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# Kinematics of a Football Kick using Video Tracking Techniques

## ABSTRACT

This project focuses on the analysis of motion during a football kick using open-source video tracking software. The objective is to study kinematic parameters like velocity, acceleration and trajectory of a football during kicking action. A slow-motion video was analyzed using Tracker software to extract positional data frame by frame. Key results indicated a peak resultant velocity of 1.36 m/s and a maximum resultant acceleration of 71.66 $m/s^2$ during the moment of impact. The results provide an understanding of how efficiently force and energy are transferred during the kick, demonstrating the connection between physics and human biomechanics.

## INTRODUCTION

**Football (Soccer)**, the world's most popular sport, is analyzed through the lens of the **Football Kick**. This fundamental action, essential for passing, crossing, and scoring, is a highly complex, multi-segmental motion that exemplifies the **kinetic chain** principle in human movement. The kick involves a rapid sequence of joint actions, primarily originating from the hip, transitioning through the knee (such as rapid knee extension), and culminating in the impact phase at the ankle and foot. The efficiency and success of the kick, measured by the ball's velocity and trajectory, hinge on the precise kinematic parameters (velocity and acceleration) achieved by the leg and foot just before, during, and immediately after ball contact. This unique nature of the kick makes it an ideal subject for bio mechanical analysis.

Sport kinematics is crucial as it quantitatively describes the movement pattern of an athlete. Kinematics focuses on the motion of objects, such as determining displacement, velocity, and acceleration. By comparing an athlete's performance with optimal models, kinematics can be used to optimize technique and enhance performance. Additionally, kinematics can aid in injury prevention and the detection of common injury patterns resulting from various body movements. For instance, analyzing the knee contraction and relaxation motion during a football shot can help identify an athlete's susceptibility to ACL injuries. Furthermore, kinematic data can be used to compare the efficiency of motion and actions between two athletes.

In football kinematics, several parameters are typically measured, including foot velocity, knee extension, ball velocity, its trajectory, and acceleration. These measurements are based on the principle of momentum transfer from the knee to the foot and subsequently to the ball. When the knee is extended, a significant momentum is generated due to the high mass and velocity of the knee. This momentum is transferred to the foot, which has a lower mass but a comparatively higher velocity. Finally, this momentum is transferred to the ball, which has the least mass, resulting in a higher velocity. The velocity of the ball is directly proportional to the velocity and impact time (ranging from 9 to 12 milliseconds) of the foot. Throughout these processes, the net momentum generated by the knee remains constant.

**AIM: To obtain the Two Dimensional positional coordinates of a football during a kick using video-based motion tracking, and to analyze the trajectory, velocity profile, and acceleration characteristics to better understand the underlying kinematics of a football shot.**

## METHODOLOGY

**Kick Details:** An anonymous YouTube video was used as the subject of this report. The video features an inside-foot curled free kick (in swinger), struck with the medial surface of the foot to impart sidespin on the ball**.**

**Equipment Used:** Since the video is from anonymous source make or build of camera is not unknown. The diameter of the football is taken as 0.22 meters.

## Video Tracking and Analysis

**Software:** An online open source Tracking software was used to detect the motion of the ball. The link to the software has been provided:
**https://opensourcephysics.github.io/tracker-online/**

**Digitization (Tracking):** Tracked points include the centre of the ball.
A Two Dimensional Cartesian coordinate system was established to measure the position of the ball with the origin at the point of contact of the ball.

**Data Processing:** The coordinates of the ball were recorded as it traveled from its resting position to the goal. This was done by analyzing the video frame by frame. For each frame, a 'x' and 'y' coordinate was recorded against the corresponding time. Using these values the trajectory of the ball was plotted. The movement of the ball along both horizontal and vertical axis were observed. The scaling process involved clicking two points on the screen corresponding to this distance to define the pixel-to-meter ratio

**Calculated Values:** From the recorded data the velocities along x (Vx) and y (Vy) directions are calculated and resultant velocity was calculated using the formula

$Vx = (x_2 - x_1) / \Delta t$
$Vy = (y_2 - y_1) / \Delta t$

$V = \sqrt{(Vx^2 + Vy^2)}$

Similarly from the velocities acceleration is calculated along 'x' (Ax) and 'y' (Ay) directions and the resultant accelerations is obtained from the formula

$Ax = (Vx_2 - Vx_1) / \Delta t$
$Ay = (Vy_2 - Vy_1) / \Delta t$

$A = \sqrt{(Ax^2 + Ay^2)}$

The obtained velocities and acceleration was then smoothed to remove some of the noise and kinks in the data using a 3 point moving average.

