Universidad de Valladolid

ESCUELA DE INGENIERÍAS INDUSTRIALES

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

VISUALIZACIÓN DE PROCESOS DE COMBUSTIÓN CON CÁMARA DE ALTA VELOCIDAD (ANEXOS)

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AnalisisVideo.m

```
clc; clear; close all;

%% INICIALIZACION
global UnaVez;
global Parar;
global Terminar;
global Avante;
global NumFotograma;
UnaVez = 0;
Parar = 0;
Terminar = 0;
Avante = 1;
NumFotograma = 0;
Ejecutar = 1;

RadioMaximo = 1000;
NumeroIteracionesRansac = 100;
AreaCelulaMinima = 1;
VelocidadCaptura = 3124; %fps

TamanoPantalla = get(groot,'ScreenSize');
PosicionFigu = [10 50 TamanoPantalla(3)*0.8
TamanoPantalla(4)*0.83];

Nombre_Video = 'H2_fr07_p100kPa_T30';
Nombre_Extension_Video = 'avi';
Directorio_Codigo = cd;
```

```
Directorio_Videos = cd('Videos\BujiaCentrada\H2\2017-10-17');
Video_Info = VideoReader(strcat(Nombre_Video, '.',
Nombre_Extension_Video));
Carpeta = cd(Directorio_Codigo);

Num_Fotogramas = Video_Info.Numberofframes;
Primer_Fotograma = read(Video_Info, 1);
NombreExcel = strcat('Datos_', Nombre_Video, '.xlsx');

%% CALCULOS PREVIOS
%RADIO DE LA CAMARA
Contorno = edge(Primer_Fotograma);
[X, Y] = coordPixelsCont(Contorno, RadioMaximo, 0, 0);
[xInliers, yInliers] = ransacCirc2(X, Y, 50000, RadioMaximo,0);
[A, B, C] = LMSCirc(xInliers, yInliers);
RadCam = sqrt(A^2+B^2-4*C)/2;
CntCamX = -A/2;
CntCamY = -B/2;
Calibracion = RadCam/5.7; %pixel/cm

%% BUCLE
ControlTratamiento();
movegui(ControlTratamiento, 'east');

Nini = 1;
Nfin = Num_Fotogramas;
NumeroFotograma = Nini;

%Variables Salida
radio = zeros(1, Nfin-Nini);
tiempo = zeros(1, Nfin-Nini);
NumeAreas = zeros(1, Nfin-Nini);
Sn = zeros(1, Nfin-Nini+1);
Stretch = zeros(1, Nfin-Nini+1);

while (Terminar == 0)
    if (NumFotograma == 1)
        NumeroFotograma = Nini;
        NumFotograma = 0;
    elseif (NumFotograma == -1)
        NumeroFotograma = Nfin;
        NumFotograma = 0;
    end
    if (Parar == 0 || UnaVez == 1)
        if (Avante == 1)
            if (NumeroFotograma < Nfin)
                NumeroFotograma = NumeroFotograma + 1;
            else
                NumeroFotograma = Nini;
            end
        else
            if (NumeroFotograma > Nini)
                NumeroFotograma = NumeroFotograma - 1;
            else
                NumeroFotograma = Nfin;
            end
        end
        UnaVez = 0;
```

```
        Ejecutar = 1;
    else
        pause(0.001);
    end
    if (Ejecutar == 1)
        Fotograma = read(Video_Info, NumeroFotograma);
        Linea(:,1) = Fotograma(Video_Info.Height/2,:);

        %RADIOS FRENTE DE LLAMA
        Contorno2 = edge(Fotograma).*(1 - Contorno);
        [X, Y] = coordPixelsCont(Contorno2, RadCam, CntCamX,
CntCamY);
        if NumeroFotograma == Nini
            [xInliers, yInliers] = ransacCirc2(X, Y,
NumeroIteracionesRansac, RadCam*.9, 0);
        else
            [xInliers, yInliers] = ransacCirc2(X, Y,
NumeroIteracionesRansac, RadCam*.9, radio(NumeroFotograma-Nini));
        end
        [A, B, C] = LMSCirc(xInliers,yInliers);
        radio(NumeroFotograma-Nini+1) = (sqrt(A^2+B^2-
4*C)/2)/Calibracion;
        tiempo(NumeroFotograma-Nini+1) = (NumeroFotograma-
Nini)*(1000/VelocidadCaptura);

        %CELULARIDAD
        MatrizRMS = stdfilt(Fotograma);
        MatrizRMS  = RestringeRadio(MatrizRMS , CntCamX ,CntCamY,
Calibracion*radio(NumeroFotograma-Nini+1)*0.8);
        FotogramaRMS = im2uint8(MatrizRMS./(max(max(MatrizRMS))));
        FotogramaRMS_Binario = im2bw(FotogramaRMS, 0.1);
        FotogramaRMSBinarioSinRuido =
bwareaopen(FotogramaRMS_Binario, 50);
        FotogramaAdelgazado =
bwmorph(FotogramaRMSBinarioSinRuido,'thin','Inf');
        FotogramaRMSBinarioInversa =
imcomplement(FotogramaAdelgazado);
        ComponentesConexos =
bwconncomp(FotogramaRMSBinarioInversa, 4);
        Propiedades = regionprops(ComponentesConexos);
        for i = 1:length(Propiedades)
            if (Propiedades(i).Area > AreaCelulaMinima)
                NumeAreas(NumeroFotograma-Nini+1) =
ComponentesConexos.NumObjects/pi/(radio(NumeroFotograma-
Nini+1)*0.8)^2;
            end
        end
        Fusion = imadjust(imfuse(imadjust(Fotograma),
FotogramaRMSBinarioInversa, 'blend'));

        %Sn y Stretch

        if(NumeroFotograma-Nini+1 <= Nfin)
            if(NumeroFotograma-Nini+1 == 1)
                continue;
            else
                Sn(NumeroFotograma-Nini+1) =
(radio(NumeroFotograma-Nini+1)-radio(NumeroFotograma-
```

```
Nini))/(tiempo(NumeroFotograma-Nini+1)-tiempo(NumeroFotograma-
Nini)); %dr/dt
                Stretch(NumeroFotograma-Nini+1) =
(Sn(NumeroFotograma-Nini+1))/(radio(NumeroFotograma-Nini));
            end
        end

        if(NumeroFotograma-Nini+1 == 1)
            continue;
        else
             end

%IMPRESION 1
        figure(1);
        nombreplot1 =
strcat('Fotograma:',num2str(NumeroFotograma),'
Tiempo:',num2str((NumeroFotograma-
Nini+1)*(1000/VelocidadCaptura)),'ms');

set(figure(1),'name',nombreplot1,'numbertitle','off','Position',Po
sicionFigu);
        subplot('position', [0 0.5 0.3 0.5]);
        imshow(Fotograma); hold on;
        subplot('position', [0.3 0.5 0.3 0.5]);
        imshow(Contorno2); hold on;
        dibujaCircABC(A, B, C, 'r');
        subplot('position', [0.63 0.6 0.3 0.3]);
        plot(tiempo, radio);
        subplot('position', [0 0 0.3 0.5]);
        imshow(FotogramaRMS_Binario); hold on;
FotogramaRMS_Binario  %FotogramaAdelgazado
%         for i = 1:length(Propiedades)
%             if (Propiedades(i).Area > AreaCelulaMinima)
%                 plot(Propiedades(i).Centroid(1),
Propiedades(i).Centroid(2), 'r.');
%             end
%         end
        subplot('position', [0.3 0 0.3 0.5]);
        imshow(Fusion); hold on;
%         for i = 1:length(Propiedades)
%             if (Propiedades(i).Area > AreaCelulaMinima)
%                 plot(Propiedades(i).Centroid(1),
Propiedades(i).Centroid(2), 'r.');
%             end
%         end
        subplot('position', [0.63 0.1 0.3 0.3]);
        plot(tiempo, NumeAreas);


%IMPRESION 2
        figure(2);
        set(figure(2),'Position',PosicionFigu);
        subplot('position', [0 0 0.5 1]);
        imshow(Fotograma);
        subplot('position', [0.55 0.2 0.45 0.65]);
        plot(Linea, 'b');
        grid on;
```

```
%IMPRESION 3
        figure(3);
        set(figure(3),'Position',PosicionFigu);
        FotogramaBinario = im2uint8(FotogramaAdelgazado);
        FotogramaBinario = imcomplement(FotogramaBinario);
        FotogramaFusionado = imadjust(imfuse(FotogramaBinario,
Fotograma, 'blend'));
        subplot('position', [0 0 0.5 1]);
        imshow(Fotograma); hold on;
        subplot('position', [0.5 0.25 0.5 0.5]);
        imshow(FotogramaFusionado); hold on;
        for i = 1:length(Propiedades)
            plot(Propiedades(i).Centroid(1),
Propiedades(i).Centroid(2), 'r.', 'MarkerSize', 5);
        end



        fprintf('**************************\n');
        fprintf('Nombre Video: %s\n', Video_Info.Name);
        fprintf('Fotograma: (%d/%d)\n', NumeroFotograma-Nini+1,
Num_Fotogramas);
        fprintf('Tiempo: %.2f (ms)\n', tiempo(NumeroFotograma-
Nini+1));
        fprintf('radio: %.2f (cm)\n', radio(NumeroFotograma-
Nini+1));
        fprintf('N celulas: %.2f (N/cm2)\n',
NumeAreas(NumeroFotograma-Nini+1));
        fprintf('Sn: %.2f (N/cm2)\n', Sn(NumeroFotograma-Nini+1));
        fprintf('Stretch: %.2f (N/cm2)\n',
Stretch(NumeroFotograma-Nini+1));

        Ejecutar = 0;
        %Solo ejecutar una vez
        if NumeroFotograma == Nfin
            Terminar = 1;
        end
    end
end

%% GUARDAR FICHERO
NombreVideo = Video_Info.Name(1:end-4);
%TABLA Titulo de cada video
TablaTitulo = table({NombreVideo});
%TABLA Variables de cada video
TablaDatos = table;
TablaDatos.tiempo = tiempo';
TablaDatos.radio = radio';
TablaDatos.NumeAreas = NumeAreas';
TablaDatos.Sn = circshift(Sn', [-1, 0]);
TablaDatos.Stretch = circshift(Stretch', [-1, 0]);

TamanoTabla = size(TablaDatos);
for i = 1:TamanoTabla(1)
    for j = 1:TamanoTabla(2)
        if(strcmp(TablaDatos(i, j).Variables, 'Inf'))
            TablaDatos(i, j) = {0};
        end
```

```
    end
end
RangoExcel1 = strcat(char(ExcelCol(1)), char('1'));
RangoExcel2 = strcat(char(ExcelCol(1)), char('2'));

writetable(TablaTitulo, NombreExcel, 'Range', RangoExcel1,
'WriteVariableNames', 0);
writetable(TablaDatos, NombreExcel, 'Range', RangoExcel2);
```

