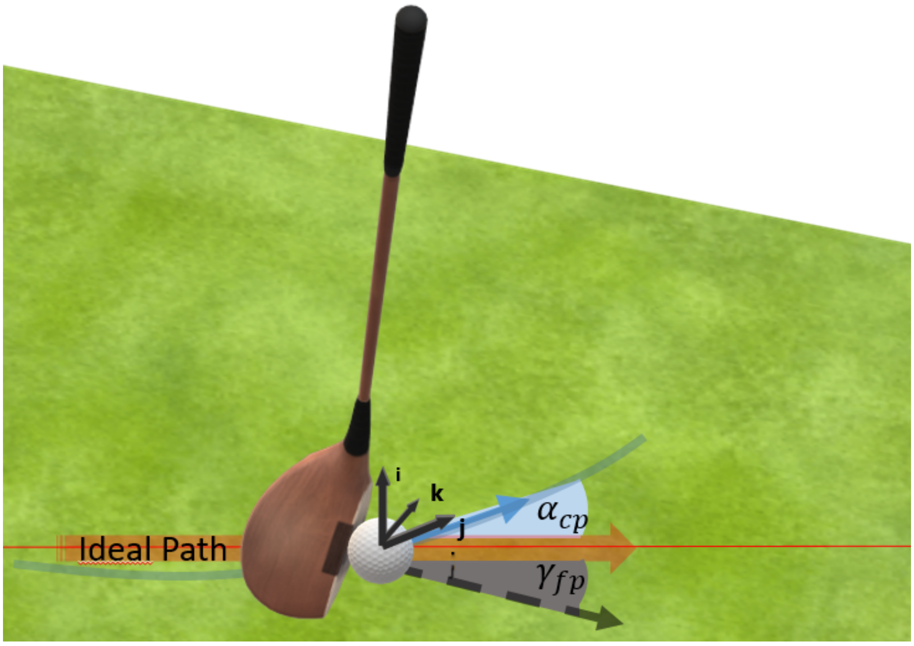

Figure 2.2: Club Path

Ainsi :

$$V_{b0} \cdot \overrightarrow{i} = V_{bi} \cdot (1 - 0.3556 \cdot miss) \cdot \cos(\theta + \arctan\left(\frac{\sin(\theta) \cdot (1 + \frac{m}{M})}{(1+e) \cdot \cos(\theta) \cdot (1 + \frac{m}{M} + \frac{5}{2})}\right)$$

$$V_{b0} \cdot \overrightarrow{j} = V_{bi} \cdot (1 - 0.3556 \cdot miss) \cdot \sin(\theta + \arctan\left(\frac{\sin(\theta) \cdot (1 + \frac{m}{M})}{(1+e) \cdot \cos(\theta) \cdot (1 + \frac{m}{M} + \frac{5}{2})}\right)$$

$$V_{b0} \cdot \overrightarrow{k} = 0$$

Le spin sur $\overrightarrow{i}$ n'est pas une composante dans l'axe du chemin de club. Le spin est applique sur le plan du sol, SideSpin est dans l'axe de la face de de club sur $\overrightarrow{j}$, et le BackSpin dans l'axe du chemin de club $\overrightarrow{k}$

$$w_{\overrightarrow{i}} = 0$$

$$w_{\overrightarrow{j}} = V_{b0}\overrightarrow{j} \cdot sin(\alpha_{cp} - \gamma_{fp}) \cdot Sac.coeffSpinLift(Sac.Type == Club)$$

$$w_{\overrightarrow{k}} = V_{b0}\overrightarrow{i} \cdot sin(\theta) \cdot Sac.coeffSpin(Sac.Type == Club)$$

2.7 Complete Model of flight

2.8 External Function for the Ordinary Differential Equation solver

Chapter 3

Bouncing and Rolling

3.1 Ball's characteristics bouncing on the grass

[RL10]

3.2 Ball's characteristics rolling on the grass

[Pen02b] [Pen02a]

