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AN IOT POWERED MQTT PROTOCOL BASED CRICKET BALL (AI-BALL) WITH DATA ANALYTICS AND MODELING CONFIGURATION USING WIRELESS SENSOR NETWORKS

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ABSTRACT
Internet of things application integrated with wireless sensor topology has changed the overall prospective of smart robotics enhancement. We have designed, modeled and prototyped the working system of cricket ball powered by IoT and WSNs technology. We are calling this model with AI-Ball. This ball is integrated with sensors like accelerometer, gyroscope, altitude analyzer, charging mechanism, AI Wi-Fi cloud module and battery compacted inside the cricket tennis ball. The IoT device has live monitoring system, a server mechanism and controlled data analytics platform for easy analysis of data on mobile as well as on laptop using 2.4 GHz frequency band for communications. The non-linear dynamicity of the ball is reduced We have manufactured this prototype for carrying out high end sports analytics which will be helpful for coaching, strategy building; projections pattern analysis of ball, player dynamic and reaction analysis; also, it provides the greater alternative for camera based technologies which are highly costly.

Keywords: *AI-ball, Internet of Things, Wireless Sensor Network*

INTRODUCTION
Sports analytics is a growing business that analyses ball, racquet, and player motion patterns for instruction, strategic insights, and forecasts the data for these analyses comes from a pricey source. Stadiums with high-resolution cameras that are analysed at Clouds and strong backend servers usually look into it. Possibility of reducing this cost barrier by a considerable amount Incorporating low-cost Inertial Measurement Unit (IMU) sensors and ultrawide band (UWB) radios cricket balls and other objects like the footwear of the players Real-time analytics. It should be possible at any time and in any location Aspiring local players Clubs may use their own data to read out their own performance. School coaches may provide quantifiable feedback to their pupils through Smartphone displays.

Our research is part of a growing interest in Internet-of-Things-based sports analytics and the development of a full-fledged Internet-of-Things product that can be utilized for an integrated AI system and the prediction of various pattern analyses. A number of football helmets equipped with sensors that can detect concussions and other brain ailments are already available on the market.

Nike is working on a prototype for an IMU that will be sold on the market. -embedded In addition to ideas [34, 47], a number of startups are researching concepts such as camera-embedded jerseys [5, GPS-enabled soccer balls [6, and bluetooth frisbees [1] and GPS-enabled soccer balls. As for us, I have yet to come across a serious attempt to correctly characterize a 3D ball in terms of the trajectory, orientation, and number of revolutions per second it makes in a single second, for example.

In spite of substantial study into wireless localization and inertial gesture recognition, there has been no direct application of the findings. Although the play-ground does not include a WiFi-like localization infrastructure, it is not meant to allow for cm-scale 3D location at ball speeds, even if such infrastructure were present. When the ball is in free fall, inertial sensors such as accelerometers are unable to detect gravity since they only sense reactive forces, which are absent when the ball is falling. More concerning is the fact that gyroscopes reach saturation at approximately 6 revolutions per second (rps) [8, despite the fact that even a rookie player can spin the ball at 12rps. The monitoring of a quickly moving/spinning object in an open playground, in contrast to human-centric localization and gesture tracking applications, provides a relatively unexplored environment. Using a top-down approach, we are able to design multiple wireless and sensor components and engineer them together into a cohesive solution. Ultra wide band (UWB) radios are employed as the technological foundation of our system to compute the object's angle of arrival, as well as its flight duration (ToF). We're communicating with the ball. If this isn't enough, we'll move on to the next phase of the project. Simulate the ball's actual motion using an underdetermined system of equations and additional constraints. We will use a non-linear error reduction framework to extract ball trajectory parameters from all of these sources of information.In and of itself, spin estimation presents a set of unique challenges. Before the ball can be tracked in its 3D revolution, it must be established in what orientation it was in when it was released. For the rest of the flight, we are left with magnetometers instead of gyroscopes because of ineffective acceleration sensors. Though they are able to capture some dimensions of rotation, magnetometers are unable to capture all of them. We've already established that the ball's spin is erratic. As air drag is the only source of power, the vehicle is somewhat constrained. torque. The magnetometer generates a sinusoidal signal with a time-varying bias, as shown in the figure (dubbed "wobble"). We work together to find a solution to this problem of curve-fitting. Identify the ball's "wobble" and its angular velocity We discovered that magnetometers can be used as gyros in a variety of free-spinning systems after conducting extensive research.Using a professional design firm, we were able to put an Intel Curie board (IMU + UWB) inside the ball [3]. Two small UWB receiver boxes, known as anchors, must be placed on the ground, but additional anchors are not possible because of the Cricket field configuration, which will be discussed later. For our investigation, we have eight Vicon-based infrared cameras strategically positioned in each of the room's four corners. its most prominent apex Infrared markers are applied to the ball in order to achieve this. Precision tracking with resolutions of 0.1 and 0.2 microns (for the purposes of location and orientation). ViCon's 10x10x4m coverage area allows us to reduce tosses by three metres, or about half of the real-life Cricket trajectory. This allows us to keep the tosses as realistic as possible while reducing their length. The terms "spin" and "velocity" are critical in this discussion.