Moving Average is measured as, Moving average= $(x_1 + x_2 + x_3 + \ldots + x_n) / n$

A 3 point moving average is measured as,
Smoothed value = (previous value + current value + next value) / 3

For velocity, Smoothed velocity at point i:

$V_i(\text{smoothed}) = (V_{i-1} + V_i + V_{i+1}) / 3$

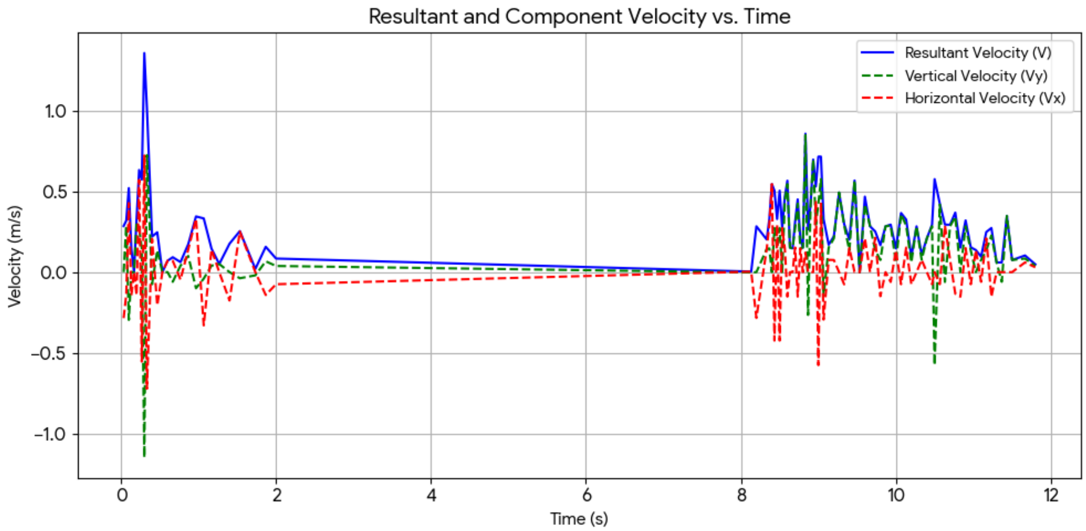
For Acceleration, Smoothed Acceleration at point i,
$A_i(\text{smoothed}) = (A_{i-1} + A_i + A_{i+1}) / 3$

