Adjusting the Putt Distance on Inclined Surfaces with respect to a Flat Putt

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Objective

- There are many different heuristic approaches for distance control in putting (e.g. *Dave Pelz's Putting Bible*).
- However, it seems that there is still a need for a unified and scientifically based concept, that can be used in practice.
- As the ball passes through different phases before the onset of pure roll, depending on various parameters like green speed, inclination and angles and many individual characteristics, we propose a correction with respect to a putt on a plane surface.
- Furthermore, we estimate the effect of the sliding phase on the proposed correction formulas.
- With *Quintic Ball Roll* and *Overhead Putt Tracker*, the validity of the correction formulas can be tested experimentally.

Methods

- The correction method is based on the physics of a rolling ball in the presence of sliding friction, rolling friction and inclination.
- Given these parameters, the total length of the putt depends obviously on the initial velocity (v_0) of the ball.
- … but also on the distance the ball flies after impact, which depends on individual features such as the loft of the club-head, the execution of the stroke etc.

→ **Concept of corrected length s_{corr}.**

"How long would a putt be on a plane surface, if it were hit with the same initial velocity that is needed to reach a length s, given the actual inclination and green speed."

Methods ctd.

For this talk, we restrict ourselves to a one-dimensional motion (along the fall line) in the presence of sliding friction (μ_S), rolling friction (μ_R) and inclination (θ).

- The coefficient of rolling friction (μ_R) can be derived from the distance measured by a *Stimp-meter* (D_{Stimp}):
- $\mu_R = \frac{7v_{0;s}^2}{10gD_{Stimp}}$.
- $v_{0;s}$: Initial velocity from Stimp-meter ($1.83 ms^{-1}$) .
- g : Acceleration of gravity ($9.81 ms^{-2}$).

Dynamic of a Golf Ball on an Inclined Surface

- The ball slides until the condition of pure rolling has been reached: $v = \omega \times r_b$.
- ω: angular velocity, r_b: radius of ball.
- Assumption: (Initial angular velocity $\omega_0 = \omega(t=0) = 0$
- $\rightarrow$ equations of motion:

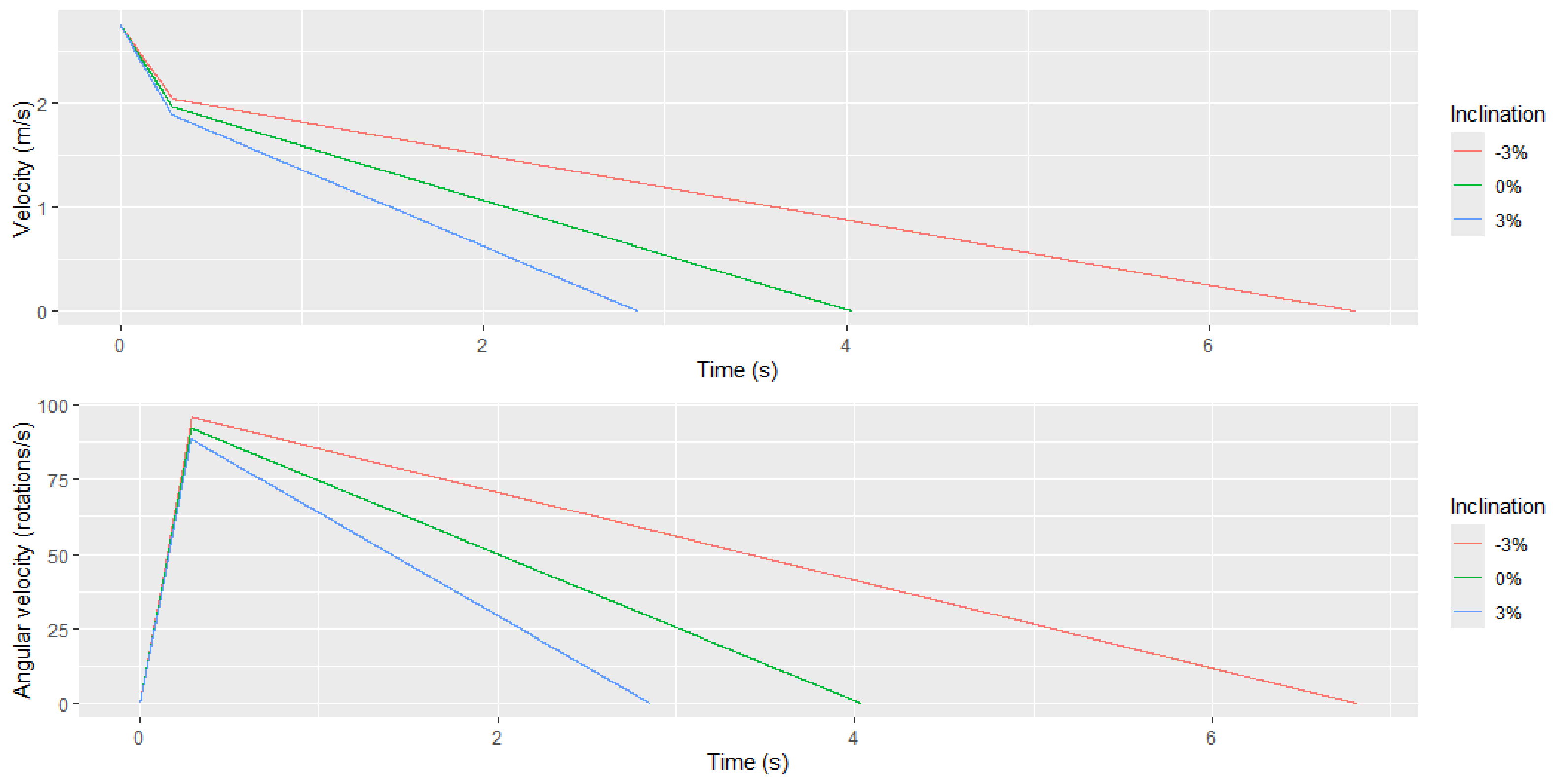
$$\ddot{\phi} = \dot{\omega} = \begin{cases} \frac{g}{r_b}\left(\frac{5\mu_G}{2} - \frac{5\theta}{7}\right) & \text{for} \quad t \leq t_R \quad (v \geq \omega r_b) \\ \dot{v}/r_b & \text{for} \quad t > t_R \end{cases}$$

