Experimental analysis of the waddling duck

Schwanen, W.

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Experimental analysis of the Waddling Duck

W. Schwanen
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W. Schwanen, student id: 444316

Coach: Dr. ir. R.I. Leine
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1 Introduction

The dynamics of systems with impact and friction is a main research topic of the section Dynamics and Control (TUE). Various dynamical systems with frictional contact have been modelled and analysed and with numerical simulations [Leine 2001]. A number of wooden toys were chosen as study objects, because of their geometrical simplicity (planar motion) and because they show periodic motion induced by impact and friction. The toy systems were modelled with a rigid-body assumption. Newton's impact law and Coulomb's friction law were assumed to describe the contact. Verification of these modelling assumptions by experimental analysis are necessary. Such an experimental analysis can be used to validate numerical results or to validate the modelling assumptions.

This report documents a traineeship of six weeks by the author in the section Dynamics and Control. The aim of this traineeship was to make an experimental analysis of the so-called Waddling Duck, a commercial wooden toy system with impact and friction. Experiments have been carried out on the Waddling Duck. The Waddling Duck will be introduced and its characteristics will be explained. The set-up of the experiments will be presented. Subsequently the formulas necessary to calculate the motion of the generalized coordinates will be derived. A close look will be taken at the results of the measurements. Conclusions and recommendations will be given at the end of this report.
2 The Waddling Duck

2.1 Assumptions

The Waddling Duck is a wooden toy that walks down an inclined wooden slope. The Waddling Duck is shown in figure 2.1. The duck consists of two rigid bodies: the body, including the front leg, which is fixed to the body, and the rear leg that is hinged to the body. (fig 2.2) The rear leg can rotate freely with respect to the body, but is constrained by the front leg and a stop, \(0 \leq \phi_b - \phi_s \leq \phi_c\) (fig 2.2). The wooden slope makes an angle of about 9 degrees with the horizontal, which can be checked with a ruler. This angle will also be measured with the results of a high-speed camera.

![The Waddling Duck](image)

Figure 2.1: The Waddling Duck.

When the Waddling Duck moves down the slope some interesting frictional and impact phenomena occur.

A planar dynamical model for the Waddling Duck has been presented in [Leine 2001]. This model uses four generalized coordinates to describe the motion of the duck. These four generalized coordinates, \(q\), are

\[
q = (x_s, y_s, \phi_s, \phi_b)
\]

(2.1)

- \(x_s\): x-translation of the centre of mass \(S\) [m]
- \(y_s\): y-translation of the centre of mass \(S\) [m]
- \(\phi_s\): rotation of the centre of mass \(S\) [rad]
- \(\phi_b\): rotation of the rear leg [rad]
In figure 2.2 a schematic representation of the duck is depicted.

![Figure 2.2: Model of the Waddling Duck [Leine 2001].](image)

The orientation of the x-axis is parallel to the slope and the y-axis is orthogonal to this slope. The following data set was used by [Leine 2001].

**Dynamics**

\[ m_b = 0.010 \text{ kg}, \ J_b = 1.0 \times 10^{-6} \text{ kg m}^2, \ m_r = 0.080 \text{ kg}, \ J_r = 1.5 \times 10^{-4} \text{ kg m}^2, \ g = 9.81 \text{ m/s}^2 \]

**Geometry**

\[ a = 0.006 \text{ m}; \ b = 0.012 \text{ m}, \ l_b = 0.040 \text{ m}, \ R = 0.100 \text{ m}, \ L = 0.050 \text{ m}, \ \phi_b = \pi/20 \text{ rad}, \ \phi_r = 0.17 \text{ rad} \]

**Contact**

\[ \mu = 0.3, \ \varepsilon = 0 \]

The friction coefficient, \( \mu \), was measured. Furthermore the impacts were modelled as completely inelastic, \( \varepsilon = 0 \), because no restitution after impact was observed by [Leine 2001].

Some of these parameters, for example \( \phi_r \), will be measured in order to validate the data set and assumptions.

### 2.2 Periodic motion

The Waddling Duck makes a periodic motion when walking. During this motion a sequence of events takes place (see figure 2.3).

First, the body swings backward and the front leg detaches from the slope. Impact occurs at the moment when the rear leg makes contact with the stop. Between the events 1 and 3 the body starts swinging in the other direction. Subsequently the front leg makes contact with the slope, while the rear leg becomes detached from the slope. The body continues to swing forward while at a certain moment the rear leg makes contact with the front leg. The body keeps swinging forward until the swinging goes in the opposite direction at event 5. At a
certain moment, event 7, the rear leg detaches from the front leg. The body keeps on swinging while the front leg is detached from the floor. The cycle starts all over again.

Figure 2.3: sequences during the periodic movement of the Waddling
3 Experiments

3.1 Set-up
To validate the dynamic model for the Waddling Duck, the motion of the Duck ought to be analysed experimentally. For this purpose the motion is recorded with a high-speed camera. A high-speed camera is chosen because the measurements can be done without additional mass or strain gauges, which has to be detached. So the characteristics of the system do not change. The camera can take up to 10000 frames per second. It turned out that a frame rate of 125 frames per second is sufficient. The frame size was chosen to be 512x480 pixels. These settings result in a quality of the pictures, that is good enough to analyse the motion of the duck which is about 1.2 Hz. Furthermore it is possible to record several periods of its motion. In figure 3.1 the set-up of the experiments is depicted.