ControlTratamiento.m

```
function varargout = ControlTratamiento(varargin)
% CONTROLTRATAMIENTO MATLAB code for ControlTratamiento.fig
%      CONTROLTRATAMIENTO, by itself, creates a new
CONTROLTRATAMIENTO or raises the existing
%      singleton*.
%
%      H = CONTROLTRATAMIENTO returns the handle to a new
CONTROLTRATAMIENTO or the handle to
%      the existing singleton*.
%
%
CONTROLTRATAMIENTO('CALLBACK',hObject,eventData,handles,...)
calls the local
%      function named CALLBACK in CONTROLTRATAMIENTO.M with the
given input arguments.
%
%      CONTROLTRATAMIENTO('Property','Value',...) creates a new
CONTROLTRATAMIENTO or raises the
%      existing singleton*.  Starting from the left, property
value pairs are
%      applied to the GUI before ControlTratamiento_OpeningFcn
gets called.  An
%      unrecognized property name or invalid value makes property
application
%      stop.  All inputs are passed to
ControlTratamiento_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI
allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help
ControlTratamiento

% Last Modified by GUIDE v2.5 17-Jul-2017 15:16:27

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn',
@ControlTratamiento_OpeningFcn, ...
                   'gui_OutputFcn',
@ControlTratamiento_OutputFcn, ...
```

```
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

end

% --- Executes just before ControlTratamiento is made visible.
function ControlTratamiento_OpeningFcn(hObject, eventdata,
handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to ControlTratamiento (see
VARARGIN)

% Choose default command line output for ControlTratamiento
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes ControlTratamiento wait for user response (see
UIRESUME)
% uiwait(handles.figure1);
end

% --- Outputs from this function are returned to the command
line.
function varargout = ControlTratamiento_OutputFcn(hObject,
eventdata, handles)
% varargout  cell array for returning output args (see
VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;
end

% --- Executes on button press in Pausa.
function Pausa_Callback(hObject, eventdata, handles)
% hObject    handle to Pausa (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
```

```
% handles    structure with handles and user data (see GUIDATA)
% Hint: get(hObject,'Value') returns toggle state of Pausa
global Parar;
if (Parar == 0)
    Parar = 1;
else
    Parar = 0;
end
end

% --- Executes on button press in Atras.
function Atras_Callback(hObject, eventdata, handles)
% hObject    handle to Atras (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hint: get(hObject,'Value') returns toggle state of Atras
global Avante;
global Parar;
global UnaVez;
Avante = 0;
if (Parar == 1)
    UnaVez = 1;
end
end

% --- Executes on button press in Adelante.
function Adelante_Callback(hObject, eventdata, handles)
% hObject    handle to Adelante (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hint: get(hObject,'Value') returns toggle state of Adelante
global Avante;
global Parar;
global UnaVez;
Avante = 1;
if (Parar == 1)
    UnaVez = 1;
end
end

% --- Executes on button press in Primer_fotograma.
function Primer_fotograma_Callback(hObject, eventdata, handles)
% hObject    handle to Primer_fotograma (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
global NumFotograma;
NumFotograma = 1;
end

% --- Executes on button press in ultimo_fotograma.
function ultimo_fotograma_Callback(hObject, eventdata, handles)
% hObject    handle to ultimo_fotograma (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
```

```
global NumFotograma;
NumFotograma = -1;
end



% --- Executes on button press in terminar.
function terminar_Callback(hObject, eventdata, handles)
% hObject    handle to terminar (see GCBO)
% eventdata  reserved - to be defined in a future version of
MATLAB
% handles    structure with handles and user data (see GUIDATA)
global Terminar;
Terminar = 1;
end
```