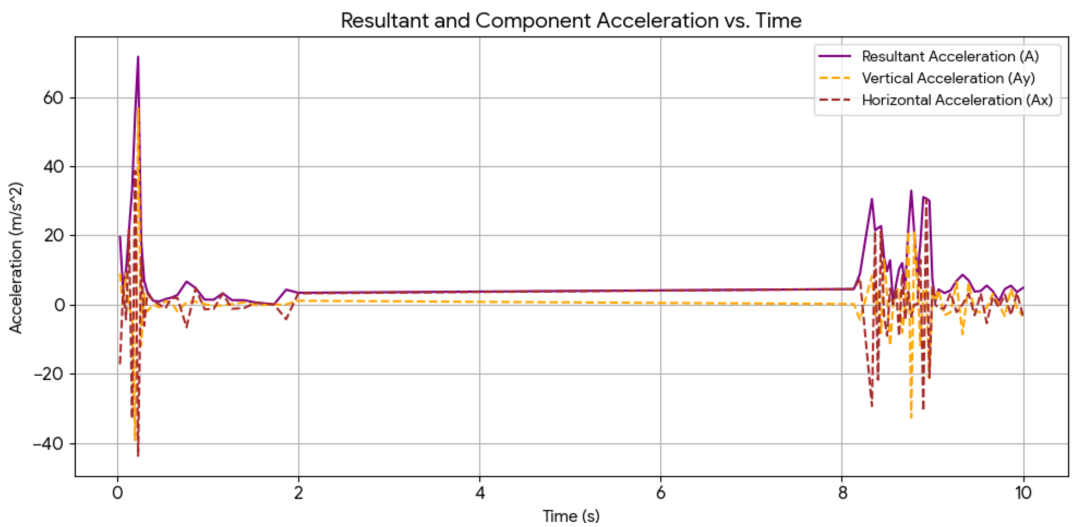
**RESULTS:**

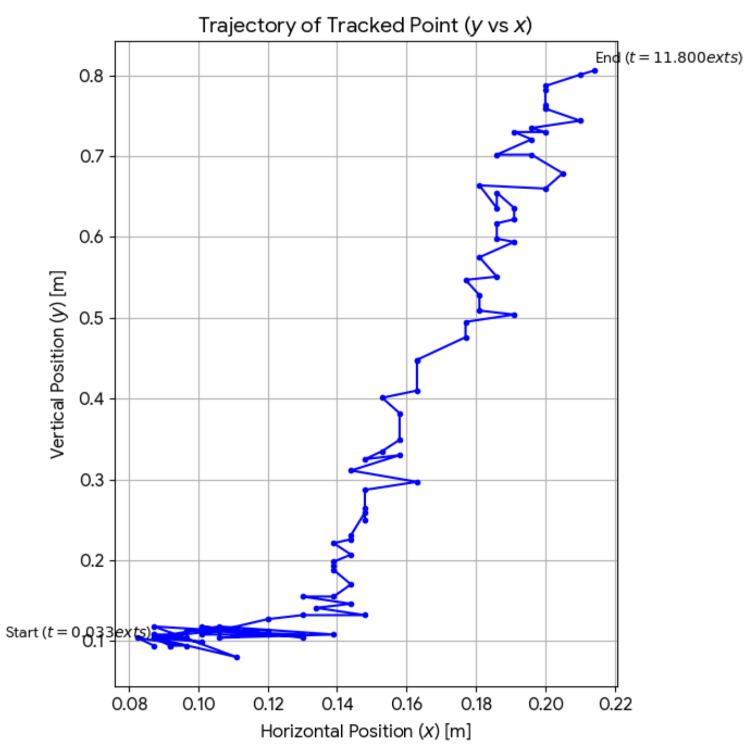
**TABLE:**

| t (s) | x (m) | y (m) | Vx (m/s) | Vy (m/s) | V (m/s) | Ax (m/s²) | Ay (m/s²) | A (m/s²) | Smoothed V (m/s) | Smoothed A (m/s²) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| 0.000 | 9.659E-02 | 9.424E-02 | | | | | | | | |
| 0.033 | 8.717E-02 | 9.424E-02 | -0.285 | 0.000 | 0.285454545454545 | | | | | |
| 0.067 | 8.246E-02 | 0.104 | -0.139 | 0.287 | 0.318736828888608 | 4.321 | 8.443 | 9.48454229012514 | 0.374862527364033 | |
| 0.100 | 9.659E-02 | 9.424E-02 | 0.428 | -0.296 | 0.520396207748947 | 17.173 | -17.661 | 24.6338955382552 | 0.327286769788276 | 17.8674536761794 |
| 0.133 | 9.188E-02 | 9.424E-02 | -0.143 | 0.000 | 0.142727272727273 | -17.300 | 8.962 | 19.4839232001578 | 0.22104116015874 | 16.1052265669933 |
| 0.167 | 9.188E-02 | 9.424E-02 | 0.000 | 0.000 | 0 | 4.198 | 0.000 | 4.19786096256685 | 0.157040931133461 | 11.2110545256871 |
| 0.200 | 8.717E-02 | 0.104 | -0.143 | 0.296 | 0.328395520673111 | -4.325 | 8.962 | 9.9513794143367 | 0.320276158325688 | 11.9255549599878 |
| 0.233 | 0.106 | 0.113 | 0.571 | 0.273 | 0.632432954303952 | 21.616 | -0.698 | 21.6274245030597 | 0.511281335482969 | 21.6187216266013 |
| 0.267 | 8.717E-02 | 0.118 | -0.554 | 0.147 | 0.573015531471843 | -33.071 | -3.696 | 33.2773609624075 | 0.854030036128202 | 36.6689659279523 |
| 0.300 | 0.111 | 8.01E-02 | 0.722 | -1.14848484848485 | 1.35664162260881 | 38.665 | -39.258899 | 55.1021123183898 | 0.984130596431818 | 53.3481124113413 |
| 0.333 | 8.717E-02 | 0.104 | -0.722 | 0.724242424242424 | 1.0227346352148 | -43.765 | 56.749311 | 71.6648639532267 | 0.866374964689964 | 48.352104680525 |
| 0.400 | 0.101 | 9.895E-02 | 0.206 | -0.075 | 0.219748636246282 | 13.859 | -11.934560 | 18.2893377699584 | 0.49638943689474 | 32.2901105357753 |
| 0.467 | 8.717E-02 | 0.108 | -0.206 | 0.135 | 0.246685039223137 | -6.162 | 3.141 | 6.91612988414083 | 0.15547789182314 | 9.6477065878469 |
| 0.533 | 8.717E-02 | 0.108 | 0.000 | 0.000 | 0 | 3.128 | -2.047 | 3.73765210944146 | 0.105661182228608 | 3.90100448274975 |
| 0.600 | 9.188E-02 | 0.108 | 0.070 | 0.000 | 0.0702985074626866 | 1.049 | 0.000 | 1.04923145466696 | 0.0541757633954059 | 1.89265020563471 |
| 0.667 | 9.659E-02 | 0.104 | 0.070 | -0.060 | 0.092228782723531 | 0.000 | -0.891 | 0.891067052795722 | 0.0747735248703278 | 1.16017305964855 |
| 0.767 | 9.188E-02 | 0.108 | -0.047 | 0.040 | 0.0617932844247658 | -1.174 | 0.997 | 1.54022067148297 | 0.109015486164136 | 1.46918977792219 |
| 0.867 | 0.106 | 0.118 | 0.141 | 0.100 | 0.173024391344111 | 1.883 | 0.600 | 1.97628160948788 | 0.193212156253403 | 2.08895796407544 |
| 0.967 | 0.139 | 0.108 | 0.330 | -0.100 | 0.344818792991333 | 1.888 | -2.000 | 2.75037161125547 | 0.283419529035779 | 3.78462327701857 |
| 1.067 | 0.106 | 0.104 | -0.330 | -0.040 | 0.332415402771893 | -6.600 | 0.600 | 6.62721661031236 | 0.274278797849612 | 4.71506239933064 |
| 1.167 | 0.120 | 0.108 | 0.140 | 0.040 | 0.14560219778561 | 4.700 | 0.800 | 4.76759897642409 | 0.176005866852501 | 4.26612749049942 |
| 1.267 | 0.120 | 0.113 | 0.000 | 0.050 | 0.05 | -1.400 | 0.100 | 1.40356688476182 | 0.123872411793198 | 2.51564912833045 |
| 1.400 | 9.659E-02 | 0.113 | -0.176 | 0.000 | 0.176015037593985 | -1.323 | -0.376 | 1.37578152380543 | 0.160005182276462 | 2.0013089626551 |
| 1.533 | 0.130 | 0.108 | 0.251 | -0.038 | 0.2540005092354 | 3.212 | -0.283 | 3.22457847939805 | 0.150005182276462 | 1.95315064362581 |