In front of fig 3.1 the camera is shown. Furthermore a plumb line, the Waddling Duck and the slope can be distinguished.

3.2 Markers
The post-processing software allows only to follow spots, which contrasts with the background, in the frame. A circle fit is applied around the black spots. A set of markers is therefore attached to the system. A marker is nothing more than a small piece of black paper that is glued to the duck. It is essential to place these markers on such positions, that the generalized coordinates can be calculated from the positions of the markers. The body has three degrees of freedom; a minimum of two markers is thus needed to obtain these degrees of freedom. In addition, the rear leg has only one interesting degree of freedom. As a consequence, three markers will be enough to derive all the generalized coordinates. The third marker can be glued to the rear leg. More markers were, however, used. In total six markers were glued to the duck. Three markers were placed on the body of the duck, two on the rear leg and one on the front leg. Figure 3.2 shows the position of the markers. Furthermore two markers are used for the plumb line and two markers are used to determine the angle of the slope.
Because the absolute position of the markers relative to the duck is important, a reference has to be chosen. A reference point has to be a fixed point, for instance the point on the beak.

**Figure 3.2: Position of the markers**

The following reference points were chosen. For marker 1, 2 and 3 the point on the duck's beak. For marker 4 and 5, the end point of the rear leg was chosen and for marker 6 the beginning of the front leg (fig 3.3). In Appendix I the distances can be found from the reference points to the markers. These were measured from out the reference points with respect to base $\bar{e}_0$.

**Figure 3.3: reference points for the markers**
3.3 Recording the motion of the Waddling Duck

During an experiment approximately 450 frames are made, because of the memory limitations of the camera. A sample frame can be seen in figure 3.4.

![Figure 3.4: return of the recording](image)

The markers can be distinguished very well. The plumb line itself is hardly visible but the two markers attached to it can be clearly distinguished. With the MatLab file *improc.m*, made by ir. H.L.A. van den Bosch, the position of each marker can be calculated. A circle fit is made, which determines the middle point of each marker. This results in a ‘motion’ in the x-y-domain. This motion is, however, in pixels, which means that the position of each marker returns the location in the frames. As a result, it is necessary to transform the position of the markers in pixels of the frame to absolute positions in the plane in which the toy is moving. When the length between two markers is known together with the pixel position within the frame, the length of one pixel is known. This can be done, because it is assumed that the camera records the motion of the duck perpendicularly. In addition, it is also assumed that the optical deformation due to the camera is small.
4 Coordinate transformation

4.1 Center of mass
In this chapter we derive the formulas to obtain the generalized coordinates, \( q \), from the marker positions. For that reason the position of the center of mass, \( S \), has to be found. Firstly the position of the center of mass, \( S \), will be expressed in the marker positions. Therefore the angle between the markers 1 and 3 placed upon the main body will be measured. Markers 1 and 3 are chosen because the distance between these two is greater than the distance between two other markers. As a result, the accuracy will be better.

![Figure 4.1: Calculation of the position of S](image)

The position of \( S \) can be calculated with respect to the base \( \tilde{e}^3 \)

\[
X_s^0 = x_1^0 + c_0 \cos(\alpha) - c_2 \sin(\alpha) \\
Y_s^0 = y_1^0 + c_0 \sin(\alpha) + c_2 \cos(\alpha)
\]

(4.1)

where

\[
\alpha = \arctan\left(\frac{y_3^0 - y_1^0}{x_3^0 - x_1^0}\right).
\]

(4.2)

The length of \( c_0, c_1 \) and \( c_2 \) were measured:

\[
c_0 = 0.041 \text{ m} \\
c_1 = 0.052 \text{ m} \\
c_2 = 0.004 \text{ m}
\]

The base \( \tilde{e}^1 \) is rotated with angle \( \phi_R \) with respect to base \( \tilde{e}^0 \),
The rotation matrix, $R$, can be used to calculate the position $S'_1$, which is the position of the center of mass with respect to the base $\ell_1$.

\[
\begin{pmatrix}
X_s^1 \\
Y_s^1
\end{pmatrix}
= R^{T} \begin{pmatrix}
X_s^0 \\
Y_s^0
\end{pmatrix}
\]  
(4.5a)

This leads to the following formulas to calculate the position of the center of mass.

\[
\begin{align*}
X_s^1 &= \cos \varphi_r X_s^0 + \sin \varphi_r Y_s^0 \\
Y_s^1 &= -\sin \varphi_r X_s^0 + \cos \varphi_r Y_s^0
\end{align*}
\]  
(4.5b)

The third generalized coordinate, $\varphi_s$, is the rotation of the body around $S$. The angle $\varphi_s$ can be obtained from (fig 4.3)

\[
\varphi_s = \alpha + \beta - \varphi_r .
\]  
(4.6)

The constant angle, $\beta$, was measured by inspecting the marker positions on a photo. From this measurement it turned out that $\beta$ is approximately 0.07 rad.
4.2 Rotation of the rear leg

The rotation of the rear leg, $\varphi_b$, can be calculated by means of marker 4 and marker 5.