coordPixelsCont.m

```
function [X,Y] = coordPixelsCont(C,Rd,Cx,Cy)
%Devuelve dos vectores con las x(colum) y las y(filas)
%de los pixels activos que hay en la imagen binaria C
%Si no encuentra nada devuelve
%    X(1)=-1;
%    Y(1)=-1;
% Se podría hacer [Y,X] = find(C);

[filas, columnas] = size(C);
numPixelsCont = 0;
for i = 1:filas
    for j = 1:columnas
        if C(i,j) == 0
            continue;
        else
            if ((i-Cy)^2+(j-Cx)^2<(Rd*0.95)^2)
                numPixelsCont = numPixelsCont + 1;
                X(numPixelsCont) = j; %coord x
                Y(numPixelsCont) = i; %coord y
            end
        end
    end
end
if numPixelsCont == 0 %Si no encuentra nada devuelve -1
    X(1) = -1;
    Y(1) = -1;
end
end
```

dibujaCirc.m

```
function dibujaCirc(centro, R, color)
%Dibujar circunferencia a partir del centro y radio.
%Para sobreimpresionar visualizar previamente imagen con
imshow(I); hold on

plot(centro(1), centro(2), [color, '+']);
i = 1;
for theta = 0:0.01:2*pi
```

```
    x(i) = centro(1) + R*cos(theta);
    y(i) = centro(2) + R*sin(theta);
    i = i + 1;
end
hold on;
plot(x, y, [color, '-']);
```

dibujaCircABC.m

```
function dibujaCircABC(A, B, C, color)
%para sobreimpresionar, la imagen tiene que ser visualizada
previamente con imshow(I); hold on;
radio = sqrt(A^2 + B^2 - 4*C)/2;
centro = [-A/2, -B/2];
dibujaCirc(centro, radio, color)
```

dibujaRectaABC.m

```
function dibujaRectaABC(A, B, C, color)
%Dibuja recta Ax + By + C = 0.  Eje X es horizontal
%Visualizar imagen previamente y mantener con hold on
% Ejemplo:
% I=imread('cameraman.tif');
% imshow(I);
% hold on;
% dibujaRectaABC(A,B,C,'g');
%-------------------------------------------------------------------
-------
if B == 0 %Recta vertical, pendiente infinita
    %punto inicial
    P(1) = -C;
    P(2) = 1;
    %punto final
    Q(1) = -C;
    Q(2) = 600; %valor alto para que valga para img grandes
    dibujaRectaPQ(P, Q, color);
else
    %lo pongo en la forma y=mx+b
    m = -A/B;
    b = -C/B;
    x(1) = 0;
    y(1) = b;
    x(2) = 600; %valor alto para que valga para img grandes
    y(2) = m*x(2) + b;
    plot(x, y, [color, '-']);
end
```

eligePuntosRand.m

```
function [xSample, ySample] = eligePuntosRand(xPixelsCont,
yPixelsCont, N)
% Elige N puntos aleatoriamente del conjunto
(xPixelsCont,yPixelsCont)
% Devuelve dos vectores: xSample con las coord x y ySample con
las coord y
xSample = zeros(N, 1);
```

```
ySample = zeros(N, 1);
numPixelsCont = length(xPixelsCont);
% N numero de puntos aleatorios
for k = 1:N
    indexRand = floor(numPixelsCont*rand()) + 1;
    xSample(k) = xPixelsCont(indexRand);
    ySample(k) = yPixelsCont(indexRand);
end
end
```

ExcelCol.m

```
function Out=ExcelCol(In)
%EXCELCOL  Converts between column name and number for Excel
representation
%   Out=ExcelCol(In) takes the input In, which may be a number,
vector,
%   char, or cell and converts it to the other representation
%
%   If IN is numeric, output will be a column cell of the column
name
%   If IN is char or cell, output will be a number or column
vector,
%      ignoring any numberic part which may be included in input
%
%   EXAMPLES:
%   ExcelCol(100)                          %Number to column name
%   ExcelCol('CV')                         %Column name to number
%   ExcelCol([1 10 100 1000 16383])        %Multiple conversions
%   ExcelCol({'A' 'J' 'CV' 'ALL' 'XFC'}) %Multiple conversions
%
%


%
% $ Author: Mike Sheppard
% $ Original Date: 4/7/2010
% $ Version: 1.0


%Optional to change representation and base
ABC=['ABCDEFGHIJKLMNOPQRSTUVWXYZ'];
base=26;

if isnumeric(In)
%Converts from column number to alpha
%1=A, 2=B,... 26=Z, 27=AA, ... 16383=XFC
In=In(:);
if ~all(In>0)
error('MATLAB:ExcelCol:NegativeColumnNumber', 'Column numbers
must be positive');
end
  for row=1:size(In,1)
   diff=1;
   i=0;
   n=In(row,:);
   while diff<=n
       letter_ind=1+mod(floor((n-diff)/base^i),base);
```

```
        i=i+1;
        temp(i)=ABC(letter_ind);
        diff=diff+base^i;
    end
    Out{row}=fliplr(temp);
    clear temp
  end
  Out=Out(:);
else
%Converts from alpha to column number
%A=1, B=2, ..., Z=26, AA=27, ... XFC=16383
    In=cellstr(upper(In));
    In=In(:);
    for row=1:size(In,1)
        alpha=char(In(row,:));
        %Delete any numbers which may appear
        alpha=(char(regexp(alpha,'\D','match')))';
        lng=length(alpha);
        temp=((base^(lng) - 1) / (base-1));
        for i=1:lng
            ind=strfind(ABC, alpha(i));
            if isempty(ind)  %ERROR
                  error('MATLAB:ExcelCol:Mixofcharacters', 'Must
be only alpha-numeric values {A-Z}, {a-z}, {0-9}');
            end
            temp=temp+(ind-1)*(base^(lng-i));
        end
        Out(row)=temp;
    end
    Out=Out(:);
end


end
```