| 1.733 | 0.130 | 0.104 | 0.000 | -0.020 | 0.02 | -1.256 | 0.088 | 1.25909192767394 | 0.14363150318202 | 1.90858680926865 |
| 1.867 | 0.111 | 0.113 | -0.142 | 0.067 | 0.156894000310661 | -1.058 | 0.650 | 1.24209002073395 | 0.0869855687439019 | 1.01636455380525 |
| 2.000 | 0.101 | 0.118 | -0.075 | 0.038 | 0.0840627059210447 | 0.501 | -0.222 | 0.54791171300786 | 0.0814858628117091 | 0.601426354260145 |
| 8.133 | 0.120 | 0.108 | 0.003 | -0.002 | 0.00350088220342147 | 0.013 | -0.006 | 0.0142773290386262 | 0.123715225892235 | 1.61368849092287 |
| 8.200 | 0.101 | 0.108 | -0.284 | 0.000 | 0.283582089552239 | -4.279 | 0.024 | 4.27887643072213 | 0.163037826888701 | 2.55819831592838 |
| 8.333 | 0.120 | 0.127 | 0.143 | 0.143 | 0.202030508910442 | 3.206 | 1.074 | 3.38144118802437 | 0.271482041521864 | 4.03695733982678 |
| 8.367 | 0.130 | 0.132 | 0.294 | 0.147 | 0.328833526102911 | 4.449 | 0.124 | 4.45055440073385 | 0.358772860155966 | 5.55206362543842 |
| 8.400 | 0.148 | 0.132 | 0.545 | 0.000 | 0.545454545454545 | 7.616 | -4.456 | 8.82419528755703 | 0.45954367008575 | 14.599860020734 |
| 8.433 | 0.134 | 0.141 | -0.424 | 0.273 | 0.504342938699795 | -29.385 | 8.264 | 30.5248303739112 | 0.45954367008575 | 20.2660411705334 |
| 8.467 | 0.144 | 0.146 | 0.294 | 0.147 | 0.328833526102911 | 21.128 | -3.696 | 21.4490978501321 | 0.4458398011675 | 24.6909995787669 |
| 8.500 | 0.130 | 0.155 | -0.424 | 0.273 | 0.504342938699795 | -21.768 | 3.808 | 22.0990705122573 | 0.36863457917666 | 22.0759514591671 |
| 8.533 | 0.139 | 0.155 | 0.273 | 0.000 | 0.272727272727273 | 21.120 | -8.264 | 22.679686015112 | 0.41403701460159 | 19.4235626340083 |
| 8.567 | 0.144 | 0.170 | 0.147 | 0.441 | 0.465040832377703 | -3.696 | 12.976 | 13.4919313746555 | 0.434625143037713 | 15.2517504186737 |
| 8.600 | 0.139 | 0.188 | -0.152 | 0.545 | 0.566107324008163 | -9.048 | 3.160 | 9.58363386625355 | 0.394221102633673 | 11.9552123735948 |
| 8.633 | 0.139 | 0.193 | 0.000 | 0.152 | 0.151515151515152 | 4.591 | -11.938 | 12.7900718798752 | 0.288227099684242 | 7.50159140543252 |
| 8.667 | 0.139 | 0.198 | 0.000 | 0.147 | 0.147058823529412 | 0.000 | -0.131 | 0.131068470168824 | 0.203520922398562 | 6.29541722283804 |
| 8.700 | 0.144 | 0.207 | 0.152 | 0.273 | 0.311988792151122 | 4.591 | 3.808 | 5.96511131847009 | 0.303178182472486 | 5.45426375186004 |
| 8.733 | 0.139 | 0.221 | -0.152 | 0.424 | 0.450486931736924 | -9.183 | 4.591 | 10.2666114669412 | 0.323482768863324 | 9.40472087145433 |
| 8.767 | 0.144 | 0.226 | 0.147 | 0.147 | 0.207972582701926 | 8.782 | -8.152 | 11.9824398289517 | 0.269991555318001 | 8.90247495880303 |
| 8.800 | 0.144 | 0.231 | 0.000 | 0.152 | 0.151515151515152 | -4.456 | 0.135 | 4.45837358051618 | 0.405528954309348 | 12.6260425046734 |
| 8.833 | 0.148 | 0.259 | 0.121 | 0.848 | 0.857099128710966 | 3.673 | 21.120 | 21.4373141045523 | 0.42444005419302 | 19.6100380907664 |
| 8.867 | 0.148 | 0.250 | 0.000 | -0.265 | 0.264705882352941 | -3.565 | -32.741 | 32.9344265872306 | 0.51534914510211 | 25.0829873679212 |
| 8.900 | 0.148 | 0.264 | 0.000 | 0.424 | 0.424242424242424 | 0.000 | 20.877 | 20.8772214119808 | 0.461972667855021 | 20.6920369363763 |
| 8.933 | 0.148 | 0.287 | 0.000 | 0.697 | 0.696969696969697 | 0.000 | 8.264 | 8.26446280991736 | 0.550480083318942 | 15.5710831716649 |
| 8.967 | 0.163 | 0.297 | 0.441 | 0.294 | 0.530228128744704 | 12.976 | -11.849 | 17.5715652930965 | 0.647458340313001 | 18.9678224320078 |