$$\ddot{x} = \dot{v} = \begin{cases} -g(\mu_G + \theta) & \text{for} \quad t \leq t_R \quad (v \geq \omega r_b) \\ -\frac{5g}{7}(\mu_R + \theta) & \text{for} \quad t > t_R \end{cases}$$

- t_R: Time when pure rolling begins: $\frac{v_0}{g}\left(\frac{14}{49\mu_G + 4\theta}\right)$

Velocity and Angular Velocity of the Ball vs. Time in Seconds According to Model

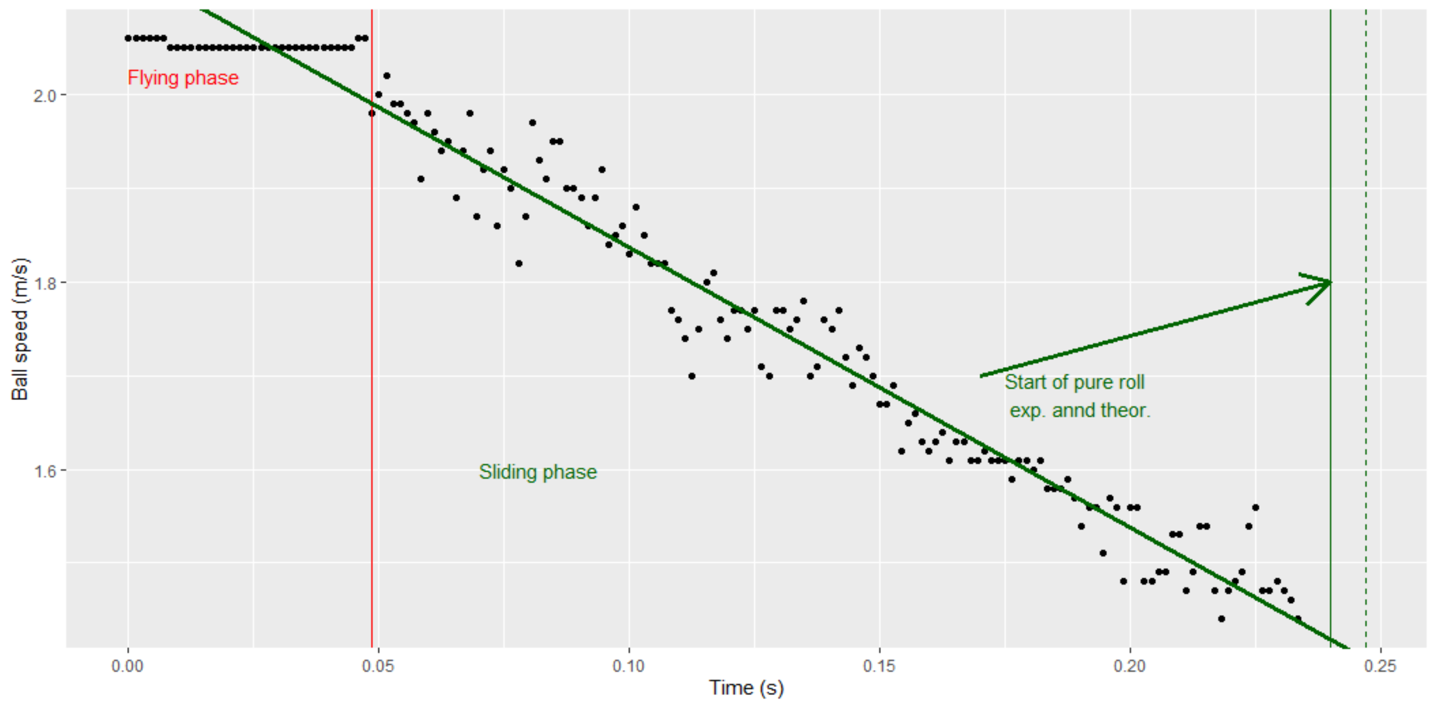
Stimp-distance: 10.5 ft, μ_G = 0.28, v_0 = 2.75 m/s



Comparing with Experimental Measurements

Data from a Single Putt

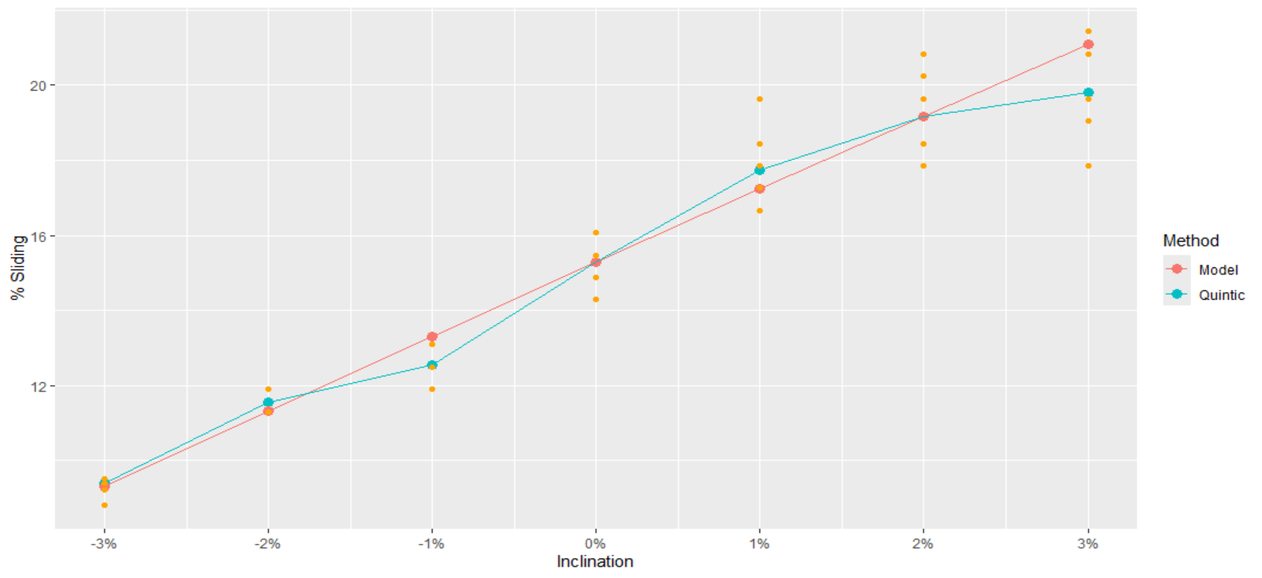
- Data of putt captured by Quintic Ball Roll.
- Putt: 3% downhill, D_{Stimp}= 10.5 ft.