GeneraMascara.m

```
function [ImagenModificada] = GeneraMascara(tamano, CentroX,
CentroY, Radio)
ImagenModificada = zeros(tamano, 'uint8');
for i = 1:tamano(1)
    for j = 1:tamano(2)
        if (i-CentroY)^2+(j-CentroX)^2 <= Radio^2
            ImagenModificada(i, j) = 1;
        end
    end
end
end
```

InliersCirc.m

```
function [xInliers, yInliers] = InliersCirc(x, y, centro, radio,
tolerancia)
% Calcula los inliers en una circunferencia con centro y radio
que hay en
% el conjunto de píxeles con coord x e y (vectores con coord x y
```

```
coord y)
% C es la imagen de contornos.
% Hasta 10.000 inliers por preasignacion de memoria
numInliers = 0;
%franja de consenso (R1,R2)
R1 = radio - tolerancia;
R2 = radio + tolerancia;
numPixelsCont = length(x);
%preasignacion para mayor rapidez
xInliers = zeros(1, 10000);  %hasta 10.000 inliers
yInliers = zeros(1, 10000);

for k = 1:numPixelsCont
    distCentro = sqrt((x(k) - centro(1))^2 + (y(k) -
centro(2))^2);
    % Si el pixel entra dentro de la franja de consenso(R1,R2)
    if ((distCentro > R1) && (distCentro < R2))
        numInliers = numInliers + 1;
        xInliers(numInliers) = x(k);
        yInliers(numInliers) = y(k);
    end
end
%Devuelve dos vectores con longitud numInliers
%(si numInliers es cero tambien funciona)
xInliers = xInliers(1:numInliers);
yInliers = yInliers(1:numInliers);
end
```

InliersRecta.m

```
function [xInliers, yInliers] = InliersRecta(x, y, A, B, C,
tolerancia)
%Calcula inliers de la recta Ax + By + C = 0
% Devuelve [A,B,C].
% Hasta 10.000 inliers por preasignacion de memoria
%Ejemplo:
% C=edge(I);
% [X,Y] = coordPixelsCont(C);
% [xInliers,yInliers] = InliersRecta( x,y,A,B,C,tolerancia)
%  n(A,B) unitario para calculo dist(P,r)
normAB = sqrt(A^2 + B^2);
A = A / normAB;
B = B / normAB;
C = C / normAB;
%preasignacion para mayor rapidez
xInliers = zeros(1, 10000);  %hasta 10.000 inliers
yInliers = zeros(1, 10000);
numInliers = 0;
for k = 1:length(x)
    distPuntoRecta = abs(A*x(k) + B*y(k) + C);
    if (distPuntoRecta < tolerancia) % Si el pixel se ajusta a la
recta
        numInliers = numInliers + 1;
        xInliers(numInliers) = x(k);
        yInliers(numInliers) = y(k);
    end
end
```

```
xInliers = xInliers(1:numInliers);
yInliers = yInliers(1:numInliers);
if (numInliers == 0) % Si no encuentra inliers devuelve [-1,-1]
    xInliers(1) = -1;
    yInliers(1) = -1;
end
end
```

LMSCirc.m

```
function [A, B, C] = LMSCirc(x, y)
%minimos cuadrados circunferencia
% Devuelve los parametros A,B,C de la circunferencia
x2+y2+Ax+By+C=0
%que ajusta los puntos con las coord en los vectores x,y
%Ejemplo ejecución:
% I=imread('chaveta01.png');
% imshow(I);
% J=imfill(I,'holes');
% C=edge(J);
% imshow(C);
% [Y,X] = find(C);
% [A,B,C]=LMSCirc(X,Y);
% hold on;
% dibujaCircABC(A,B,C, 'r');
suma_x = 0;
suma_x2 = 0;
suma_y = 0;
suma_y2 = 0;
suma_x_x2_y2 =0;
suma_y_x2_y2 = 0;
suma_x2_y2 = 0;
suma_xy = 0;

n=length(x);
for k=1:n
    suma_x=suma_x + x(k);
    x2 = x(k)*x(k);
    suma_x2 = suma_x2 + x2;
    suma_y = suma_y + y(k);
    y2 = y(k)*y(k);
    suma_y2 = suma_y2 + y2;
    s_x2_y2 = x2 + y2;
    suma_x_x2_y2 = suma_x_x2_y2 + x(k)*s_x2_y2;
    suma_y_x2_y2 = suma_y_x2_y2 + y(k)*s_x2_y2;
    suma_x2_y2 = suma_x2_y2 + s_x2_y2;
    suma_xy = suma_xy + x(k)*y(k);
end

M1 = zeros(3);
M1(1,1) =  suma_x2;
M1(1,2) =  suma_xy;
M1(1,3) =  suma_x;
M1(2,1) =  suma_xy;
M1(2,2) =  suma_y2;
M1(2,3) =  suma_y;
M1(3,1) =  suma_x;
```

```
M1(3,2) =  suma_y;
M1(3,3) =  n;

M2(1,1) = -suma_x_x2_y2;
M2(2,1) = -suma_y_x2_y2;
M2(3,1) = -suma_x2_y2;

inversaM1 = pinv(M1);
R = inversaM1*M2;

A = R(1);
B = R(2);
C = R(3);
```

LMSRecta.m

```
function [A,B,C] = LMSRecta(x,y)
%Ajusta por minimos cuadrados a recta Ax + By + C = 0 calcula eje
inercia
% Devuelve [A,B,C]. n(A,B) unitario. Viene bien para calculo
dist(P,r)
% x,y contiene las x (columnas)y las y (filas) de los pix de cont

sum_x=0;                %sumatorio x
sum_y=0;                %sumatorio j
Ixx = 0;
Iyy = 0;
Ixy = 0;
n=0;

% Media de las coord X e y (centro gravedad)
cx=mean(x);
cy=mean(y);
centro=[cx,cy];

n=length(x);
for k=1:n
    Ixx = Ixx + (x(k) - cx)^2;
    Iyy = Iyy + (y(k) - cy)^2;
    Ixy = Ixy + (x(k) - cx)*(y(k) - cy);
end

%Tita es el angulo de la recta con el eje x (horiz)
tita=0.5*atan2( 2*Ixy, Ixx-Iyy );
m=tan(tita);
b=cy-m*cx;
% mx-y+b=0.
A=m; B=-1; C=b;

%Normalizo n(A,B)=1
n=[A,B];
normAB=norm(n);
A = A/normAB;
B = B/normAB;
C = C/normAB;
```

```
end
```