The angle $\varphi_b$ follows from the relation (fig 4.4)

$$\gamma - \delta - \varphi_b - \varphi_r + \frac{1}{2}\pi = 0,$$

which can be written as

$$\varphi_b = \frac{1}{2}\pi - \delta + \gamma - \varphi_r,$$

where

$$\delta = \arctan\left(\frac{c_3}{c_4}\right)$$

and

$$\varphi_b = \left(\frac{1}{2}\pi - \delta + \gamma - \varphi_r\right).$$
The distances $c_3$ and $c_4$ were measured.

$c_3 = 0.007 \text{ m}$
$c_4 = 0.015 \text{ m}$

### 4.3 Contact distances

The Waddling Duck contains four contact points (fig 2.2). The contacts close and open during the periodic motion of the toy. The time-dependent state of a contact is expressed by the normal contact distance $g_N$. If $g_N=0$ the contact is closed, else it is open. Likewise, a tangential contact distance, $g_T$, is defined. The contact sticks if $g_T=0 \land g_N=0$ and slips if $g_T \neq 0 \land g_N=0$.

In figure 2.2 can be seen that there are four contact distances, corresponding to the numbers 1, 2, 3, and 4. The contact distance $g_{NJ}$ is the smallest distance between the tread of a regular point on the fixed front leg and the slope. So the closest point on the tread is a regular point on the circle segment when $\varphi_s > 0$ or the corner of the foot when $\theta \geq \varphi_s$.

There can be derived that [Leine 2001]

$$g_{N1} = \begin{cases} Y_s^1 + F_1 - R & \varphi_z > 0 \\ Y_s^1 + G_1 & \varphi_z \leq 0 \end{cases} \quad (4.10)$$

$$g_{T1} = \begin{cases} X_s^1 + F_2 + R\varphi_s & \varphi_z > 0 \\ X_s^1 + G_2 & \varphi_z \leq 0 \end{cases} \quad (4.11)$$

The tread of the rear leg is at a distance $g_{N2}$ from the slope with tangential contact distance $g_{T2}$

$$g_{N2} = \begin{cases} Y_s^1 - D_2 + H_1 & \varphi_b \geq 0 \\ Y_s^1 - D_2 + I_1 - R & \varphi_b < 0 \end{cases} \quad (4.12)$$

$$g_{T2} = \begin{cases} X_s^1 + D_1 + H_2 & \varphi_b \geq 0 \\ X_s^1 + D_1 + I_2 + R\varphi_b & \varphi_b < 0 \end{cases} \quad (4.13)$$

In this formulas the following abbreviations are used.

$$F_1 = -(L+c-R)\cos\varphi_z - (b-a)\sin\varphi_z,$$
$$G_1 = -(L+c)\cos\varphi_z - (b-a)\sin\varphi_z$$
$$H_1 = -a\sin\varphi_b - L\cos\varphi_b$$
$$I_1 = -a\sin\varphi_b -(L-R)\cos\varphi_b$$
\[ F_2 = (L + c - R) \sin \varphi_s - (b - a) \cos \varphi_s \quad (4.14a) \]
\[ G_2 = -(l + c) \sin \varphi_s - (b - a) \cos \varphi_s \]
\[ H_2 = -a \cos \varphi_b + L \sin \varphi_b \]
\[ I_2 = -a \cos \varphi_b + (L - R) \sin \varphi_b . \]

Furthermore the following abbreviations are introduced,

\[ D_1 = d \cos \varphi_s + c \sin \varphi_s \]
\[ D_2 = -d \sin \varphi_s + c \cos \varphi_s . \quad (4.14b) \]
\[ d = 2a - b \]

The rotation of the rear leg, \( \varphi_b \), is constrained by contact point 3 (the front leg) and contact point 4 (the stop).

\[ g_{N3} = \varphi_b - \varphi_s \quad (4.15) \]
\[ g_{N4} = \varphi_c + \varphi_s - \varphi_b \quad (4.16) \]
5 Measurements

In this chapter the measurements, which have been conducted, will be discussed. First of all will be shown how impr0c.m post-processes the measurements. Subsequently the motion of the generalized coordinates will be shown and the experimental values for the contact distances will be depicted.

5.1 Motion of the markers

As discussed earlier the MatLab-file impr0c.m reads out the frames by making a circle fit around the center of each marker. In figure 5.1 is shown which motion the markers undergo during time. The markers on the slope (7 and 8) and the plumb line (9 and 10) are stationary. The marker 7 and 8 are used to validate the angle of the slope, where the markers 9 and 10 are used to determine the vertical.

