Golf Project LiDAR Tracking

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Introduction

The golf project, part of the Sports Technology and Simulation branch at the Engineering IDEAs Clinic at the University Waterloo, is a multidisciplinary project aimed at replicating or enhancing certain aspects of the full golfing experience. This includes modelling/manufacturing of golf clubs, object tracking and analysis of golf ball spin through high-speed cameras, sound analysis of a golf shot, and finally, tracking and simulation generation of a golf ball's trajectory.

This report provides an overview of the plan associated with the entirety of the golf project, the code for the trajectory generation and simulation, expected difficulties of the LiDAR sensor, as well as further extensions and applications relevant to the golf project and the patent outlined by Mechatronics Engineering Professor, Sanjeev Bedi.

Golf Project and Tracking System

The ultimate goal outlined in Professor Sanjeev Bedi's patent is to implement a relatively low-cost golf ball tracking system within a driving range or golf course through multiple LiDAR (Light Detection and Ranging) sensors, as opposed to the more conventional radar technology used for golf ball tracking. LiDAR sensors illuminate surrounding surfaces with lasers, usually with ultraviolet or near-infrared light, and can generate a "3D environment" through the distance measured from the reflections of those emitted lasers. Some common applications of LiDAR sensors include mapping land/terrain, identifying furniture, or detecting nearby objects for collision prevention. The golf project push LiDAR sensors to their limit by using them to identify and track golf balls, small and high-speed airborne objects. Future plans after a LiDAR tracking system is implemented would be to offer golfers of the golf course to use a smartphone application to view the statistics on their performance.

The golf project currently has in possession *Velodyne's VLP-16*, a LiDAR sensor capable of firing 16 vertical lasers. To theoretically verify the capabilities and limitations associated with the *VLP-16* during a pandemic and when an open space was not available, a MATLAB script/simulation was written. The latest iteration of the simulation can generate a golf ball's trajectory and find points of intersection between the golf ball and a highly accurate replication of the *VLP-16* in the microseconds.

Independent Variables of the LiDAR Sensor

Ignoring external factors which could affect the *VLP-16* in an outdoor setting, the *VLP-16* has independent variables that may influence the number of intersections found. For example, the RPM setting changes how fast the internal motor spins, ultimately increasing/decreasing the distance between two horizontally fired lasers. At the highest RPM setting of 1200, more of the golf ball's trajectory may be identified but detection at farther distances becomes much less probable due to the large angular resolution between two adjacent lasers. On the other hand, at the lowest RPM setting of 300, while the sensor is more capable of identifying small objects at larger distances, the general probability of it catching the high-speed golf ball is much lower.

Furthermore, instead of simply utilizing the LiDAR sensor upright, it can also be used on its side so that the lasers are fired either perpendicular or parallel to the flight of the golf ball. With the perpendicular configuration, we theorized that while a smaller section of the golf ball's lengthwise trajectory would be covered, the LiDAR sensor would be able to reliably identify the golf ball a few times. On the other hand, while the parallel configuration of the sensor can cover a much larger portion of the golf ball trajectory's horizontal length, there is a chance that the golf ball can pass through the large, 2° horizontal gaps between laser firings. Our initial proposal assumed the use of 4 LiDAR sensors, one placed near the tee box, two spaced evenly between the tee box and the green, and one placed near the green. In this initial proposal, the two middle LiDAR sensors were placed in the perpendicular orientation but according to our simulations, the perpendicular orientation proved to actually be less reliable.

Golf Ball Trajectory Generation

UW's Chemical Engineering student, Rama Al-Enzy, is a previous Engineering IDEAs Clinic coop student who wrote a Python script for the generation of a golf ball's trajectory under certain conditions, including lift, drag, and gravity. While we initially used the Python script to generate the positions of a golf ball, we have translated the Python code into MATLAB for efficiency and improved ease of use.

VLP-16 Simulation and Intersection Finder in MATLAB

Initial simulations in MATLAB were created with the intent to just replicate the general laser emission pattern of the *VLP-16*, without taking into consideration the nuances in the firing pattern and any calculations to find intersections with surfaces created in MATLAB. However, as the coop term progressed, newer simulations included features such as finding intersection points between the laser emission pattern and static triangles/spheres. The latest implementation prompts the user for the conditions of the golf ball trajectory generation (lift, gravity, drag, etc.) and then finds the intersection points between a moving golf ball and multiple, position-configurable, and highly accurate replications of the *VLP-16* within MATLAB. Data including points of intersection, the golf ball's position, azimuth, and vertical angle are then exported into an Excel file.