Chapter 4

Hardware

Figure 4.1: The suitecase

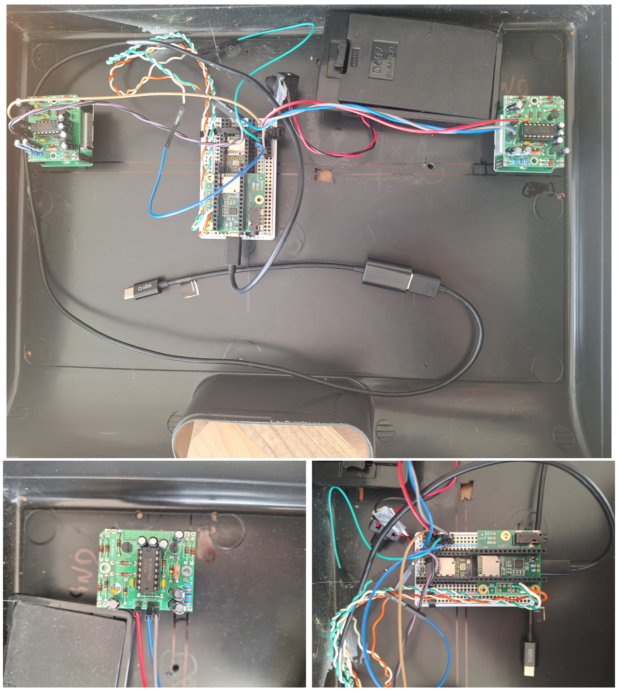

Figure 4.2: Internal with Arduino, Radar, Amplifier, Audio Boards

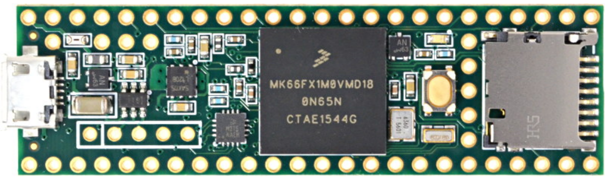

Figure 4.3: Tiny Arduino

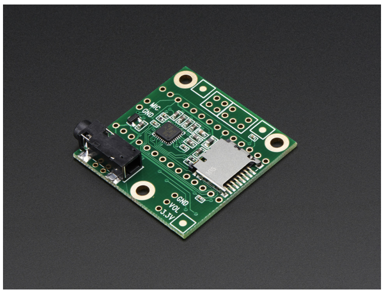

Figure 4.4: Audio Board

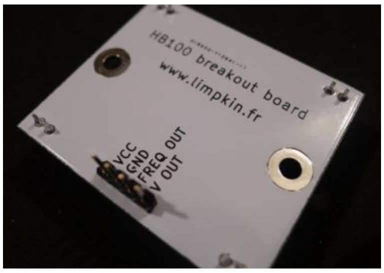

Figure 4.5: Audio Amplifier Board

Figure 4.6: Radar Board

Chapter 5

Data Anlysis

5.1 Filtered Radar Captures

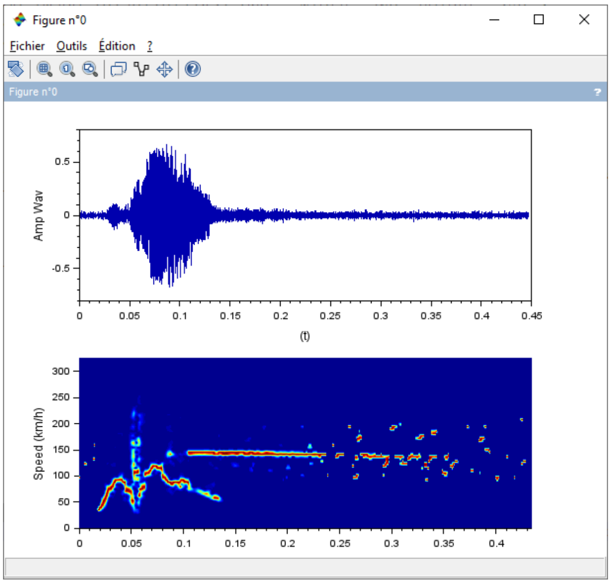

Figure 5.1: Wav Radar Captures and its echo