The camera has a misalignment as can be seen from the markers 9 and 10 in figure 5.1. The data have therefore to be corrected for the misalignment by a rotation of the coordinate frame over an angle $\varphi_k$ such that marker 9 and 10 form a straight vertical line. The angle by which has to be rotated, $\varphi_k$, can be calculated by formula 5.1. The position of each marker has to be rotated with $\varphi = \arctan \frac{x_9 - x_{10}}{y_9 - y_{10}}$.

This leads to a value for $\varphi_k$ of approximately 0.0386 rad.

The angle of the slope was assumed to be $\pi/20$ rad in [Leine 2001]. Measurement of the angle can validate this assumption. This validation is required because $\varphi_k$ is the rotation angle of the origin. By means of formula (5.2) the angle can be calculated,
\[ \phi_r = \arctan \frac{y_2^0 - y_1^0}{x_2^0 - x_1^0}. \] (5.2)

This results in an angle \( \phi_r \) of 0.1692 rad.

### 5.2 Motion of the generalized coordinates

In chapter 4 formulas were derived for calculating the generalized coordinates. These formulas were used for plotting the motion of the generalized coordinates (see Figures 5.2-5.5). The periodic character can be seen very clearly. The period time can be estimated from these figures and is about 0.84 seconds.

Furthermore can be seen that the motion seems to be instationary. Looking at the results from the \( y \)-motion and the rotation around the center of mass implies that the amplitude varies during time.

![Figure 5.2: X-movement of the center of mass, \( X_1^1 \)](image-url)
Figure 5.3: Y-movement of the center of mass, $Y_s$

The rotation of the rear leg does not seem to be stationary either. When looking at figure 5.5 it can also be seen when impact occurs. At these moments a small divergence in the rotation can be distinguished.

Figure 5.4: Rotation around the center of mass, $\varphi_s$
5.3 Contact distances

With means of the formulas from paragraph 4.3 the contact distances of the experimental motion of the duck can be derived. These distances were also calculated and plotted in time.

The contact distances vary also periodically during time. The dashed line represents $g_{NI}$. Theoretically, it should be zero when the front leg touches the slope. At the same time $g_{N2}$ has his maximum value. In figure 5.7a can be seen that point two is then at the top of the rear leg. Figure 5.7b shows the position of the Waddling Duck when $g_{N2} = 0$. 
The contact distances $g_{N3}$ and $g_{N4}$ are depicted in figure 5.8. In both contact distances occurs a drift. This drift may not occur because $g_{N3}$ and $g_{N4}$ are both body-fixed quantities. In the case of $g_{N3}$ this means that its value may not become less then zero. The reason for this drift will be discussed in section 5.4. There have occurred some uncertainties. As can be seen in figure 5.7b marker 4, used to determine $\varphi_b$, is not completely visible during the whole motion. Furthermore it seems that marker 5 is not glued exactly in the middle of the rear leg. This however cannot be the main reason for the error.
5.4 Validation of the measurements

In order to find out what causes this drift some verifications has been made. First the distance between the markers 5 and 6 has been calculated. The result from this calculation is shown in figure 5.9. The distance is minimum when the legs are closed and reaches its maximum at the moment that $\theta_s$ is at its minimum. A clear drift cannot be observed.

A second validation that has been made is to check the influence of the camera. The duck has been placed upon the slope at two different positions. For these positions the difference between markers 1 and 3 has been calculated. The distance between marker 1 and marker 3 should be stationary, because it is body-fixed. Figure 5.10 shows that indeed there is a small difference for this two positions but when this is transformed to a distance in meters the difference is 3 mm.

Figure 5.9: distance between marker 5 and 6

Figure 5.10: distance between marker 1 and 3 for different positions of the Waddling Duck
Furthermore the y-positions of the 6 markers, glued to the Waddling Duck are depicted in figure 5.11. Again there cannot be distinguished a clear drift. 

![Figure 5.11: Y-position of the markers](image)

As a last validation the distance between marker 1 and 3 has been depicted. The value for the calculation from pixels to meters is also shown in figure 5.12. They both vary during time. Especially in the beginning both values change much.

![Figure 5.12: Distance between marker 1 and 3 (upper case) and the transformation factor from pixel position to absolute displacements (lower case)](image)

Looking at these results the main reason for the drift seems to be the optical deformation due to the camera. This deformation could also explain the change in amplitude for the generalized coordinates. A correction for this deformation has to be made. With a so-called grid this can be done. Unfortunately this correction could not be applied due to time limitations.

In order to validate the numerical results from the dynamical model it will be necessary to correct this optical deformation.
6 Conclusion

The main conclusion of this traineeship is an experimental analysis of the Waddling Duck by means of a high-speed camera is feasible. However, the results still contain some errors. The main reason for this error seems to be the optical deformation due to the camera. This means that the dimensions of an object differ for different positions in front of the camera. A correction has therefore to be made for this optical deformation. This can be done with means of a grid. With this grid a transformation can be made which corrects for the optical deformation.

Furthermore attention has to be paid to the position of the markers. The markers have to be visible during the whole motion so the middle point can be found exactly. As could be seen in the results a divergence from the real motion was returned due to the position of marker 4. Because at the moment $g_{N2}$ is zero, marker 4 cannot be seen in total. As a result of this, the circle fit is made only around the visible part, so the calculated middle point of the marker does not correspond to the real center.