Researchers found that the median location accuracy is 8cm and the median orientation error is 11.2cm after testing 100 different throws. UWB clip-on wearers are tracked with a median 1.2m inaccuracy even when they are 80 metres away from the field's edge, where the mainstay of tracking is located. It is possible to provide real-time feedback to human participants thanks to the sub-second latency of all findings.Clearly, there is a lot of room for further study and advancement. For the most part, this has been the case.no mention of the question of energy. Perhaps wireless charging will be able to resolve the problem in the future, or perhaps rapid rotation will autonomously scavenge energy from the environment. Our technique for the time being provides a battery life of 75 minutes between charges, which is suitable for short training sessions to be conducted. For the second time, our aerodynamic motion models are rudimentary and have not been subjected to rigorous testing. It's possible that this resulted in positive effects in indoor contexts. Furthermore, we were unable to achieve throw speeds greater than 45 miles per hour or 12 rotations per second, both of which are extremely high for our application. Women account for almost half of all professionals. In conclusion, although this research study was primarily concerned with cricket, we believe that our methodologies might be extended to other sports with small modifications. However, this has not been proven to be the case. Our latest project is adapting iBall to other sports such as baseball and frisbee.

In conclusion, the following are the contributions made through this paper:

- Under the constraints of Cricket, recasting the problem of object tracking as an information fusion problem. In order to achieve the required accuracy, an optimization framework for combining time of flight (ToF) data, air-drag motion models, and noisy angle of arrival (AoA) estimations must bedeveloped.
- Understanding the various possibilities that arise from free-fall motion is essential. In free-fall situations, the magnetometer is used to measure rotation and rotation axis at the same time, simulating the operation of an inertialgyroscope.

Following on from these technological components, which have been stitched together through extensive engineering effort, the remainder of the article builds on them.

We begin with a brief history of cricket, and then move on to problems, possibilities, design, and implementation.

1.1 Background and the underlying platform

1.2 A Brief Introduction to Cricket

If you're new to cricket, here are some of the most important rules to remember. During a cricket match, the batting and bowling teams alternate, with one team designated as the bowling or fielding team for each session. The teams then switch roles for the second session. With two goals and two wickets on either side of the pitch, a playing field is set up right in the middle of the field. Wickets are made up of three separate parts. Wooden sticks are stacked vertically in Figure 1. (see illustration). There is an opposing player in front of the batting side of the plate. As the bowler walks up to the wicket and throws the ball at the batsman, the wicket is referred to as a stump. All of the bowling team's other players are known as fielders. distributed throughout the park.

It is one of the bowler's primary goals to hit the wicket or to force a fielder to catch the ball before it hits the ground before it hits the ground. In cricket, dismissal refers to a batsman being bowled out by a bowler. on the other hand, the batsman's objective on the other side is to avoid being out while slamming the ball as hard as he possibly can Term "border" refers to the fact that the park extends beyond the fielder's line of sight. A ball is said to have bounced when it hits the ground. At the very least, it must travel through the earth.once before it can proceed to the other side of the border. If the batting side scores four more points (called runs); if the bowling side scores four more points (called runs); if the bowling side scores four more points (called runs); if the bowling side scores four more points (6 runs) when the ball travels beyond the boundary without bouncing These points are added to the team's overall score. Whenever one of the following events occurs, the session is brought to a close. All 11 batsmen are out after N deliveries have been bowled or after N deliveries have been bowled. whatever comes first has to go. At the end of the day, the group with the player who has the highest overall score is declared the victorious group.

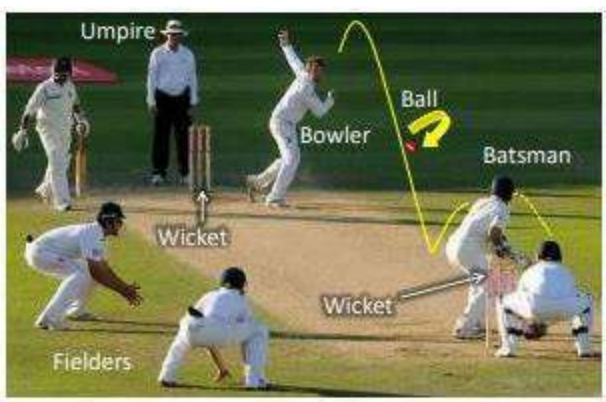


Figure 1: A cricketer in action is depicted. The bowler and the batsman each have their own set of wickets.