ransacCirc2.m

```
function [xInliers_max, yInliers_max] = ransacCirc2(xPixelsCont,
yPixelsCont, numMinInliers, rmax, rmin)
% RANSAC Circ que finaliza cuando alcanza un num.  superior a
numMinInliers
% xPixelsCont,yPixelsCont contiene las x % (columnas)y las y
(filas) de los
% pix de cont
% numMinInliers: Itera hasta que encuentre al menos numInliers
% xInliers son las columnas!
% yInliers son las filas!
% xInliers e yInliers hay que pasarlos LMS para calcular
circunferencia
% con mejor precisión
% ------------------------- EJECUCION---------------------------
-----
% Cont=edge(I);
% [X,Y] = coordPixelsCont(Cont);   %coord punt.contorno a vectores
X e Y
% [xInliers,yInliers] = ransacCirc2( X,Y, 900);    %900 inliers
% [A,B,C]=LMSCirc(xInliers,yInliers);   %ajuste de los inliers por
min.cuadrados
% dibujaCircABC(A,B,C, 'r');
% ------------------------------------------------------------------
----
numInliers = 10;
xInliers_max = zeros(1,numInliers);
yInliers_max = zeros(1,numInliers);
%numIteraciones = 0;
tolerancia = 10;
for i = 1:numMinInliers
    [xSample, ySample] = eligePuntosRand(xPixelsCont, yPixelsCont,
3);
    %circunf que pasa por estos tres puntos
    [A, B, C] = LMSCirc(xSample, ySample);
    radio = sqrt(A^2 + B^2 - 4*C)/2;
    centro = [-A/2, -B/2];
    if (radio < rmax && radio > rmin)
        [xInliers, yInliers] = InliersCirc(xPixelsCont,
yPixelsCont, centro, radio, tolerancia);
        if(length(xInliers) > numInliers)
            numInliers = length(xInliers);
            xInliers_max = xInliers;
            yInliers_max = yInliers;
        end
    end
end
end
```

ransacRecta.m

```
function [mejorxInliers, mejoryInliers] = ransacRecta(x, y,
numMaxIter)
% x,y contiene las x (columnas)y las y (filas) de los pix de cont
```

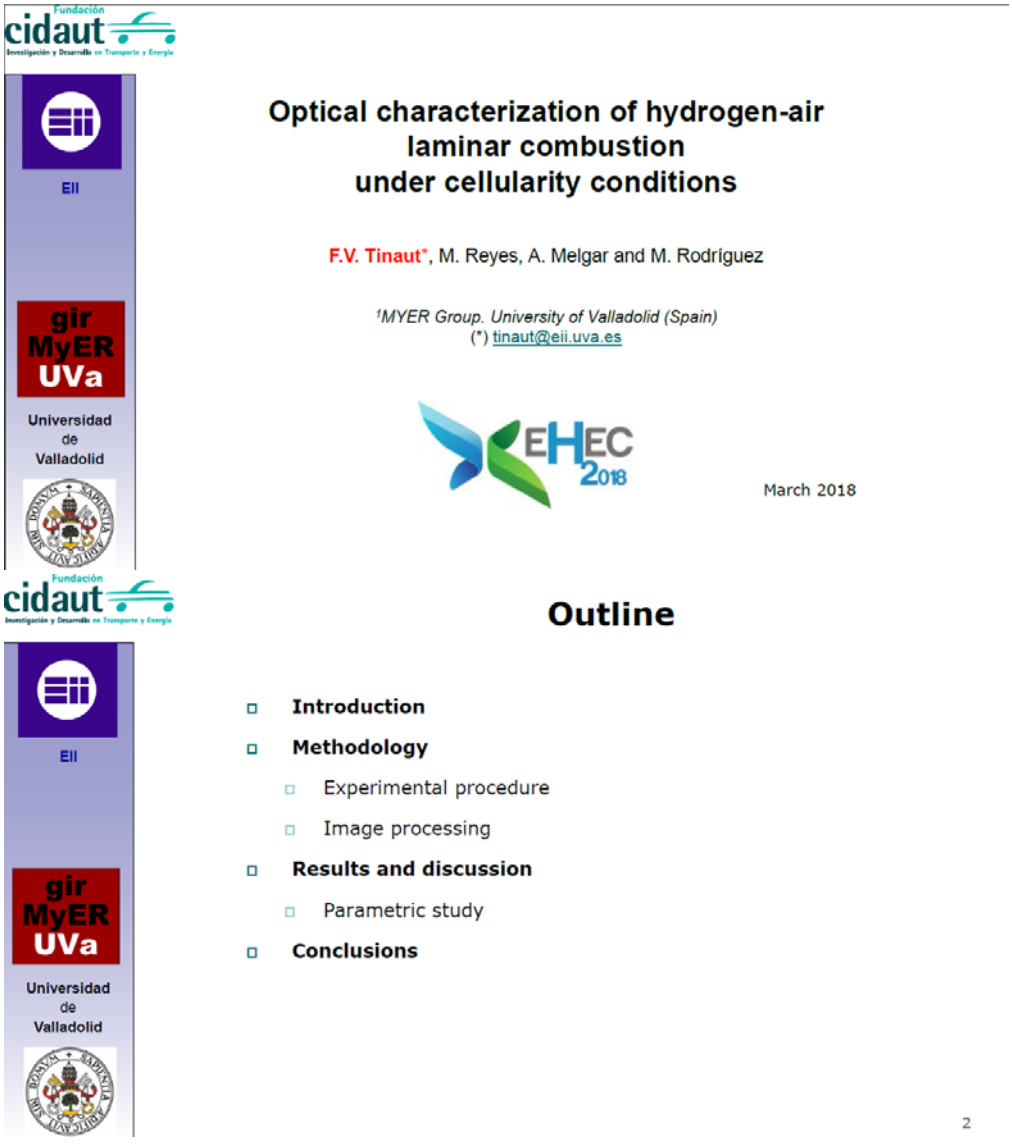
```
% numMaxIter numero máximo de iteraciones
% mejorxInliers son las columnas! del mejor modelo encontrado
% mejoryInliers son las filas!
% xInliers e yInliers hay que pasarlos LMS para afinar recta
% -------------------------- EJECUCION--------------------------
---------
% Cont=edge(I);
% [y,x] = find(Cont);   %coord punt.contorno a vectores X e Y
% [xInliers,yInliers] = ransacRecta( x,y, 100);    %10
iteraciones
% [A,B,C]=LMSRecta(xInliers,yInliers);   %ajuste inliers por
min.cuadrados
% dibujaRectaABC(A,B,C, 'r');
% ----------------------------------------------------------------
---------
tolerancia = 1; %distancia max a recta para que sea inlier
numInliers = 0;
mejorNumInliers = 0; %el numero de inliers más alto q se ha
encontrado
for numIteraciones = 1 : numMaxIter
    [xSample,ySample] = eligePuntosRand(x, y, 2);
    %recta que pasa por estos dos puntos
    [A, B, C] = LMSRecta(xSample, ySample);
    [xInliers, yInliers] = InliersRecta(x, y, A, B, C,
tolerancia);
    numInliers = length(xInliers);
    if numInliers > mejorNumInliers
        mejorNumInliers = numInliers;
        mejorxInliers = xInliers;
        mejoryInliers = yInliers;
    end
end
```