Also a closer look should be taken at the position of the center of mass. It is not sure whether the position of the center of mass has been determined correctly. If indeed the determined position of the center of mass does not correspond to the real position of the center of mass, this would result in a change of the amplitude in the motion for the generalized coordinates.
Appendix I: Position of the markers

The position is calculated with respect to base $\bar{\alpha}_0$. The distances were measured starting in the reference point thus towards each marker.

<table>
<thead>
<tr>
<th>marker</th>
<th>reference point</th>
<th>1mm to the left</th>
<th>35.5 mm down</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1mm to the left</td>
<td>35.5 mm down</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>25 mm to the right</td>
<td>9 mm up</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>92 mm to the right</td>
<td>32 mm down</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>7 mm to the left</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>22 mm to the left</td>
<td>6 mm down</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>21 mm to the right</td>
<td>6 mm down</td>
</tr>
</tbody>
</table>
Appendix II: Matlab Programs

improc.m

function [XMT,YMT]=improc(meting,int)
% auteur: H.L.A.v.d.Bosch
% IMPROC is een programma om TIF files te lezen en te
% behandelen.
% [XMT,YMT]=IMPROC geeft een volledig interactief programma
% om markers te volgen en te bepalen.
% [XMT,YMT]=IMPROC(METING) volgt en bepaalt de posities van
% de
% van meting METING interactief.
% [XMT,YMT]=IMPROC(METING,0) volgt en bepaalt de posities van de
% van meting METING niet interactief.

padm='.';
pade='.';

int=1;
maxz=100;
nclines=20;
eval(['load nrs.txt'])
nrs

file=['f_000',num2str(nrs(1)),'.tif'];
eval(['data=imread(file);'])

if int
    figure(1)
    imshow(data)
    zoom on
end

origineel=data;

% Marker bepaling

% Thresholding

thr=1;
while thr
    thresh=40;
    disp(' ')
    if int
        thresh=definp('Welke waarde voor threshold van edges: ',thresh);
    end
    data=data thresh;
    if int
        imshow(data)
        disp(' ')
        opnieuw=definp('Opnieuw? [y/n] ','n');

23
if opnieuw=='n'
    opnieuw=0;
end
if opnieuw
    imshow(data)
    thr=1;
else
    thr=0;
end
else
    thr=0;
end
end
if int
    imshow(data)
end

% Markerselectie

select=1;
nmark=6;
while select
    if int
        nmark=definp('Hoeveel markers wil je volgen: ',nmark);
        disp('')
        disp('Klik op de markers die je wilt post processen.')
        disp('Hint: Zet het plaatje op volledig scherm.')
        [XM,YM]=ginput(nmark);
        XM=round(XM);
        YM=round(YM);
    end
end

% Eenmalig bepaalde initiele ruwe coordinaten

if exist([pade,'\init.mat'])
    file=[pade,'\init'];
    eval(['load ',file])
else
    if -int
        error(['Er is geen init.mat bestand! Gebruik interactieve mode!'])
    else
        file=[pade,'\init'];
        eval(['save ',file,' XM YM'])
    end
end

XM,YM
nmark=length(XM);
bwmarkers=-bwselect(~datac,XM,YM,4);
if int
    imshow(bwmarkers)
end

if int
    disp('')
    opnieuw=definp('Opnieuw? [y/n] ','n');
    if opnieuw=='n'
        opnieuw=0;
    end
    if opnieuw
        imshow(datac)
select=1;
else
  select=0;
end
else
  select=0;
end
end

clear data

winsize=24;
if int
  winsize=definp('Welke (oneven) windowgrootte: ',winsize+1);
  winsize=winsize-1;
end

% Data processing voor alle opeenvolgende plaatjes

bekend=ones(1,nmark);
meanxmc=XM;
meanymc=YM+winsize/2;
XMT=[];
YMT=[];
if int
  figure (2)
end
for nr=nrs(1):nrs(2)
  if nr ~= 0 & any(bekend)
    file=[padm,'\f_000',num2str(nr),'.tif'];
    eval(['data=imread(file);'])
    for i=1:winsize/2
      data=[data(1,:); data; data(min(size(data)),:)];
    end
    if int
      imshow(data)
    end
  end
  XM=round(meanxmc);
  YM=round(meanymc);