Baseball analogy: The similarities between cricket and baseball in terms of ball and player tracking are striking. The baseball spins and travels although the duration of the journey is similar in terms of speed and pace the word "pitch" is similarly similar. Differences may occur as a result of the feasibility of putting stitching patterns on the ball Baseball has a lot of anchors (in contrast to 2 in Cricket). In this way, the ball’s trajectory tracking problem may get easier in baseball, but the spinning issue remains.

The entire deployment in real-world situations is shown in Figure 3. The ball and anchors exchange UWB signals to calculate the ball's range and angle of arrival (AoA) based on phase variations at different antennas. For trajectory estimation, the range and AoA data are combined. In terms of spin analytics, the data is sent out by sensors within the ball for off-ball processing. On the pitch, players may wear the same uniform if they choose to. For 2D localization and tracking, an IMU/UWB device (as shown in the ball) is used tracking.

SYSTEM DESIGN: 3D SPIN TRACKING

Cricketers are interested in three primary spin-related metrics: (1) rotations per second, (2) rotation axis, and (3) seam plane1. All three measures may be calculated from a sensory standpoint if the ball's 3D orientation is monitored throughout time. This sparks a conversation on rotation, orientation, and coordinates frames.

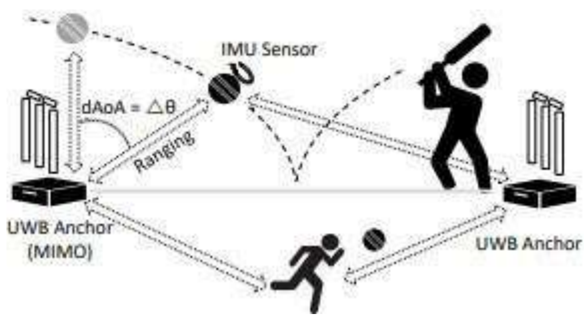


Figure 2: Two anchors and a ball deployed on the ground, while players optionally have the device in their Shoes.

FOUNDATIONS OF ORIENTATION

The orientation of an object is defined as the vector representation of the object's local X, Y, and Z axes in its global coordinate frame. It is possible to decompose a rotation of an object into a series of X, Y, and Z rotations, as shown in the diagram. To put it another way, if you want to change the orientation of an object, you can rotate it along each of the three axes (in the appropriate quantities) until you get the desired result. The gyroscope measures each of them individually. The angular velocity is a measure of how many times the object rotates in a given period of time. According to this logic, if one knows the orientation of an object in the global coordinate system, one can use a gyroscope to monitor the object's orientations. Over time, angular velocity was tracked.

Using gravity and magnetic North to express the object's initial orientation in the global framework should be possible because they are both globally recognised directions. An effect of this is that it is possible to align the local representations of gravity and North with the recognised global directions. Consider the following illustration:.

The item may now be rotated around the X axis until the measured gravity is in its own Z direction, and then around the Z axis until the measured magnetic field (compass) is in its own Y direction. The local and global frames are now perfectly aligned, and the entire rotation is represented by a single matrix R:

$$[X\,Y\,Z]R = [X_g Y_g Z_g]$$

The inverse of this rotation matrix, is used to determine an object's orientation, RO. If an item has to rotate 30 degrees clockwise to align with the global framework, then its orientation must be 30 degrees counter-clockwise. As a result, we can calculate both starting orientation and angular velocity; any spin-related analytics should ideally be trackable based onthem.

Challenges with In-Flight Balls: In the actual world, and especially in this cricket scenario, challenges arise:

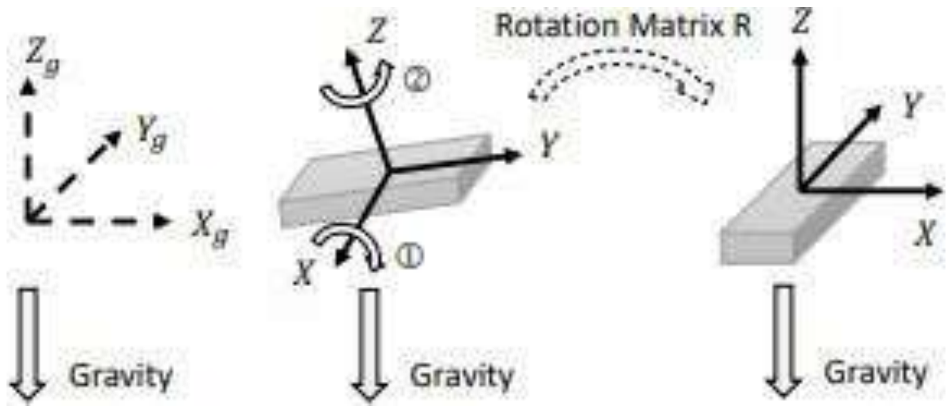


Figure 3: Rotating local axes to align local directions of gravity and magnetic North with the global directions.