RestringeRadio.m

```
function [ImagenModificada] = RestringeRadio(ImagenOriginal,
CentroX, CentroY, Radio)
[filas, columnas] = size(ImagenOriginal);
ImagenModificada = zeros(size(ImagenOriginal));

for i = 1:filas
    for j = 1:columnas
        if (i-CentroY)^2 + (j-CentroX)^2 >= Radio^2
            ImagenModificada(i, j) = 0;
        else
            ImagenModificada(i, j) = ImagenOriginal(i, j);
            %ImagenModificada(i, j) = 1;
        end
    end
end
end
```

2. OPTICAL CHARACTERIZATION OF HYDROGEN-AIR LAMINAR COMBUSTION UNDER CELLULARITY CONDITIONS



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Optical characterization of hydrogen-air laminar combustion under cellularity conditions

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EHEC 2018

March 2018

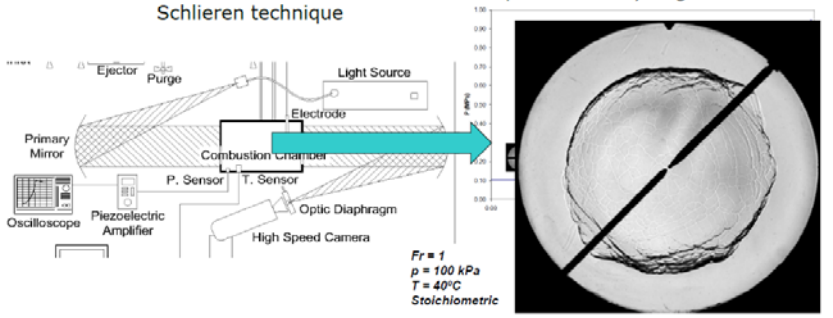
Outline

- **Introduction**
- **Methodology**
  - Experimental procedure
  - Image processing
- **Results and discussion**
  - Parametric study
- **Conclusions**

2

1. Introduction

- Characterization of hydrogen as a **single fuel** in the combustion process inside an **optical-access cylindrical combustion bomb**
- Combustion bomb instrumented:
  - **Instantaneous pressure** during the combustion is registered
  - **Visualization of** the combustion process of hydrogen with Schlieren technique

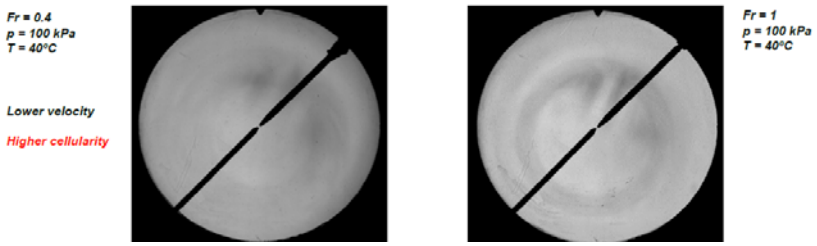


3

1. Introduction

- Characterization of hydrogen as a **single fuel** in the combustion process inside an **optical-access cylindrical combustion bomb**
- Combustion bomb instrumented:
  - **Instantaneous pressure** during the combustion is registered
  - **Visualization of** the combustion process of hydrogen with Schlieren technique

Lean mixture | *Stoichiometric mixture*



4

1. Introduction

- **Cellular structure:** wrinkling of flame front due to instabilities
  - This causes an **increase of apparent combustion velocity**

Fig. 11. Wrinkled flame front sketch

- **OBJECTIVE**: characterization of the *lean combustion* of *hydrogen-air* mixtures to investigate the onset of **cellular instabilities** and quantify their intensity
  - **Cellularity Density (Cell#/cm2)**
  - Identify the dependence of the cellularity density on the main operating variables: **pressure, temperature and equivalence ratio**.

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Outline

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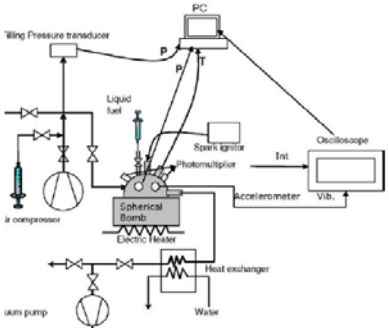
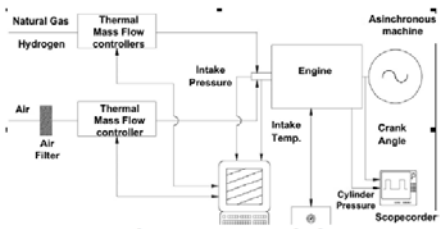
Methodology: Experimental facilities

A. Spherical Constant Volume Combustion Bomb



Moderate pressures (up to 200 bar)
Pressure and Chemiluminescence register

B. Internal Combustion Engine



Some results presented in WHEC 2016

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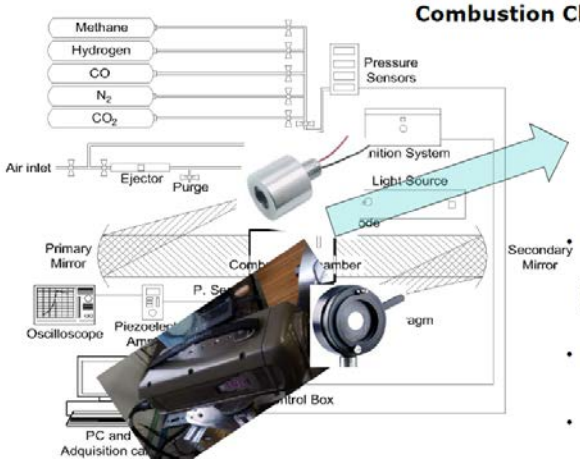
Experimental facilities

C. Optical-Access Cylindrical Combustion Chamber



Cylindrical chamber with optical quartz bases
Diameter: 114.3 mm
Length: 135 mm

- Schlieren photography method based on density gradient.
- High speed CMOS camera – up to 300,000 fps