| 9.000 | 0.144 | 0.311 | -0.576 | 0.424 | 0.715177195224603 | -30.816 | 3.943 | 31.0674391930094 | 0.65352750639797 | 26.429297343718 |
| 9.033 | 0.158 | 0.330 | 0.424 | 0.576 | 0.715177195224603 | 30.303 | 4.591 | 30.648887545048 | 0.586395972184039 | 30.5629964328617 |
| 9.067 | 0.148 | 0.325 | -0.294 | -0.147 | 0.328833526102911 | -21.128 | -21.259 | 29.9726625605276 | 0.404469936844015 | 22.6079222260903 |
| 9.133 | 0.153 | 0.335 | 0.076 | 0.152 | 0.16939908920453 | 5.604 | 4.524 | 7.20221657269536 | 0.240038079467249 | 12.6774532450236 |
| 9.200 | 0.158 | 0.349 | 0.075 | 0.209 | 0.221881623094306 | -0.017 | 0.857 | 0.857480601847839 | 0.294606008577224 | 4.14545654718296 |
| 9.267 | 0.158 | 0.382 | 0.000 | 0.493 | 0.492537313432836 | -1.114 | 4.233 | 4.37667246700569 | 0.337366325834242 | 2.84688928490237 |
| 9.333 | 0.153 | 0.401 | -0.076 | 0.288 | 0.297680040975583 | -1.148 | -3.101 | 3.30651478585358 | 0.330339237773322 | 3.91634166246738 |
| 9.400 | 0.163 | 0.410 | 0.149 | 0.134 | 0.200800358911548 | 3.358 | -2.292 | 4.06583773454288 | 0.35521485966387 | 4.73529470293426 |
| 9.467 | 0.163 | 0.448 | 0.000 | 0.567 | 0.567164179104478 | -2.228 | 6.460 | 6.83353158840632 | 0.255988179338675 | 6.49758865868245 |
| 9.533 | 0.163 | 0.448 | 0.000 | 0.000 | 0 | 0.000 | -8.593 | 8.59339665309815 | 0.344800754651727 | 7.46687700015673 |
| 9.600 | 0.177 | 0.476 | 0.209 | 0.418 | 0.467238084850702 | 3.119 | 6.237 | 6.97370275896571 | 0.250273391467647 | 6.42489242131491 |
| 9.667 | 0.177 | 0.495 | 0.000 | 0.284 | 0.283582089552239 | -3.119 | -2.005 | 3.70757785188087 | 0.334330547917613 | 4.86448137332212 |
| 9.733 | 0.191 | 0.504 | 0.212 | 0.136 | 0.252171469349897 | 3.164 | -2.231 | 3.91216350911978 | 0.234208101163891 | 4.36384675791096 |
| 9.800 | 0.181 | 0.509 | -0.149 | 0.075 | 0.166870744589537 | -5.394 | -0.921 | 5.47179891273222 | 0.234208101163891 | 4.40552891109964 |
| 9.867 | 0.181 | 0.528 | 0.000 | 0.284 | 0.283582089552239 | 2.228 | 3.119 | 3.83262431144693 | 0.2482140146076 | 3.40833389310833 |
| 9.933 | 0.177 | 0.547 | -0.061 | 0.288 | 0.294189209681024 | -0.918 | 0.065 | 0.920578455145845 | 0.241589725624004 | 3.07747135557614 |
| 10.000 | 0.186 | 0.551 | 0.134 | 0.060 | 0.146997877638748 | 2.909 | -3.406 | 4.47921130013563 | 0.269029035794464 | 3.61273984131031 |
| 10.067 | 0.181 | 0.575 | -0.075 | 0.358 | 0.36590002006362 | -3.119 | 4.455 | 5.43842976864946 | 0.279404908090607 | 4.50197115979094 |
| 10.133 | 0.191 | 0.594 | 0.152 | 0.288 | 0.325316826569453 | 3.426 | -1.066 | 3.58827241058774 | 0.262261955034073 | 4.6071867477959 |
| 10.200 | 0.186 | 0.598 | -0.075 | 0.060 | 0.095569018469147 | -3.375 | -3.406 | 4.79485806415051 | 0.234822644863613 | 3.96846075606608 |
| 10.267 | 0.186 | 0.617 | 0.000 | 0.284 | 0.283582089552239 | 1.114 | 3.342 | 3.52225179345999 | 0.162096166370086 | 3.88955078910542 |
| 10.333 | 0.191 | 0.622 | 0.076 | 0.076 | 0.107137391088871 | 1.148 | -3.149 | 3.35154250970576 | 0.199891568173902 | 3.05362565514625 |
| 10.400 | 0.191 | 0.636 | 0.000 | 0.209 | 0.208955223880597 | -1.131 | 1.988 | 2.28708266227299 | 0.203109890086283 | 2.40460802026272 |
| 10.467 | 0.186 | 0.655 | -0.075 | 0.284 | 0.293237055289381 | -1.114 | 1.114 | 1.57519888880942 | 0.359316618309185 | 10.0002954254466 |
| 10.500 | 0.186 | 0.636 | 0.000 | -0.576 | 0.575757575757576 | 2.261 | -26.041 | 26.1386047252574 | 0.431171968093542 | 14.1954788758302 |