- y-axis: ball speed after impact
- x-axis: time in seconds

Percentage of Sliding Phase - Measured Values and Model Predictions

- Mean values taken from 10 putts on a artificial surface with speed of 10.5 ft (Stimp meter distance) at various inclinations.
- -3% inclination: 8% Sliding 92% Rolling
- +3% inclination: 20% Sliding 80% Rolling
- Ratio of Sliding and Rolling phases is influenced heavily by surface inclination!



Length Correction

- By splitting the whole putting trajectory into the sliding phase and the rolling phase, it is straightforward to calculate a correction factor.
- However, that correction depends on the coefficient of sliding friction friction μ_S or the ratio λ between gliding friction and rolling friction
- $\lambda = \mu_S/\mu_R$, which is commonly not measured at golf courses.

→ How accurate is the correction, when considering only rolling motion?

Derivation of the Length Correction Considering Sliding and Rolling Phase

- θ: Inclination. (θ = tangent of inclination angle in radians)
- v_0 :Initial velocity of the ball after impact with club head.
- t_R :Time of onset of pure rolling. $\frac{v_0}{g}\frac{14}{49\mu_S+4\theta}$
- v_1 :Velocity of the ball at onset of pure rolling. $v_0-\left(1-\frac{14(\mu_S+\theta)}{49\mu_S+4\theta}\right)$.
- S_S: Distance covered in sliding phase. $v_0 t_R-g(\theta+\mu_S)\frac{t_R^2}{2}$.
- S_R :Distance covered in rolling phase .$\frac{7}{10}\frac{v_1^2}{g(\mu_R+\theta)}$.

$$\rightarrow S_{tot}=S_S+S_R$$

- $S_0=S_0(v_0,\theta,\mu_S,\mu_R)$:Total distance on plane surface ($\theta=0$).

$$S_0=\frac{v_0^2}{g}\left(\frac{24\mu_G+35\mu_S}{98\mu_G\mu_R}\right)$$

→ Correction factor: $c_{SR}=S_{tot}/S_0$

Length Correction Considering Sliding and Rolling (Phase II)

S_{tot}: **Total distance (sliding phase + rolling phase).**

$$S_{tot} = \frac{7v_0^2\left(8\theta^2 + 4\theta(7\mu_S - 3\mu_R) + 7\mu_S(35\mu_S + 24\mu_R)\right)}{2g(4\theta + 49\mu_S)^2(\theta + \mu_R)}$$

→ **Correction factor**: $c_{SR} = S_{tot}/S_0$

$$1/c_{SR} = \frac{343\mu_S\mu_R\left(8\theta^2 + 4\theta(7\mu_S - 3\mu_R) + 7\mu_S(35\mu_S + 24\mu_R)\right)}{(4\theta + 49\mu_S)^2(\theta + \mu_R)(35\mu_S + 24\mu_R)}$$

Length Correction Considering only the Rolling Phase

- When considering the whole trajectory as “pure roll” the correction formula is very simple:
- The initial speed in order to achieve a total length s considering only rolling motion is given by:

$$v_0(s, \theta) = \sqrt{\frac{10}{7} s g (\mu_R + \theta)}$$

- By setting:
- $v_0(s, \theta) = v_0(s_{corr}, \theta = 0)$
- It follows:

$$s_{corr} = c_R \times s \quad \text{and} \quad c_R = 1 + \frac{\theta}{\mu_R} \quad \theta \text{ in radians}$$

Error in the Correction Factor when Considering only Pure Roll

- c_{SR} correction factor considering both, sliding and rolling phase.
- Table: Maximum difference between c_{SR} and c_R (in %).

