2D and 3D Motion Analysis

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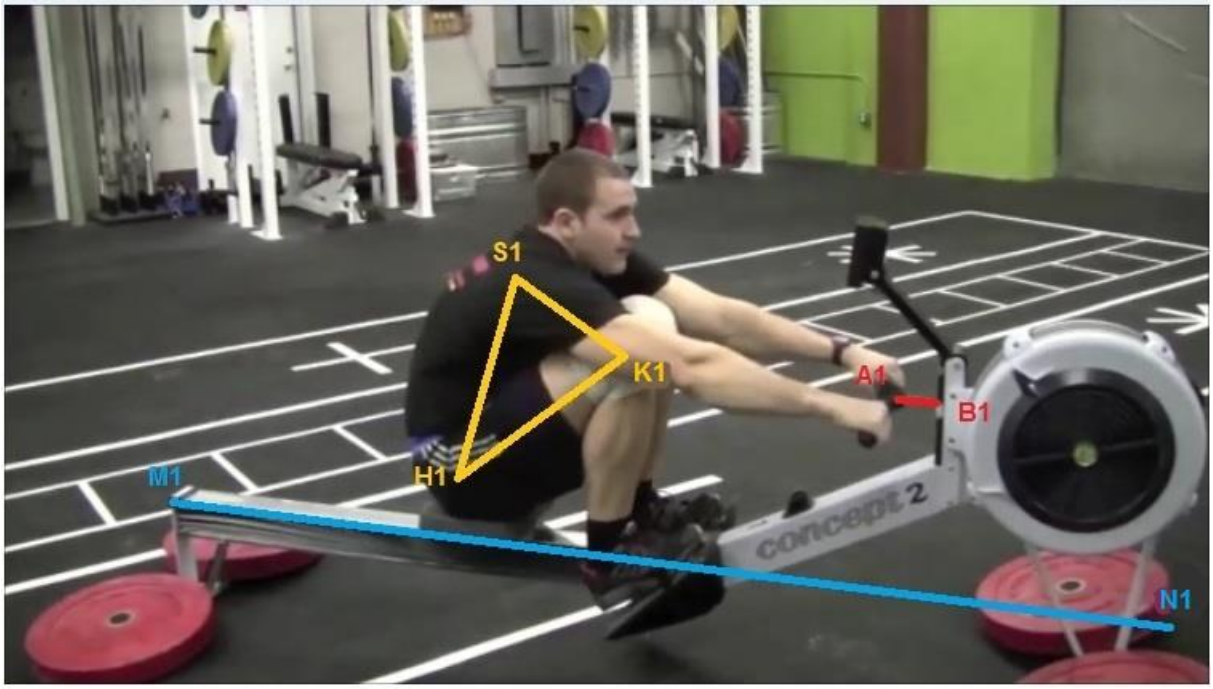
In this project we will focus on the 2D motion analysis in sport activities. We are going to do some measurements to analyze an athlete's movements on a rowing machine. The aim is to measure the distance of the handle of the rowing machine and its speed. On the other hand, we are going to measure the angle between his shoulders and knees at the hip point. We choose the video with the proper megapixel of: Frame width (1280), Frame height (720) and Frame rate of (29 frames/second). We then cut the part of the video (10 second out of 3.51 min) which is a complete scene from start to end of the movement with windows live movie maker. Next, we select a frame from the start of the movement for "Frame 1" and the end of the movement for "Frame 2". After that, we assign some points on each frame and name them as below:

- **A**: The handle of the rowing machine.
- **B**: The Base point – It is the point that the cable is connected to the machine and it doesn't have any movement.
- **H**: Athlete's Hip.
- **S**: Athlete's Shoulder
- **N**: Athlete's Knees
- **M**: End of the rowing machine
- **N**: Head of the rowing machine