Simulation Testing

After doing numerous tests with the overall LiDAR configuration aligning with our initial proposal of utilizing 4 sensors, we made some discoveries that contradicted our initial assumptions. For instance, the perpendicular orientation of the sensor actually proved to be much less reliable in picking up points of intersection compared to the parallel orientation. This is especially true in the case of when the trajectory curves left or right but in situations where the golf ball moves in a perfectly straight line, there is still the chance that the middle sensors in the parallel orientation do not identify any points due to the large horizontal gap.

Furthermore, while we initially intended to use lower RPM values for the middle LiDAR sensors as at that point of the trajectory, the golf ball would be close to or at its apex position of its flight, LiDAR sensors of lower RPMs performed noticeably worse than their higher RPM counterparts.

The most recent testing of the MATLAB simulation has consisted of implementing various test cases that are similar to the real-life numbers generated by an average driver swing. However, it has become apparent that the number of unique intersection points (omitting repeated points with negligible position changes) is not consistent while using very similar parameters.

An example of this behaviour is shown below. Figure 1 and Figure 2 depict two test cases with all contact-related independent variables set the two exact same value, apart from the spin angle varying by 1 degree. Each individual LiDAR position and respective RPM values were also kept constant, and were chosen to reflect the general path that the ball would follow for the chosen contact values.

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 40
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 1

Precise Moving Golf Ball Intersection:
Point of Intersection = [    5.4740,    -0.1332,     1.3972]  |
Point of Intersection = [    5.4927,    -0.1299,     1.3938]  |
Point of Intersection = [    5.4999,    -0.1201,     1.3935]  |
Point of Intersection = [   17.9026,    -0.5330,     3.9255]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   22.2446,    -0.7438,     4.5913]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   62.9458,    -3.9643,     6.2229]  |

Precise Moving Golf Ball Intersection:
Point of Intersection = [  100.0064,    -9.1092,     0.6218]  |
Point of Intersection = [  102.0047,    -9.4420,     0.1224]  |
```

Figure 1

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 40
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 2

Precise Moving Golf Ball Intersection:
Point of Intersection = [    5.4721,    -0.2278,     1.3872]  |
Point of Intersection = [    5.4810,    -0.2190,     1.3863]  |
Point of Intersection = [    5.4834,    -0.2069,     1.3871]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   43.1303,    -2.8746,     6.4820]  |
Point of Intersection = [   50.7688,    -3.6634,     6.6336]  |
Point of Intersection = [   62.4481,    -5.0439,     6.2618]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   61.0975,    -4.8700,     6.3528]  |
Point of Intersection = [   62.9792,    -5.1142,     6.2371]  |
Point of Intersection = [   68.5758,    -5.8355,     5.8047]  |

Precise Moving Golf Ball Intersection:
```

Figure 2

As shown above, each individual LiDAR garnered a different number of intersection points between the two near-identical cases. This behaviour was exhibited throughout all our test case runs. A similar experiment was conducted below. Figure 3 keeps all conditions from the previous experiment, with the change of an increase of initial velocity. Figure 4 changes the spin angle by 1 degree. Figure 5 decreases the initial velocity by 0.1 m/s.

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 45
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 1

Precise Moving Golf Ball Intersection:
Point of Intersection = [    9.1078,    -0.2202,     2.2720]  |
Point of Intersection = [    9.1160,    -0.2338,     2.2723]  |
Point of Intersection = [   15.7605,    -0.4614,     3.7052]  |
Point of Intersection = [   17.9564,    -0.5351,     4.1326]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   88.6748,    -7.2761,     8.1745]  |
Point of Intersection = [  121.4192,   -13.0307,     3.9746]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf

Precise Moving Golf Ball Intersection:
Point of Intersection = [  138.9216,   -16.8605,     0.2981]  |
Point of Intersection = [  138.9350,   -16.8589,     0.2965]  |
Point of Intersection = [  138.9448,   -16.8535,     0.2960]  |
Point of Intersection = [  138.9516,   -16.8449,     0.2963]  |
```

Figure 3

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 45
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 2

Precise Moving Golf Ball Intersection:
Point of Intersection = [    9.1304,    -0.3768,     2.2685]  |
Point of Intersection = [    9.1359,    -0.3913,     2.2687]  |
Point of Intersection = [   17.9687,    -0.8461,     4.1333]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [   90.8280,    -9.2759,     8.0209]  |
Point of Intersection = [   97.2761,   -10.4037,     7.4432]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [  106.8882,   -12.2362,     6.3202]  |
Point of Intersection = [  115.6535,   -14.0489,     5.0151]  |

Precise Moving Golf Ball Intersection:
Point of Intersection = [  136.5276,   -18.8592,     0.9514]  |
Point of Intersection = [  140.4277,   -19.8317,     0.0322]  |
Point of Intersection = [  140.4142,   -19.8316,     0.0322]  |
Point of Intersection = [  140.4038,   -19.8450,     0.0324]  |
```