| 10.567 | 0.181 | 0.664 | -0.075 | 0.418 | 0.424521273233668 | -1.114 | 14.831 | 14.8726330134239 | 0.431489352890756 | 16.7023498393822 |
| 10.633 | 0.200 | 0.660 | 0.288 | -0.061 | 0.294189209681024 | 5.493 | -7.250 | 9.09581177946528 | 0.337315846068024 | 10.0038962803744 |
| 10.700 | 0.205 | 0.679 | 0.075 | 0.284 | 0.293237055289381 | -3.183 | 5.137 | 6.04324404823411 | 0.318685262803353 | 6.12752961974483 |
| 10.767 | 0.196 | 0.702 | -0.134 | 0.343 | 0.368629523439655 | -3.119 | 0.891 | 3.24353303153509 | 0.271127243414729 | 4.83151937382713 |
| 10.833 | 0.186 | 0.702 | -0.152 | 0.000 | 0.151515151515152 | -0.260 | -5.201 | 5.20778104171219 | 0.280202008833612 | 4.87370775397069 |
| 10.900 | 0.196 | 0.721 | 0.149 | 0.284 | 0.320461351546029 | 4.489 | 4.233 | 6.16980918866478 | 0.208547541522816 | 5.13119172209714 |
| 10.967 | 0.191 | 0.730 | -0.075 | 0.134 | 0.153666121507268 | -3.342 | -2.228 | 4.01598493591445 | 0.203497036472311 | 4.65850798943328 |
| 11.033 | 0.200 | 0.730 | 0.136 | 0.000 | 0.136363636363636 | 3.197 | -2.035 | 3.7897298437206 | 0.128532925446684 | 3.64562274936113 |
| 11.100 | 0.196 | 0.735 | -0.060 | 0.075 | 0.095569018469147 | -2.926 | 1.114 | 3.13115346844833 | 0.1601134569696 | 3.67616648866949 |
| 11.167 | 0.210 | 0.744 | 0.209 | 0.134 | 0.248407716076018 | 4.010 | 0.891 | 4.10761615383955 | 0.205708186147984 | 4.29302448669303 |
| 11.233 | 0.200 | 0.759 | -0.152 | 0.227 | 0.273147823898787 | -5.462 | 1.408 | 5.6403038377912 | 0.193752344170706 | 4.37325497967 |
| 11.300 | 0.200 | 0.763 | 0.000 | 0.060 | 0.0597014925373134 | 2.261 | -2.501 | 3.37184494737925 | 0.130850269657805 | 3.59809429692063 |
| 11.367 | 0.200 | 0.759 | 0.000 | -0.060 | 0.0597014925373134 | 0.000 | -1.782 | 1.78213410559144 | 0.155962611186492 | 3.7795401945365 |
| 11.433 | 0.200 | 0.782 | 0.000 | 0.348 | 0.348484848484848 | 0.000 | 6.185 | 6.18464153063881 | 0.160937735564601 | 4.01806940517728 |
| 11.500 | 0.200 | 0.787 | 0.000 | 0.075 | 0.0746268656716418 | 0.000 | -4.087 | 4.08743257930159 | 0.175377857880677 | 3.54495023658291 |
| 11.667 | 0.210 | 0.801 | 0.060 | 0.084 | 0.10302185948554 | 0.359 | 0.055 | 0.362776599808341 | 0.0752641721386918 | 1.62127788306407 |
| 11.800 | 0.214 | 0.806 | 0.030 | 0.038 | 0.0481437912588936 | -0.224 | -0.348 | 0.413624470082279 | 0.10307976839759 | 0.618816433938947 |
| 11.933 | 0.205 | 0.825 | -0.068 | 0.143 | 0.158073654448336 | -0.735 | 0.791 | 1.08004823192622 | 0.103565019215843 | 0.691411493982661 |
| 12.067 | 0.205 | 0.839 | 0.000 | 0.104 | 0.104477611940299 | 0.505 | -0.286 | 0.580561779939484 | 0.115629538595408 | 0.593978964884368 |
| 12.233 | 0.205 | 0.853 | 0.000 | 0.084 | 0.0843373493975904 | 0.000 | -0.121 | 0.121326882787401 | 0.10086247214257 | 0.292715593548143 |
| 12.400 | 0.205 | 0.872 | 0.000 | 0.114 | 0.11377245508982 | 0.000 | 0.176 | 0.176258117917543 | 0.0871462561046397 | 0.100587287871922 |
| 0.000 | 9.659E-02 | 9.424E-02 | 0.009 | 0.063 | 0.0633289638265086 | -0.001 | 0.004 | 0.00417686291082108 | 0.154185321456958 | 3.09862161396977 |
| 0.033 | 8.717E-02 | 9.424E-02 | -0.285 | 0.000 | 0.285454545454545 | -8.915 | -1.901 | 9.11542986108096 | 0.222506779389887 | 6.20138300470564 |
| 0.067 | 8.246E-02 | 0.104 | -0.139 | 0.287 | 0.318736828888608 | 4.321 | 8.443 | 9.48454229012514 | 0.374862527364033 | 14.4112892298204 |
| 0.100 | 9.659E-02 | 9.424E-02 | 0.428 | -0.296 | 0.520396207748947 | 17.173 | -17.661 | 24.6338955382552 | | |
| 0.000 | 9.659E-02 | 9.424E-02 | | | | | | | | |