(1) We have to live with this inaccuracy because rotation is time-integral of angular velocity. Gyroscopes can't handle more than 5 rotations per second (rps) while the ball can be spun at 12 rps by even novice players. (Attainment for professionals is greater than or equal to 30) Finally, the force of gravity is irrelevant. In free fall, the local coordinate frame can't be rotated or aligned using accelerometers, so this is a lost opportunity. 2 For the most part, the methods currently in use are unable to compute. The initial rotation or orientation of the ball is critical when it is in flight.MQTT

In order to communicate information from a distant place, Internet of Things (IoT) and machine-to- machine (M2M) technologies need the usage of a message and connection protocol.

A few desired characteristics of such a protocol are as follows:
Code with a tiny footprint (to make it easy to implement in small devices) Power usage is very low.

Low bandwidth usage is a plus. Latency is very low.

The use of a publish/subscribe pattern (sometimes known as a "pub/sub")

MQTT satisfies all of these criteria, and it has the support of the major public cloud providers, including Amazon Web Services, Microsoft Azure, and Google Cloud Platform, to propel it forward. Throughout this essay, we'll look at the reasons why MQTT is the most popular messaging protocol for Internet of Things (IoT) devices. In 1999, IBM published the initial version of MQTT (Message Queuing Telemetry Transport), which is a lightweight messaging protocol that was created by the company. The pub/sub pattern is used to communicate with devices, servers, and applications; messages are translated between them. With a focus on minimising battery loss and bandwidth usage, the MQTT protocol was originally developed for the purpose of connecting sensors on oil pipelines with communications satellites, among other things.

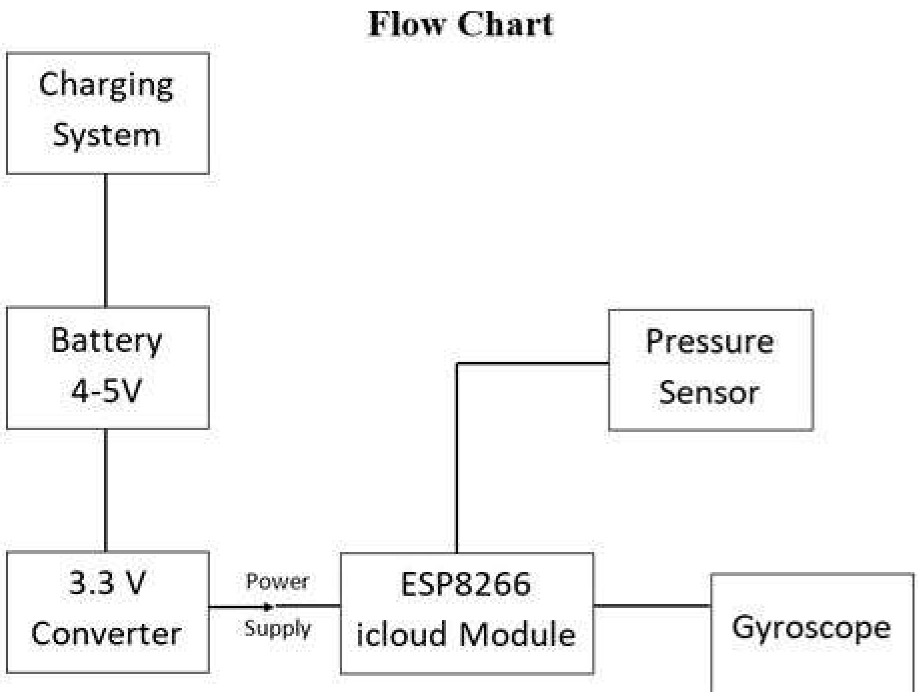
In the years since its creation, MQTT has seen continuous development, with version 5.0 being released in May 2018. Version 3.1.1 of the specification was submitted to the OASIS consortium in 2013 and was later approved as an international standard by the ISO.

MQTT is a messaging protocol.

In the MQTT protocol, the connected devices are referred to as "clients," and they interact with a server referred to as the "broker" in order to exchange information. The broker is in charge of the transfer of data between customers between each other.

The broker then distributes this information to any customers who have subscribed to that subject (known as "subscribers"). When a client (known as the "publisher") wishes to disseminate information, the client will publish to a specific topic. The publisher does not need any information about the number of subscribers or their geographic region. As a result, subscribers do not need any information about the publisher. Any customer may be a publisher, a subscriber, or a combination of the two. Customers are usually unaware of one another, and only the broker who acts as a middleman is aware of the other clients. This configuration is referred to as the "pub/sub model" in the industry.