5.1.1 Filtering

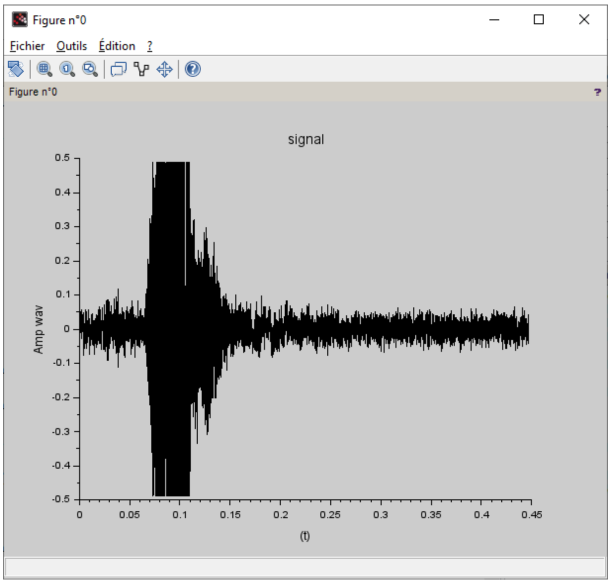

Figure 5.2: Captured Raw Data Wav

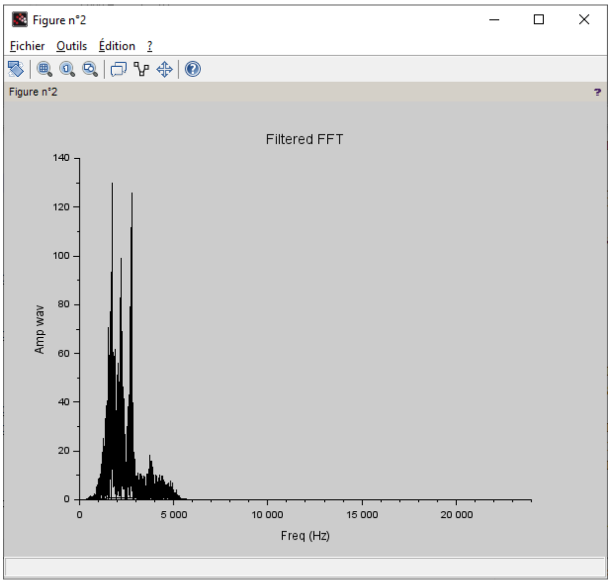

Figure 5.3: FFT of Filtered Raw Data

5.1.2 Final Result

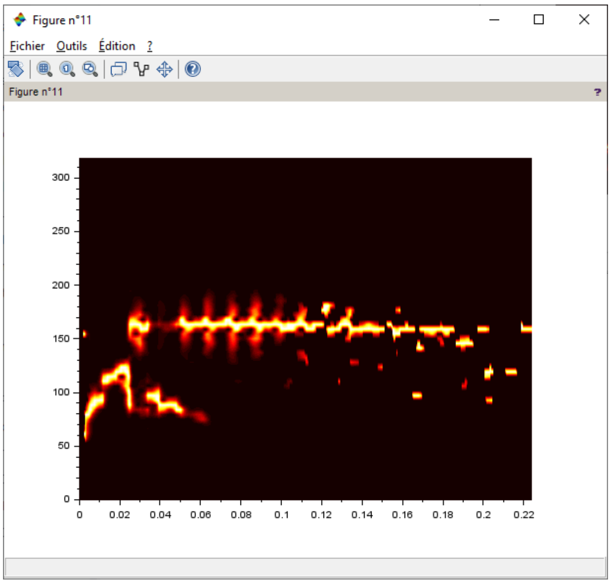

Figure 5.4: My power density Algorithm Results to identify Speed and BackSpin

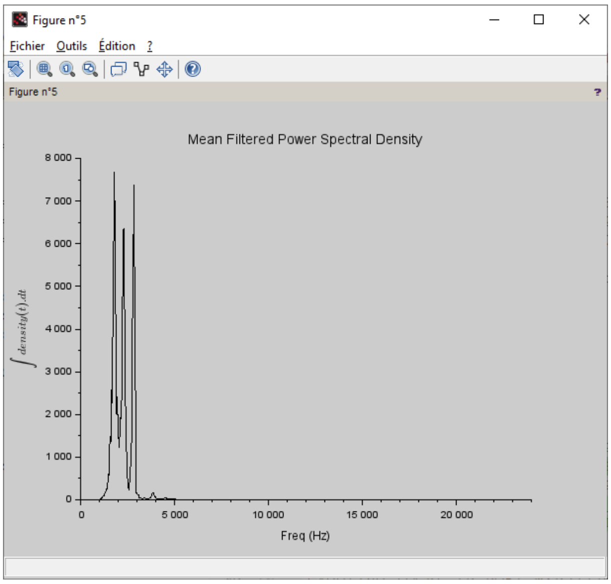

Figure 5.5: Results of normalized mean filtered power spectral density

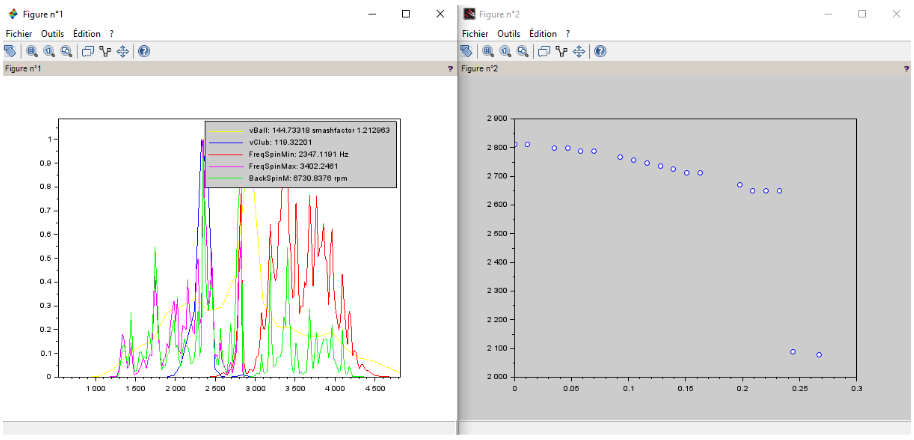

Figure 5.6: Results of the filtered Density and caracteristics identification