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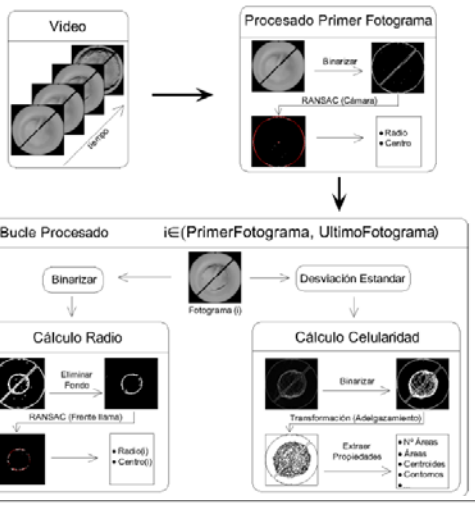
Image processing



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Results

Flame development and cellularity study

- Flame Front Radius
- (Time derivative of Flame Front Radius provides Stretched Flame Velocity)
- Cellularity Density:

$$Cellularity\ Density\ = Cell\ \#/cm^2$$

- Parametrical study of the influence of:
  - Equivalence ratio F_r: 0.3 to 1.0
  - Pressure (initial pressure, P_i: 0.1 to 3.0 MPa)
  - Temperature (initial temperature, T_i: 40, 80ºC)

Test		Equivalence Ratio Fr					
		0.3	0.4	0.5	0.6	0.7	1.0
Initial Pressure (kPa)	100	X	X	X	X	X	X
	125			X			
	150			X			
	175			X			
	200			X			
	250			X			
	300			X			

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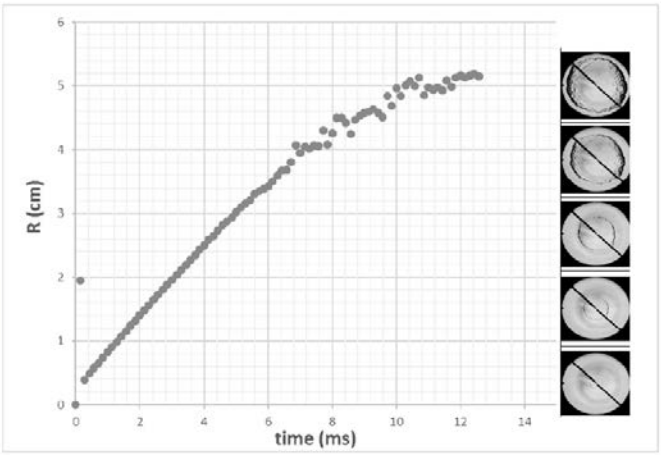
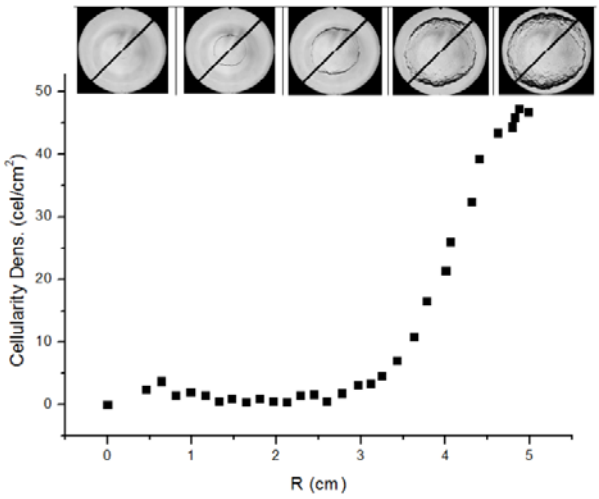
Results: Flame Front Radius vs Time



Fr = 0.6
p = 1 bar
T = 40ºC
Hydrogen

11

Results: Cellularity Density vs Flame Radius



Fr = 0.6
p = 1 bar
T = 40ºC
Hydrogen

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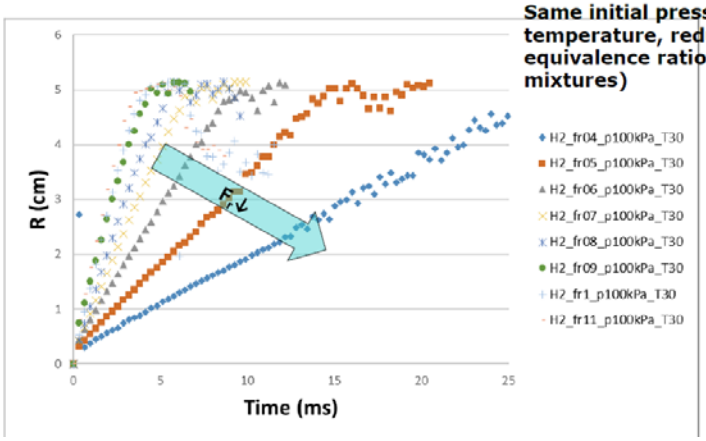
Results: Influence of equivalence ratio
Flame Front Radius vs Time



Same initial pressure and temperature, reduction of equivalence ratio (leaner mixtures)

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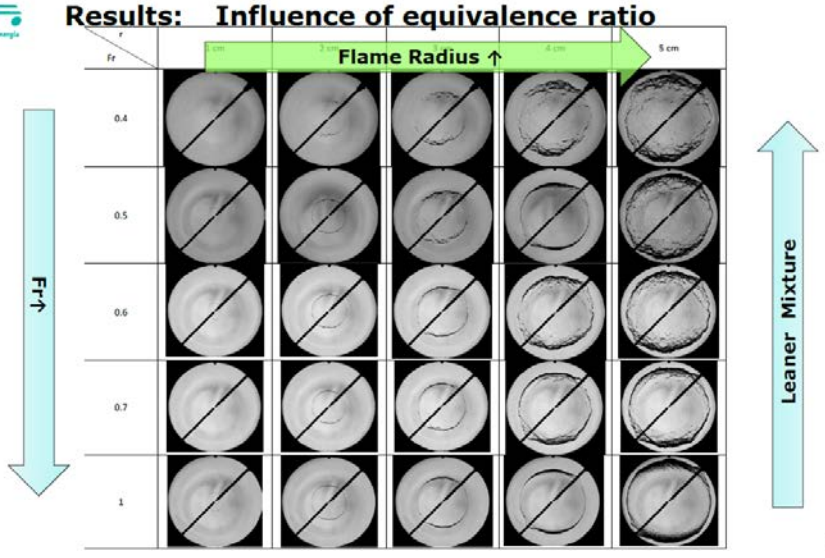
Results: Influence of equivalence ratio