Figure 4

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 44.9
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 1

Precise Moving Golf Ball Intersection:
Point of Intersection = [    9.0874,    -0.2105,     2.2700]  |
Point of Intersection = [    9.0894,    -0.2263,     2.2696]  |
Point of Intersection = [    9.1033,    -0.2377,     2.2707]  |
Point of Intersection = [   15.7258,    -0.4610,     3.6985]  |
Point of Intersection = [   17.9138,    -0.5369,     4.1243]  |

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf

Rotated Precise Moving Golf Ball Intersection (Parallel to Golf
Point of Intersection = [  119.4776,   -12.6347,     4.1676]  |
Point of Intersection = [  121.5347,   -13.0712,     3.8064]  |

Precise Moving Golf Ball Intersection:
Point of Intersection = [  134.0206,   -15.7212,     1.2410]  |
Point of Intersection = [  138.5636,   -16.7671,     0.1626]  |
Point of Intersection = [  138.5751,   -16.7597,     0.1623]  |
```

Figure 5

As noted above, one major consistency was the difference between the ability of the perpendicular LiDAR versus the parallel LiDAR to detect the mid-flight points. Figure 6 below follows all parameters as Figure 5, with the only change being the orientation of the LiDAR from parallel (Figures 1 to 5) and perpendicular (Figure 6).

```
Lift, Drag, Both, or just Gravity: both
Inital velocity in m/s: 44.9
Angle of the velocity in degrees: 15
Rifle spin in rads/sec: 1
Side spin in rads/sec: 1
Back spin in rads/sec: 1
Spin angle in degrees: 1

Precise Moving Golf Ball Intersection:
Point of Intersection = [    9.0874,    -0.2105,     2.2700]
Point of Intersection = [    9.0894,    -0.2263,     2.2696]
Point of Intersection = [    9.1033,    -0.2377,     2.2707]
Point of Intersection = [   15.7258,    -0.4610,     3.6985]
Point of Intersection = [   17.9138,    -0.5369,     4.1243]

Rotated Precise Moving Golf Ball Intersection (Perpendicular

Rotated Precise Moving Golf Ball Intersection (Perpendicular

Precise Moving Golf Ball Intersection:
Point of Intersection = [  134.0206,   -15.7212,     1.2410]
Point of Intersection = [  138.5636,   -16.7671,     0.1626]
Point of Intersection = [  138.5751,   -16.7597,     0.1623]
```

Figure 6

Figures 7 and 8 below show the visualization of the experiment conducted in Figures 5 and 6, respectively.

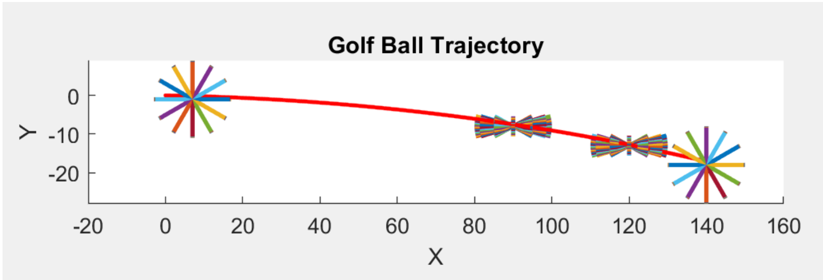

Figure 7

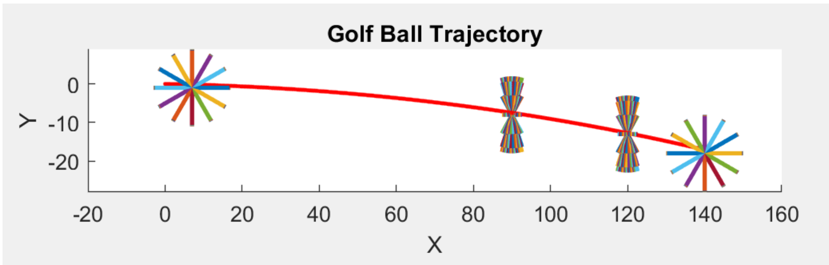

Figure 8

Difficulties

- Large variations in points of intersection after minute changes to arguments (Sensor position, speed, spin, etc.)
- Abundance of independent variables associated with the simulation and overall project
- Uncertainty with regards to the reliability of the simulation compared to real-world tests of the sensor especially considering the potential involvement of factors such as wind or the laser light not being properly reflected from the golf ball
- Generated trajectory of golf ball not as high as expected, raising concerns regarding the accuracy of the trajectory generation algorithm. Further calculations may be required to verify the trajectory.