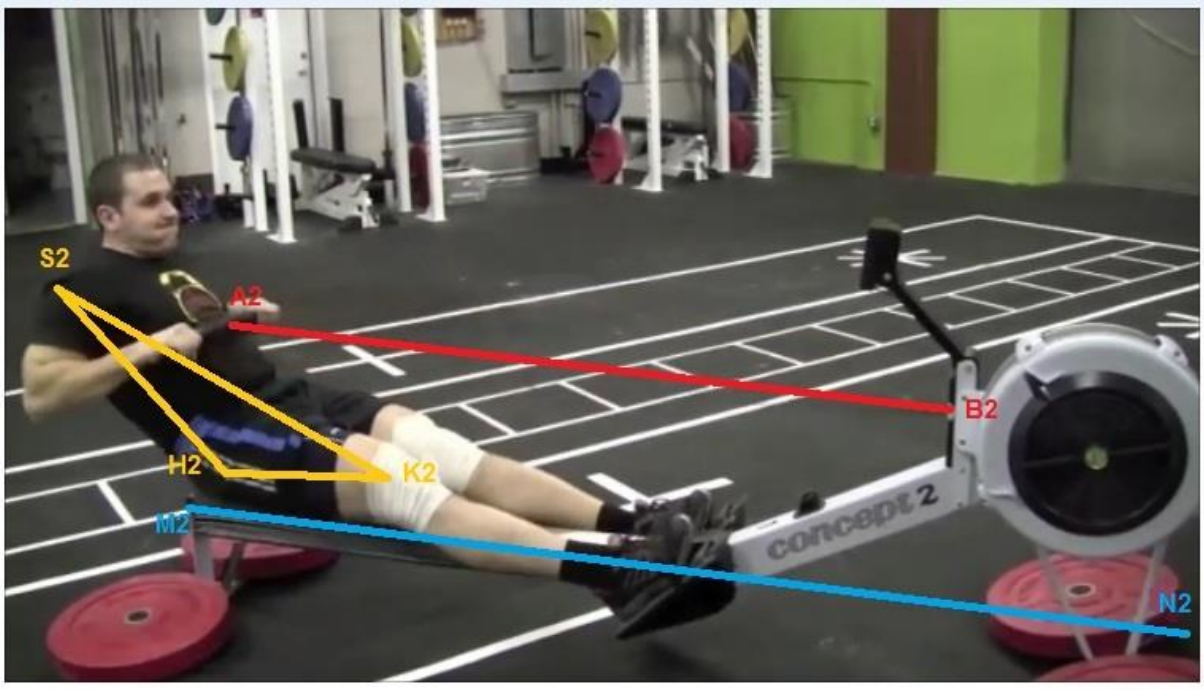
- For our assigned points used in “Frame 1” we are choosing index “1” after our letters to refer to the corresponding frame and index “2” after letters for frame two.

Video Frame 1 - Start



00:04.30/00:10.73

Video Frame 2 - End



00:05.20/00:10.73

Calculating the Angles

In this part we will calculate the angle between the athlete's shoulders and knees at the hip point in both video frames hence we form a triangle with these 3 points. To calculate the angles of the triangle HSK, we measure each side length. In order to measure them, we took the coordinates of points H1, S1 and K1 in "Frame 1", then H2, S2 and K2 in "Frame 2" and put them in the formula [1]:

Formula [1]: $$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}.$$

After finding the lengths, we will calculate the angles using the formulas [2] and [3]:

Formula [2]: $$a^2 = b^2 + c^2 - 2bc\cos(\alpha)$$

Formula [3]: $$\alpha = \arccos\left(\frac{b^2 + c^2 - a^2}{2bc}\right)$$

We named each angle corresponding to its corner point's name:

Video Frame 1	Video Frame 2
h_1 = angle at the point H_1	h_2 = angle at the point H_2
s_1 = angle at the point S_1	s_2 = angle at the point S_2
k_1 = angle at the point K_1	k_2 = angle at the point K_2

The following charts show the calculation of angles in "Frame 1" and "Frame 2". In each chart you will find our given data (inputs) in red color and the calculated data based on the formulas in black (outputs).