FLOWCHART



BATTERY CHARGING SYSTEM: **THE CHARGING SYSTEM IS CRITICAL TO THE OPERATION OF THE ELECTRICAL SYSTEM. IT IS RESPONSIBLE FOR SUPPLYING POWER TO THE LIGHTS, RADIO, HEATING, ELECTRICAL SYSTEMS OF THE ENGINES, AND VARIOUS OTHER ELECTRICAL ACCESSORIES. IT ALSO MAINTAINS THE CHARGE OF THE BATTERIES AND RECHARGES THEM AS NECESSARY.**

For proper maintenance of the charging system, you must first gain an understanding of how it operates. Chargers have three major components: an alternator, a voltage regulator, and batteries. The alternator is the most important of these.

Power generated by the alternator can be used to run the vehicle's accessories, as well as recharge the battery. The crankshaft drives a belt, which provides the majority of the machine's power. In order for the batteries and other accessories to get power, mechanical energy is converted to electrical energy by the alternator while turning the crankshaft.

For the alternator to function properly, the voltage regulator serves as an electrical traffic cop. Whenever the vehicle's electrical needs change or the batteries need to be recharged, it adjusts the alternator power accordingly.

The system's chemical electricity comes from the batteries. To start the engine, they're primarily responsible for triggering the ignition. The alternator can also supply power to the car's accessories when the electrical demand exceeds the alternator's capacity.

Battery 4-5Volts: Avoid putting the battery in the reach of children. Maintenance-free lead acid sealed battery with a voltage of 4.0 DC. Instructions on How to Use This Product: Typically found in electronic devices such as video games, UPS systems, and other similar devices. When the temperature is 25°C, the self discharge rate is less than 5 percent per month. Please charge your battery prior to using it for the first time to ensure proper performance. The battery in this picture is a solder terminal type battery, which means it is suitable for soldering directly to it. We recommend that you charge your battery for four hours before using it for the first time to ensure that it has a long and trouble-free life. This procedure processes the battery and extends its life span while also restoring its full capacity. Always completely drain the battery before recharging it in order to get the longest possible life out of the device's batteries. Product that is friendly to the environment.

3.3 V Converter: A DC/DC converter that produces 12V at 3.3V and up to 3A of output current (10W) the ability to be waterproof and dustproof Take a Deep Breath Car Module de alimentation en énergie Supply voltage: 12 volts DC (the input voltage must be 3 volts higher than the output voltage) (Input Voltage must Higher 3V than Output Voltage) Voltage at the output: 3.3V There is a total current output of 3A and a total power output of 10W from this device. Short circuit and high temperature protection are also available in the event of an electrical emergency. The efficiency is 90 percent.

Supply of electrical power:

Power supplies are electrical devices that provide electricity to a load. There are many critical functions of a power supply that revolve around its ability to convert the output of an external source into a form that can be used to power a load. Electric power converters have since been referred to as power supplies because of this. Freestanding power supplies and load-side power supplies (PSA and LSA, respectively) are two types of power supplies. The following should be taken into account: Power supplies used in desktop computers and other consumer electronics fall into this category. Power conditioning is required to keep the load safe from electronic noise and voltage surges at the input adjustment to ensure that when the source power is interrupted, the input power does not fluctuate or drop off (uninterruptible power supply).

Among other features, power supplies have one or more power input and one or more power output connectors. In addition to a battery, fuel cell, a generator, or another power source, a user can draw power from an electrical outlet. While wireless energy transmission is used in some power supplies, the input and output connections are almost always made by hardwiring. For example, external monitoring and control of the power supply are frequently found in power supplies, as are other types of inputs and outputs of this type.

ESP8266icloud Module: It is a Wi-Fi microchip that is low cost, with a complete TCP/IP stack and microcontroller capabilities, manufactured by Espress if Systems in Shanghai, China.

This module manufactured by Ai-Thinker originally attracted notice in August 2014 as the ESP- 01 chip, which was developed by a third-party company. This little gadget enables microcontrollers to connect to a Wi-Fi network and use Hayes-style instructions to establish basic TCP/IP connections. On the other hand, before there was any English-language documentation, only basic information was known about the chip and the various instructions it received. Many people found the module's pricing and the fact that there were no external components intriguing, leading them to research the chip, software, and documentation written in Chinese on the module, as well as to translate the information.[3]

This chip offers 1 megabyte of flash memory and has an ESP8266 chip. This single-chip gadget is capable of connecting to Wi-Fi.[4]

The ESP32 series of microcontroller chips, which include the pin-compatible ESP32-C3, have superseded the original microcontroller chips (including the ESP8266).

Pressure Sensor: Pressure sensors use pressure as an analogue signal, which they transform into an electrical signal.