% Bepaling contourlijnen

% c=contourc(double(data),nclines);
% if exist('c')
%    limit=size(c,2);
%    i = 1;
%    nlines = 0;
%    while(i < limit)
%      x_level = c(1,i);
%      npoints = c(2,i);
%      nexti = i+npoints+1;
%      if c(:,i+1) == c(:,i+npoints)
%        nlines=nlines+1;
%        xdatat{nlines} = c(1,i+1:i+npoints);
%        ydatat{nlines} = c(2,i+1:i+npoints);
%      end
%      i=nexti;
%    end
% end

if int
for i=1:nlines
    line(xdatat{i},ydatat{i})
end
end

Selectie van relevante contourlijnen

xdata=cell(nmark,nclines);
ydata=cell(nmark,nclines);
for i=1:nmark,
    if bekend(i)
        zarea=data((YM(i)-round(winsize/2)):YM(i)+round(winsize/2)),(XM(i)-round(winsize/2)):XM(i)+round(winsize/2));
        carea=contourc(double(zarea),nclines);
        maxc=max(max(double(zarea)));
        minc=min(min(double(zarea)));
        limit=size(carea,2);
        j = 1;
        nlines(i) = 0;
        while(j < limit)
            z_level = carea(1,j);
            npoints = carea(2,j);
            nextj = j+npoints+1;
            if carea(:,j+1) == carea(:,j+npoints) & z_level < maxz
                if (carea(:,j+1) == carea(:,j+npoints)) & (npoints > 30) & (z_level > minc+0.1*(maxc-minc)) & (z_level < minc+0.4*(maxc-minc))
                    if (carea(:,j+1) == carea(:,j+npoints)) & (z_level > minc+0.001*(maxc-minc)) & (z_level < minc+0.5*(maxc-minc))
                        nlines(i)=nlines(i)+1;
                        xdata{i,nlines(i)} = carea(1,j+1:j+npoints);
                        ydata{i,nlines(i)} = carea(2,j+1:j+npoints);
                        end
                end
            end
        end
    end
end

Repositioneren van de contourlijnen

for i=1:nmark
    if bekend(i)
        for j=1:nclines
            for k=1:nlines(i)
                xdata{i,j}=xdata{i,j}+XM(i)-round(winsize/2)-1;
                ydata{i,j}=ydata{i,j}+YM(i)-round(winsize/2)-1;
            end
        end
    end
end

if int
    imshow(data)
for i=1:nmark
    if bekend(i)
        for k=1:nlines(i)
            line(xdata{i,k},ydata{i,k})
        end
    end
end
pause(.2)
end

% Check indien slecht geconditioneerde matrix

if nr>260
  imshow(uint8(double(data)+100))
  for i=nmark:nmark
    for k=1:nlines(i)
      line(xdata{i,k},ydata{i,k})
    end
  end
  pauze
end

% Marker positiebepaling m.b.v. circlefit methode.

xmc=zeros(nmark,nclines);
ymc=zeros(nmark,nclines);
rmc=zeros(nmark,nclines);
for i=1:nmark
  if bekend(i)
    for j=1:nclines
      if ~isempty(xdata{i,j})
        [xmc(i,j),ymc(i,j),rmc(i,j)]=circlefit(xdata{i,j}(1:length(xdata{i,j})-1),ydata{i,j}(1:length(xdata{i,j})-1));
      end
    end
  end
end
for i=1:nmark
  if bekend(i)
    meanxmc(i)=mean(xmc(i,1:nlines(i)));
    stdxmc(i)=std(xmc(i,1:nlines(i)));
    meanymc(i)=mean(ymc(i,1:nlines(i)));
    stdymc(i)=std(ymc(i,1:nlines(i)));
  end
end
for i=1:nmark
  if bekend(i)
    if isnan(meanxmc(i))
      bekend(i)=0;
      disp(['!! Marker ',num2str(i),', wordt niet meer gedetecteerd '])
    end
    disp(['Laatst bekende positie: XM = ',num2str(XM(i))])
    disp([' YM = ',num2str(YM(i))])
  end
end
if int
  hold on
  plot(meanxmc,meanymc,'x')
  hold off
end
% Check indien slecht geconditioneerde matrix

% imshow(data)
% line(meanxmc,meanymc)
% pause(.01)

% Opslag van variabelen

XMT=[XMT; meanxmc(:)']
YMT=[YMT; meanymc(:)']
end
eind6.m

% zelf toegevoegd
save positie XMT YMT
save nmark

if int
figure(3)
plot(XMT,YMT,'rx',XMT,YMT,'b',XMT(1,:),YMT(1,:), 'ro')
for i=1:nmark
if i<10
text(XMT(1,i),YMT(1,i),'t=0', 'Marker: ',num2str(i))
else
text(XMT(1,i),YMT(1,i),'t=0', 'Marker: ',num2str(i))
end
end
zoom on
end

close all
clear all

% Stage Waddling Duck
% auteur: W. Schwanen

load positie;

%YMTg = gespiegelde YMT over horizontaal (oorsprong ligt onder)
%aantal_pixels_ydir = 480;
%YMTg=aantal_pixels_ydir*ones(size(YMT))-YMT;

figure(4)
plot(XMT,YMTg, XMT(:,7), YMTg(:,7), 'o', XMT(:,8), YMTg(:,8), 'o', XMT(:,9), YMTg(:,9), 'o', XMT(:,10), YMTg(:,10), 'o')
xlabel('x-position in pixels')
ylabel('y-position in pixels')
title('motion of the markers')

% data markers vaststellen
% coordinates in e_s in pixels
X1=XMT(:,1);
X2=XMT(:,2);
X3=XMT(:,3);
X4=XMT(:,4);
X5=XMT(:,5);
% aanpassen van horizontaal