**GRAPHS:**


Resultant and Component Velocity vs. Time
Resultant Velocity (V)
Vertical Velocity (Vy)
Horizontal Velocity (Vx)
Velocity (m/s)
Time (s)


Resultant and Component Acceleration vs. Time
Resultant Acceleration (A)
Vertical Acceleration (Ay)
Horizontal Acceleration (Ax)
Acceleration (m/s^2)
Time (s)


Trajectory of Tracked Point (y vs x)
End (t = 11.800exts)
Start (t = 0.033exts)
Vertical Position (y) [m]
Horizontal Position (x) [m]

The kinematic plots confirm the analysis of the smoothed data, highlighting the approach, impact, and post-impact phases of the tracked object.

**Trajectory(y vs x):** The trajectory graph plots the vertical position(y) with the horizontal position(x) of the ball.

**Velocity(V vs t):** This graph illustrates the resultant velocity (V) over the recorded time period (approximately 0 to 14 seconds).

The initial spike around t=0.300 s confirms the occurrence of the **Maximum Resultant Velocity** (Vmax ≈1.36 m/s). This brief, high peak is characteristic of the primary impact or the maximum velocity of the accelerating leg just before contact.

**Acceleration(A vs t):** The graph plots the resultant acceleration against time. Acceleration is the rate of change in velocity.

The initial, massive spike around t=0.300 s confirms the **Maximum Resultant Acceleration** (Amax ≈71.66 $m/s^2$ **).** This spike is the most critical visual confirmation of the **Impulse**—the application of high force over a very short time—which defines the moment of foot-to-ball contact.

The correlation also shows that velocity peaks when acceleration spikes.

**The maximum observed resultant velocity of the tracked point was 1.36 m/s, coinciding exactly with a peak resultant acceleration of 71.66 $m/s^2$at t=0.300 s.**

## INFERENCE

The kick event is characterized by a sharp increase in velocity and acceleration in a very short time frame.The peaks as visualized in the graphs at t=0.300s for both velocity and acceleration simultaneously correlate the to the key event of kicking the ball at t=0.300s.

### Velocity profile:

**Before the impact**, the tracked object's velocity remained low, fluctuating between 0.0 m/s and 0.6 m/s in the moments leading up to the collision. **During the impact phase**, there was a sudden and sharp increase in the **Resultant Velocity (V)**, which peaked at 1.357 m/s at t=0.300 s. This sharp peak represents the moment of maximum acceleration and momentum transfer. At the point of maximum resultant velocity, the horizontal velocity (Vx ) was positive (0.722 m/s), indicating forward motion. However, the vertical velocity (Vy ) was strongly negative (−1.148 m/s), suggesting a predominantly **downward** vector at t=0.300 s. This implies that the kick resulted in an object with a negative vertical trajectory or that the tracking point moved downward sharply.

A secondary, extended period of velocity occurs between approximately t=8.000 s and t=10.500 s. This suggests a sustained period of movement, which could represent the final phase of the kick (the follow-through) or possibly a secondary motion captured by the tracking system. However, the overall velocity during this second period is lower than the initial peak.

### Acceleration profile:

**Peak Acceleration**: The plot demonstrates a substantial surge in the Resultant Acceleration (A), reaching a precise value of 71.66 $m/s^2$at the moment of maximum velocity (t=0.300 s). This significant acceleration over a short period is indicative of the Impulse exerted during the foot-to-ball contact phase.

**Component Acceleration**: At the peak of the resultant acceleration, the Vertical Acceleration (Ay) component (56.75 $m/s^2$at t=0.300 s) surpasses the Horizontal Acceleration (Ax) component (−43.77 $m/s^2$at t=0.300 s).