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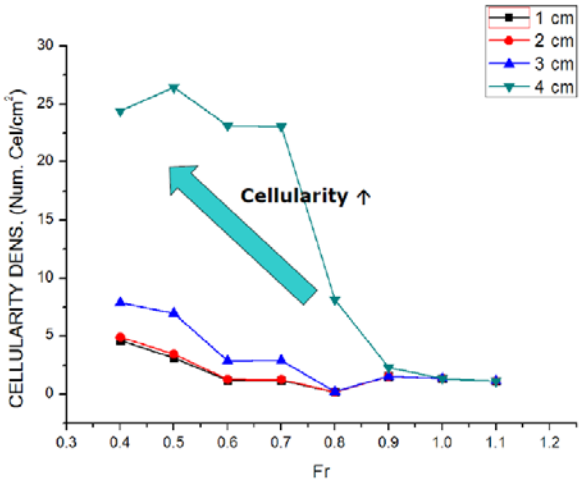
Results: Influence of equivalence ratio



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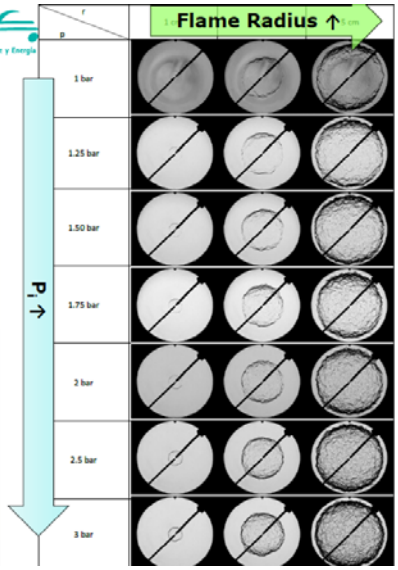
Results: Influence of pressure



Fr = 0.5
p_i = 0.125 MPa
T_i = 40ºC
Hydrogen

Fr = 0.5
p_i = 0.3 MPa
T_i = 40ºC
Hydrogen

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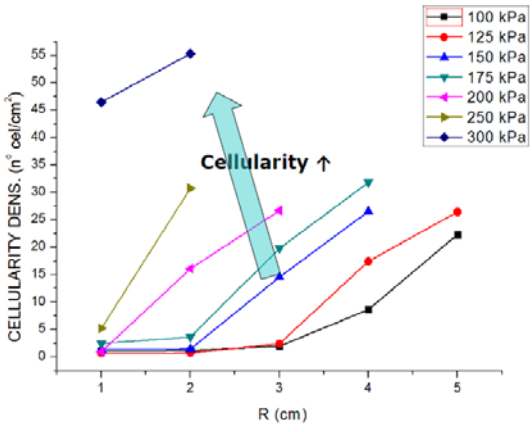
Results: Influence of pressure



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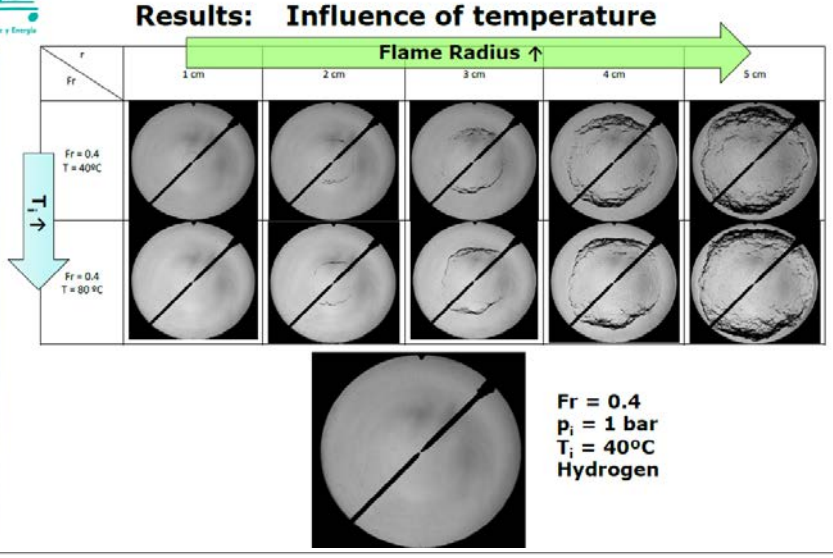
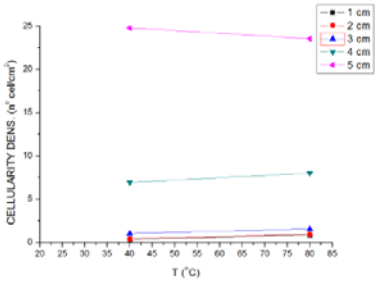
Results: Influence of temperature

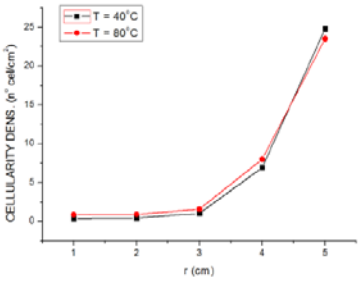


Fr = 0.4
p_i = 1 bar
T_i = 40ºC
Hydrogen

18

Results: Influence of temperature





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4. Conclusions

- The combustion process of hydrogen-air has been studied using an **optical cylindrical chamber** with a Schlieren technique and **a high-speed camera**.
- An algorithm has been developed to characterize the **cellular structure of the hydrogen-air flames** by accounting for the number of cells per squares cm, under different experimental conditions.
- Results show that **hydrogen-air flames** present **a more cellular character** as:
  - Mixture is **leaner** (reduction of equivalence ratio)
  - Bomb **pressure increases**
  - Bomb **temperature increases** (although the explored range is short).

- The authors **acknowledge the support** of Regional Government of Castilla and León as Excellence Research Group GR203

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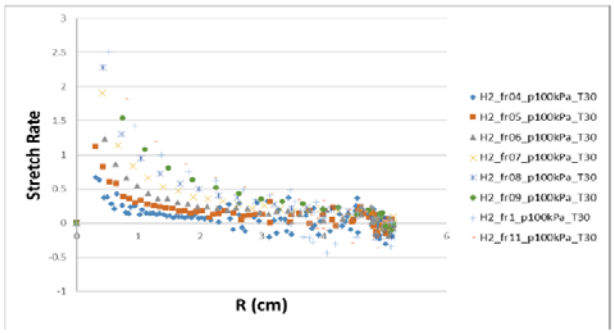
March 2018

Stretch effect investigation

K = Stretch Rate (1/s)
S_n = Stretched Flame Propagation Velocity

$$K = \frac{1}{A_f}\frac{dA_f}{dt} = \frac{2}{R_f}\frac{dR_f}{dt} = \frac{2}{r_f}S_n$$



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