% phig wordt gemeten aan de hand van de verticaal
\[ \text{phig} = \text{abs}(\text{atan}(\frac{X_{9} - X_{10}}{Y_{9} - Y_{10}})) ; \]

\[
\begin{align*}
[X_{1\_0}, Y_{1\_0}] &= \text{rotation}([X_{1}, Y_{1}], \text{phig}) ; \\
[X_{2\_0}, Y_{2\_0}] &= \text{rotation}([X_{2}, Y_{2}], \text{phig}) ; \\
[X_{3\_0}, Y_{3\_0}] &= \text{rotation}([X_{3}, Y_{3}], \text{phig}) ; \\
[X_{4\_0}, Y_{4\_0}] &= \text{rotation}([X_{4}, Y_{4}], \text{phig}) ; \\
[X_{5\_0}, Y_{5\_0}] &= \text{rotation}([X_{5}, Y_{5}], \text{phig}) ; \\
[X_{6\_0}, Y_{6\_0}] &= \text{rotation}([X_{6}, Y_{6}], \text{phig}) ; \\
[X_{7\_0}, Y_{7\_0}] &= \text{rotation}([X_{7}, Y_{7}], \text{phig}) ; \\
[X_{8\_0}, Y_{8\_0}] &= \text{rotation}([X_{8}, Y_{8}], \text{phig}) ; \\
[X_{9\_0}, Y_{9\_0}] &= \text{rotation}([X_{9}, Y_{9}], \text{phig}) ; \\
[X_{10\_0}, Y_{10\_0}] &= \text{rotation}([X_{10}, Y_{10}], \text{phig}) ;
\end{align*}
\]

% calculating with respect to base el
\[ \text{phir} = \text{atan}((Y_{7\_0} - Y_{8\_0}) / (X_{7\_0} - X_{8\_0})) ; \]

\[
\begin{align*}
[X_{1\_1}, Y_{1\_1}] &= \text{rotation}([X_{1\_0}, Y_{1\_0}], \text{phir}) ; \\
[X_{2\_1}, Y_{2\_1}] &= \text{rotation}([X_{2\_0}, Y_{2\_0}], \text{phir}) ; \\
[X_{3\_1}, Y_{3\_1}] &= \text{rotation}([X_{3\_0}, Y_{3\_0}], \text{phir}) ; \\
[X_{4\_1}, Y_{4\_1}] &= \text{rotation}([X_{4\_0}, Y_{4\_0}], \text{phir}) ; \\
[X_{5\_1}, Y_{5\_1}] &= \text{rotation}([X_{5\_0}, Y_{5\_0}], \text{phir}) ; \\
[X_{6\_1}, Y_{6\_1}] &= \text{rotation}([X_{6\_0}, Y_{6\_0}], \text{phir}) ; \\
[X_{7\_1}, Y_{7\_1}] &= \text{rotation}([X_{7\_0}, Y_{7\_0}], \text{phir}) ; \\
[X_{8\_1}, Y_{8\_1}] &= \text{rotation}([X_{8\_0}, Y_{8\_0}], \text{phir}) ; \\
[X_{9\_1}, Y_{9\_1}] &= \text{rotation}([X_{9\_0}, Y_{9\_0}], \text{phir}) ; \\
[X_{10\_1}, Y_{10\_1}] &= \text{rotation}([X_{10\_0}, Y_{10\_0}], \text{phir}) ;
\end{align*}
\]

% omrekenen naar verplaatsingen in meters
\[ X_{13} = X_{1\_1} - X_{3\_1} ; \]
\[ Y_{13} = Y_{3\_1} - Y_{1\_1} ; \]
\[ X_{45} = X_{4\_1} - X_{5\_1} ; \]
\[ Y_{45} = Y_{4\_1} - Y_{5\_1} ; \]
\[ X_{78} = X_{7\_1} - X_{8\_1} ; \]
\[ Y_{78} = Y_{7\_1} - Y_{8\_1} ; \]

% the distance between markers 1 and 3 is 0.093 meters.
\[ \text{Delta}_{13} = \sqrt{(X_{13}^2 + Y_{13}^2)} ; \]
\[ \text{in e0} \]
\[ \text{schaling}_{13} = 0.093 / \text{Delta}_{13} ; \]
calculating generalized coordinates 
\( (X_s, Y_s) \):

- \( X_s \) and \( Y_s \) movement of the centre of mass

\[ CO = 0.041; \]
\[ cl = 0.052; \]
\[ c2 = 0.004; \]
\[ dY_{31} = Y_3 - Y_1; \]
\[ dX_{31} = X_3 - X_1; \]
\[ alfa = \arctan\left(\frac{dY_{31}}{dX_{31}}\right); \]
\[ X_s - 1 = x_1 - 1 + c_0 \cos(alfa) - c_2 \sin(alfa); \]
\[ Y_s - 1 = y_1 + c_0 \sin(alfa) + c_2 \cos(alfa); \]