**This suggests that the force applied during the contact phase had a notable upward vertical component, despite the downward velocity vector at that instant.** This is a direct result of Newton's second law of motion which states force is proportional to acceleration. So,

F=mA

The purpose of a successful kick is not just to generate and maintain the motion but to radically change it. The impulse force generating a higher vertical acceleration component is to counter the downward velocity of the ball so as the ball rises. To launch the ball into the air (which requires a final positive Vy to create an arc), the foot must apply a force that not only brings the downward velocity to zero but also accelerates it up against gravity

The instantaneous upward net force (impulse) is needed to overcome the net downward momentum and reverse the direction of motion, thus achieving an upward launch.

The graph also shows smaller, continuous fluctuations in acceleration between t=8.000 s and t=10.500 s, corresponding to the secondary velocity movement. This shows the object was being constantly accelerated and decelerated during that time, consistent with a dynamic follow-through or a period of unstable flight/re-contact.

### Trajectory:

**Axis Scale:** Observe the narrow scale of the axes, signifying that the tracked motion occurred within a confined space (approximately 0.15 meters horizontally and 0.7 meters vertically). This aligns with tracking the *ball's* motion after the kick (e.g., if the calibration was exceptionally close to the camera).

**Initial Path:** The trajectory commences in the lower-left corner (at t=0.033 seconds) around (0.087, 0.094).

**Launch:** The path transitions into a steeper, generally upward-and-rightward trajectory between x≈0.14 meters and x≈0.20 meters, indicating the **directional change** imparted by the kick impulse.

**Post-Launch Flight:** The path ascends and shifts to the right, demonstrating the object gaining vertical distance (y-position) over horizontal distance (x-position) after the primary event. The minor fluctuations are the anticipated result of smoothing and minor tracking noise during the projectile motion.

**Magnus effect:** An important parameter that influences the swinging motion of the football is the Magnus effect. This effect occurs when the ball rotates, causing one side of the ball to move in the direction of the air and the other side to move in the opposite direction. Similar to Bernoulli's principle, this results in lower pressure on one side and higher pressure on the other, generating a sideways force that causes the ball to curve. The data accurately represents this phenomenon by the upward and rightward trajectory of the ball.

By utilizing the post-impact values of Vx and Vy, we can determine the launch angle of the ball. θ=arctan( $Vx/Vy$ **For the data point at t=0.333 s, the angle θ is calculated as arctan(0.722/0.724), which is approximately 45.1°**. This angle is a classic projectile angle for achieving maximum range.

| **Parameter** | **Value** | **Time (s)** |
|---|---|---|
| **Maximum Resultant Velocity (Vmax)** | 1.357 m/s | 0.300s |
| **Maximum Resultant Acceleration (Amax)** | 71.66 $m/s^2$ | 0.300s |
| Horizontal Velocity at Vmax (Vx) | 0.722 m/s | 0.300s |
| Vertical Velocity at Vmax (Vy) | -1.148 m/s | 0.300s |

## LIMITATIONS AND ERRORS

The observed peak velocity of 1.36 m/s is significantly lower than published football launch speeds, which typically range from 15 m/s to over 30 m/s.

The error might occur due to the difficulty in video tracking of a high velocity small sized object. Due to the first time use of the software and high acceleration spike, the error in velocity measurement can be due to systematic scaling implementation error during digitization. While the **correct physical dimension** for the football's diameter (0.22 m ) was entered into the software, the error likely occurred when selecting the corresponding points on the video frame. oThe error might also have occurred due to the shift of the tracker from the centre of mass of the ball to an off centre point.

The secondary movement between t=8–12 s is likely due to continued tracking during the follow-through or an unintended tracking segment; hence interpretation was limited.

The acceleration spike ( A =71.66 $m/s^2$ ) although obtained at time t=0.300s is the most reliable finding of the impact event, as acceleration is independent of the ball's launch speed. This spike confirms the high impulsive force applied, which is the physical evidence of the kick.

The primary limitation of the study is the inability to accurately measure the impulse velocity of the ball. The recorded value, Vmax=1.36m/s, is kinematically unreliable, possibly due to a shift in the tracking marker or incorrect calibration of the scaling factor. Consequently, the analysis focused primarily on the **acceleration and temporal parameters** to characterize the force generation.

## CONCLUSION

The kinematic analysis successfully characterized the nature of the football kick, primarily confirming the **rapid, impulsive force generation** during the contact phase. Despite the limitation of obtaining a reliable launch velocity, the high acceleration and analysis of component forces demonstrate that the kick achieved an **effective and powerful transfer of momentum** and correct trajectory control necessary for projectile motion

**The kinematic analysis successfully characterized the nature of the football kick, primarily confirming the rapid, impulsive force generation during the contact phase. Despite the limitation of obtaining a reliable launch velocity, the kinematic results strongly indicate that the kick demonstrated an effective and powerful transfer of momentum necessary to launch the football.**

## REFERENCES

1.Tracking software : https://opensourcephysics.github.io/tracker-online/
2.You Tube Video Source (Anonymous)