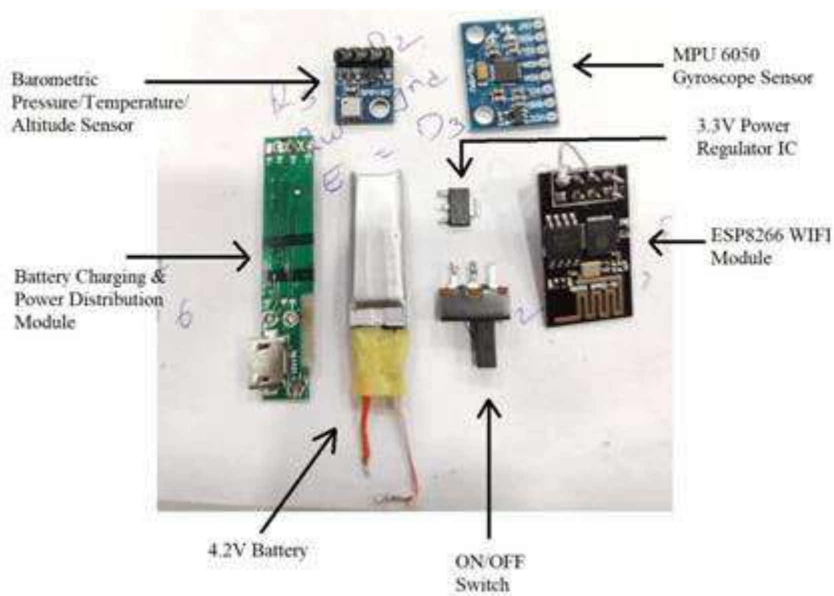
During the steam era, pressure measurement devices became more popular. At the time, mechanical pressure detecting gauges that moved a needle and gave a visual indication of pressure were invented. Pressure transducers and pressure switches are used to measure pressure electrically nowadays.

Gyroscope: A gyroscope (from the Greek gûros, "circle" and skopéō, with the idea of "looking to watch," the former a measuring instrument and the latter an orientation maintainer) is a tool used for the measurement or control of orientation and angular velocity. [1][2] In which the axis of rotation (spin axis) may adopt any direction by itself, it is a spinning wheel or disc. Angular momentum is conserved when the orientation of this axis is unaltered by tilting or rotation of the mounting.

MEMS gyroscopes used in electronic devices are often referred to as gyrometers, whereas fibre optic gyroscopes are termed gyroscopes. Additionally, solid-state ring lasers, quantum gyroscopes, and the highly sensitive microchip-packaged gyroscopes found in electronic devices are also discovered.[3]

Inertial navigation systems, such as those used in the Hubble Telescope, are just a fe applications of gyroscopes. Because of their accuracy, gyroscopes are also employed in gyrotheodolites, which are used in underground mining to maintain a desired direction. [4] Gyroscopes may be used to build gyrocompasses, which work with or instead of magnetic compasses to aidin the stability of vehicles (such bicycles, motorcycles, and ships). Gyrocompasses are employed in systems where they contribute to the overall inertial reference system, such as automobiles.

Some consumer devices, such as cellphones, use MEMS gyroscopes.



COMPONENTS USED ARE LISTED BELOW

1. BMP 110 Barometric pressure/Temperature/AltitudeSensor
2. Battery Charging and Power DistributionModule
3. 4.2V LipoBattery
4. ON/OFFSwitch
5. 3.3V Power RegulatorIC
6. MPU6050 GyroscopeSensor
7. ESP8266 Wi-FiModule

FUNCTIONAL ALGORITHM

1. As Switch gets on power from battery is delivered to completecircuit.

2. First Gyroscope sensor and pressure sensor read its initial values and sent to microcontroller in Wi-FiModule.
3. Then microcontroller calculates the Physical orientation of device using the values of gyroscope sensor also pressure is calculated using the values of pressuresensor.
4. Wi-Fi Module connects to the router using given SSID and password in program, once connection is established Wi-Fi module calculates Received Signal Strength, depending on the signal strength microcontroller calculates the distance of device fromrouter.
5. As all values are calculated, these values are sent to web server over the connected Wi-Fi network and user can see the graphs of calculated values using the IP given to device byRouter.