% rotation around the centre of mass
\[ beta = \pi/45; \]
\[ phis_1 = alfa + beta - phir; \]

% rotation of the rear leg
\[ a = 0.006; \]
\[ b = 0.012; \]
\[ c = 0.005; \]
\[ deltatime = 1/125; \]
\[ time = 0:delatime:400/125; %400 zijn het aantal foto's \]

% rotation of rear leg
\[ c5 = 0.007; \]
\[ c6 = 0.015; \]
\[ dy_{45} = Y_4 - Y_5; \]
\[ dx_{45} = X_4 - X_5; \]
\[ gamma = \arctan(dy_{45}/dx_{45}); \]
\[ delta = \arctan(c6/c5); \]
\[ phib_1 = gamma - delta + \pi/2 - phir; \]
% % %

figure(6)
plot(time, Xs_1)
title('X-movement of centre of mass')
Xlabel('time [s]
Ylabel('X-movement [m]

figure(7)
plot(time, Ys_1)
title('Y-movement of centre of mass')
Xlabel('time [s]
Ylabel('Y-movement [m]

figure(8)
plot(time, phis_1)
title('rotation around the centre of mass')
Xlabel('time [s]
Ylabel('phis [rad]

figure(9)
plot(time, phib_1,'r')
title('rotation of rear leg')
Xlabel('time [s]
Ylabel('phibl [rad]

% controle
% calculating difference in x-position between marker 9 and 10
deltax9-10=x9_1-x10_1;

% calculating distance between marker4 and 5
% delta45=sqrt(dy45.^2+dx45.^2);
% deltalin=sqrt((xlin-x3).^2+(ylin-y3).^2);

DX45=XMT(:,4)-XMT(:,5);
DY45=YMTg(:,4)-YMTg(:,5);
D45=sqrt(DX45.^2+DY45.^2);
dy12_1=y1_1-y2_1;
dx12_1=x1_1-x2_1;
d12=sqrt(dy12_1.^2+dx12_1.^2);
dy23=y2_1-y3_1;
dx23=x2_1-x3_1;
d23=sqrt(dy23.^2+dx23.^2);
dy56=y5_1-y6_1;
dx56=x5_1-x6_1;
delt56=sqrt(dy56.^2+dx56.^2);
figure(10)
plot(time,delt56,'o')

% opslaan van belangrijke waarden
save coordinates Xs_1 Ys_1 phis_1 phib_1 time
save markerpositions x1_1 x2_1 x3_1 x4_1 x5_1 x6_1 y1_1 y2_1 y3_1 y4_1 y5_1 y6_1 phir

rotation.m
% auteur: W.Schwanen

% rotation is a function to rotate over a certain angle. It calculates the
% rotation for each time the angle is calculated
function [X,Y]=rotation(m_0,angle)
  m_1 = [I];
  for i=1:length(angle);
    anglecurrent=angle(i);
    R=[cos(anglecurrent) -sin(anglecurrent); sin(anglecurrent) cos(anglecurrent)];
    M=R.*m_0(i,:);
    m_1=[m_1 M];
  end

  m_1=m_1';
  X=m_1(:,1);
  Y=m_1(:,2)

contact.m
% auteur: W. Schwanen
% calculating contact distances
load coordinates4

%setting constants
a=0.006;
b=0.012;
c=0.005;
d=2*a-b;
L=0.050;
R=0.100;

% calculating normal contact distances
%calculating gN1
gN1=[];
F1=[];
G1=[];
for i=1:length(phis_1)
  F1(i) =-(L+c-R)*cos(phis_1(i)) -(b-a)*sin(phis_1(i));
  G1(i) =-(L+c)*cos(phis_1(i)) -(b-a)*sin(phis_1(i));
  if phis_1(i)>0
    gN1(i)=ys_1(i)+F1(i)-R;
  elseif phis_1(i)<0
    gN1(i)=ys_1(i)+G1(i);
  end
end

gN1=gN1';

% calculating gN2
for i=1:length(phis_1)
  D2(i)=-d*sin(phis_1(i))+c*cos(phis_1(i));
  H1(i)=-a*sin(phib_1(i))-L*cos(phib_1(i));
  I1(i)=-a*sin(phib_1(i))-(L-R)*cos(phib_1(i));
  if phib_1(i)>=0
    gN2(i)=ys_1(i)-D2(i)+H1(i);
  elseif phib_1(i)<0
    gN2(i)=ys_1(i)-D2(i)+I1(i)-R;
  end
end

gN2=gN2';
% plotting gN1 and gN2
figure(1)
plot(time, gN1, '-', time, gN2, '--')
xlabel('time [s]')
ylabel('gN1 and gN2 [m]')

% calculating gN3
G3 = phi_b - 1 - phi_s - 1;

% calculating gN4
phi_c = 0.17;
gN4 = phi_c + phi_s - 1 - phi_b - 1;

% plotting gN3 and gN4
figure(2)
plot(time, gN3, '-', time, gN4, '--')
xlabel('time [s]')
ylabel('gN3 and gN4 [rad]')
title('normal contact distances of rear leg')
References