D_s (ft)	lambda	maximum error
8	3	1.19%
8	4	0.81%
8	5	0.60%
8	6	0.48%
10	3	1.50%
10	4	1.02%
10	5	0.76%
10	6	0.60%
12	3	1.82%
12	4	1.23%
12	5	0.92%
12	6	0.72%

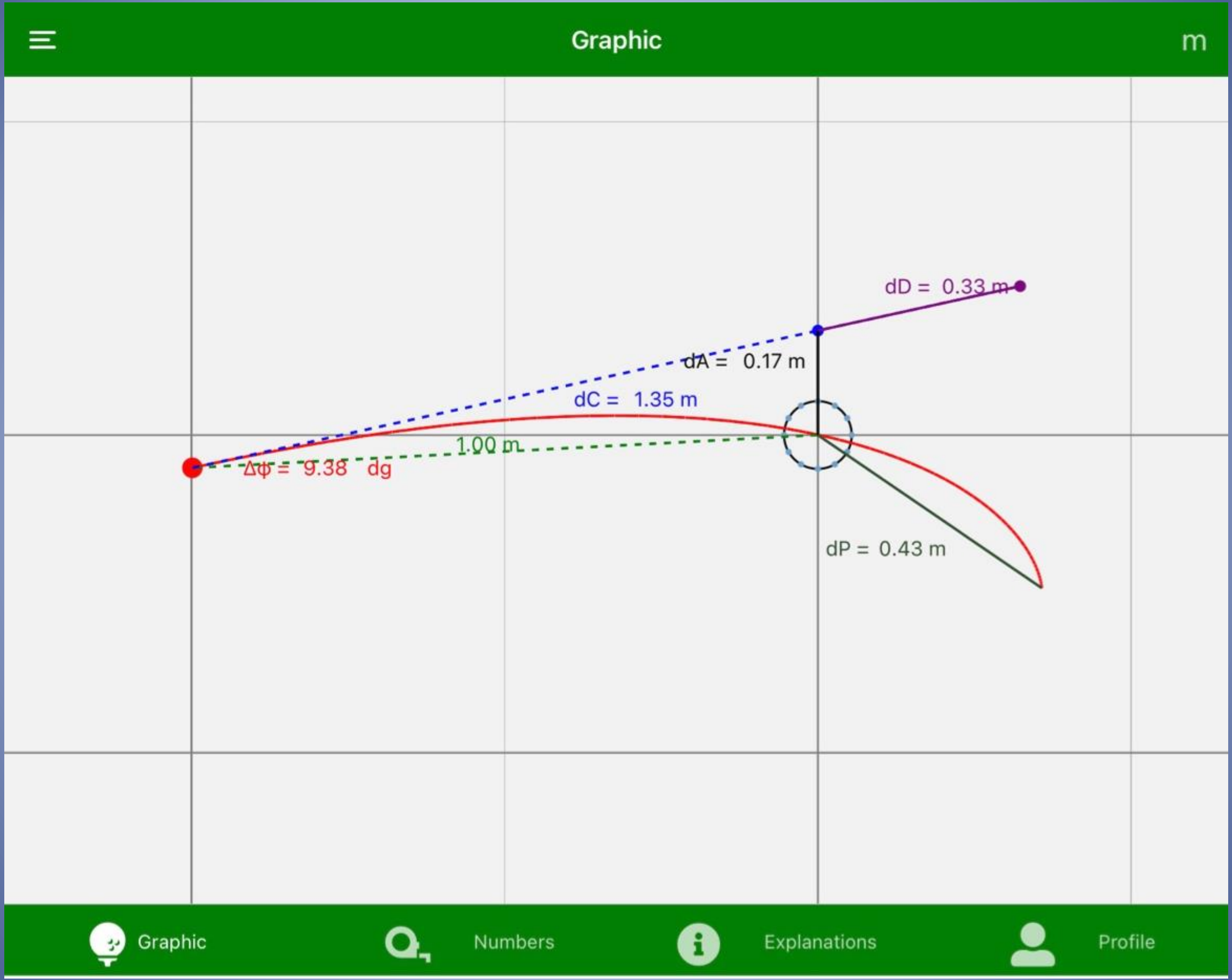
Conclusions

- Concept of length correction *with respect to a putt on a plane surface* is useful and easy to apply.
- Model in excellent agreement with experimental measurements.
- Length corrections derived only considering the rolling phase are more than sufficient for practical purposes.

Further Developments

- Equations of motion where there is an angle between the fall line and the line ball-hole.
- $\rightarrow$ Curved trajectories.

- The corrected distance and curved trajectories are now implemented in **www.puttalyze-app.com**



Graphic
m
dD = 0.33 m
dA = 0.17 m
dC = 1.35 m
1.00 m
Δφ = 9.38 dg
dP = 0.43 m
Graphic
Numbers
Explanations
Profile

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