Calculation of Angles in Video Frame 1					
Point 1 (H_1)		**Point 3 (K_1)**		**Point 1 (H_1)**	
x1	285	x1	389	x1	285
y1	297	y1	223	y1	297
Point 2 (S_1)		**Point 2 (S_1)**		**Point 3 (K_1)**	
x2	321	x2	321	x2	389
y2	174	y2	174	y2	223
Length	128.16	**Length**	83.82	**Length**	127.64
cos s_1 =	**0.333**	**cos h_1 =**	**0.785**	**cos k_1 =**	**0.322**
s_1 =	**70.54**	**h_1 =**	**38.25**	**k_1 =**	**71.21**

Control	
$s_1+h_1+k_1$ =	**180.00**

Calculation of Angles in Video Frame 2					
Point 1 (H_2)		**Point 3 (K_2)**		**Point 1 (H_2)**	
x1	143	x1	244	x1	143
y1	297	y1	300	y1	297
Point 2 (S_2)		**Point 2 (S_2)**		**Point 3 (K_2)**	
x2	36	x2	36	x2	244
y2	181	y2	181	y2	300
Length	157.81	**Length**	239.64	**Length**	101.04
cos s_2 =	**0.954**	**cos h_2 =**	**-0.700**	**cos k_2 =**	**0.882**
s_2 =	**17.54**	**h_2 =**	**134.39**	**k_2 =**	**28.07**

Control	
$s_2+h_2+k_2$ =	**180.00**

As we have shown in the above charts, the athlete has started his movement in the hip angle of 38.25º and has finished in 134.39º. Then the rotation in hip point from start to end will be:

134.39º - 38.25º = **96.14 º**

Final Distance and Speed

In order to measure the movement of the handle from the point "A_1" in "Frame 1" to the point "A_2" in "Frame 2", we needed a base point in each frame, because there is a little camera movement in the video. We considered calibrating each frame dimensions separately to get a better result to cover the movement of the camera. We assigned the points "B_1" and "B_2" in each frame as a base point and measured the distance between "A_1" and "B_1" in "Frame 1" and "A_2" and "B_2" in "Frame 2". The difference between the length of (A_1B_1) and (A_2B_2) will be the movement of the handle of the rowing machine (Distance). As we needed a calibration in each frame, we assigned the overall length of the rower machine as a constant value for calibration. The rowing machine in our video is "Concept 2 – Model D" according to official website of its producer[1], and it overall length is 2.44 meters. After finding the coordinates of all points in both frames in the similar manner by using formula [1], we calculate the distances. The following charts show the calculations:

Calculation of Distances in Video Frame 1		
Coordinates	**x**	**y**
Point1 (A_1)	560	249
Point2 (B_1)	584	251

d_1=	**24.1**	pixel	**9.3**	cm
	1 pixel =	0.38731818	cm	

Calibration

Coordinates	**x**	**y**
Point1 (M_1)	106	313
Point2 (N_1)	731	392

D_1=	**630.0**	pixel	**244**	cm

Calculation of Distances in Video Frame 2		

Coordinates	x	y
Point1 (A_2)	146	204
Point2 (B_2)	600	256

d_2=	457.0 pixel	177.0 cm
	1 pixel = 0.38731818 cm	

calibration

Coordinates	x	y
Point1 (M_2)	106	313
Point2 (N_2)	731	392

D_2=	630.0 pixel	244 cm

To calculate the speed of the handle, we need duration and distances from "Frame 1" to "Frame 2". Time at starting point is 4.30 seconds and at the end is 5.20 seconds. The difference in time between frame 2 and frame 1 will be the duration of the movement in seconds. Movement is the difference between "d_1" and "d_2" where "d_1" and "d_2" are distances between the handle and the base point in frames 1 and 2. Finally we calculate the speed by dividing the final distance to duration time. The calculations are as the followings:

Time in Frame 1 = 4.30 s	Duration = 0.90 s
Time in Frame 2 = 5.20 s	

d_1 (Frame 1) = 9.3 cm	Final Distance = 167.7 cm = 1.677 m
d_2 (Frame 2) = 177.0 cm	

v = s / t	Speed = 1.863 m/s

[1] http://www.concept2.com/indoor-rowers/model-d