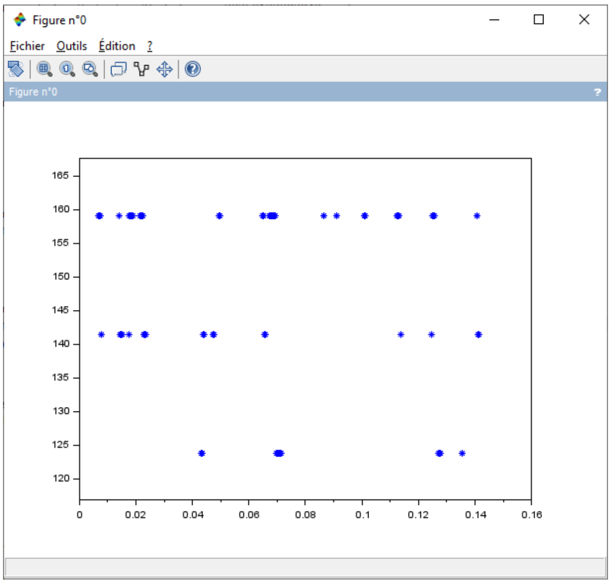

Figure 5.7: Speed and Backspin echos

Chapter 6

Listings

6.1 Golfball.sci

```
// Copyright (C) 2016 - Corporation - Author
//
// About your license if you have any
//
// Date of creation: 16 juin 2016
//
//SCI2C: DEFAULT_PRECISION= DOUBLE
//
// ReadWave : FFT_Mat.sce
//
```

Listing 6.1: Listing of the golf ball fligth

//

Conflicts of Interest

The authors declare no conflict of interest.

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