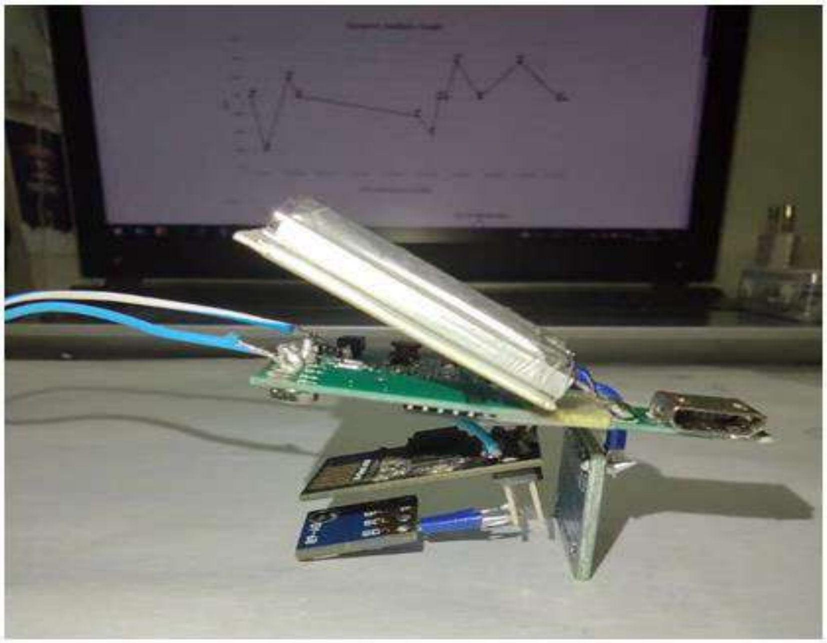


Fig 4: Side View of Physical Circuit

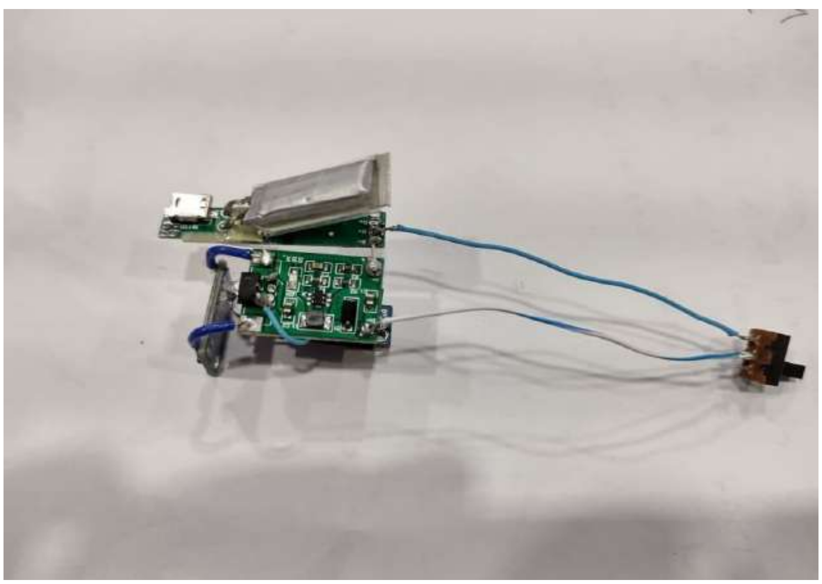


Fig 5: Top View of Physical Circuit

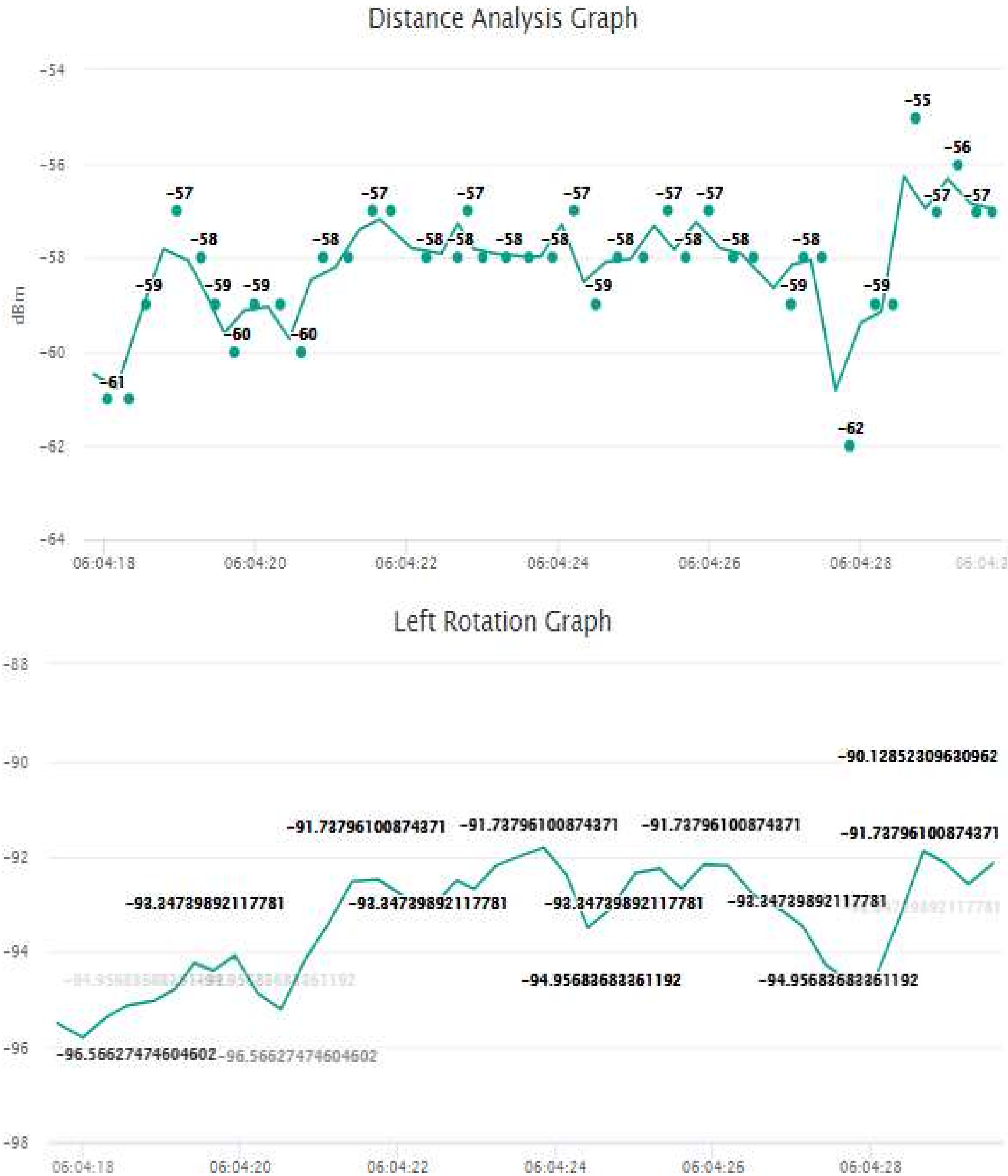


Figure: 6 Distance of Device from Router

Above Figure 6.is showing the distance of device from router using Received Signal Strength by ESP8266 Wi-Fi module also the Left Rotation Graph shows the Rotation of device in leftward direction using the values of MPU6050 gyroscope sensor

Figure:7 is showing the Right Rotation Graph shows the Rotation of device in rightward direction also the Z-axis graph using the values of MPU6050 gyroscope sensor and Pressure analysis graph is generated from the values of BMP 110 Barometric pressure sensor.

CONCLUSION

The prototype has been tested with different dynamics of throwing the ball and characteristics reading has been carried out successfully. Non-linear error reduction is used to include wireless, inertial sensing, and other types of imperfect information into a nonlinear error reduction framework. Comparing the average ball placement inaccuracy to a mm-level ground truth, the average ball placement inaccuracy is 3.5cm, while the average rotational error is 1cm. It is possible to achieve an error rate of less than 5% even at the conclusion of the trip. As a result, the results are not influenced by any calibration or training procedures used. The experimented data was successfully able to communicate with the ground station with no data or packet loss. The system is working on MQTT protocols so data reduction is minimum and protocols are optimized for all the sensor dataset.

REFERENCES

[1] BAHL, P., AND PADMANABHAN, V. N. Radar: An in-building-based user location and tracking system. In INFOCOM 2000.Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE (2000), vol. 2, Ieee, pp.775–784.

[2] BAKER, C. A calculation of cricket ball trajectories. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 224, 9 (2010), 1947–1958.

[3] CHINTALAPUDI, K., PADMANABHA IYER, A., AND PADMANABHAN, V. N. Indoor localization without the pain. In Proceedings of the sixteenth annual international conference on Mobile computing and networking (2010), ACM, pp.173–184.

[4] FUSS, F., FERDINANDS, R., DOLJIN, B., AND BEACH, A. Development of a smart cricket ball and advanced performance analysis of spin bowling. In ICSST 2014: Advanced Technologies in Modern Day Sports (2014), Institute for Sports Research (ISR),pp.588–595.

[5] FUSS, F. K., LYTHGO, N., SMITH, R. M., BENSON, A. C.,AND GORDON, B. Identification of key performance parameters during off-spin bowling with a smart cricket ball. Sports Technology 4, 3-4 (2011), 159–163.

[6] FUSS, F. K., AND SMITH, R. M. Accuracy performance parameters of seam bowling, measured with a smart cricket ball.Procedia Engineering 72 (2014),435–440.

[7] FUSS,F.K.,SMITH,R.M.,AND SUBIC,A.Determination of spin rate an daxe swithan instrumented Cricket ball. Procedia Engineering 34 (2012), 128–133.

[8] GUPTA, S., MORRIS, D., PATEL, S., AND TAN, D. Sound wave: using the Doppler effect to sense gestures. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (2012), ACM, pp.1911–1914.

[9] HACH, R. Symmetric double sided two-way ranging. IEEE P80215 (2005),802–15.

[10] HAHNEL, D., BURGARD, W., FOX, D., AND THRUN, S. An efficient fast slam algorithm for generating maps of large-scale cyclic environments from raw laser range measurements. In Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003IEEE/RSJ International Conference on (2003), vol. 1, IEEE, pp.206–211.

[11] HALVORSEN, P., SÆGROV, S., MORTENSEN, A., KRISTENSEN, D. K., EICHHORN, A., STENHAUG, M., DAHL, S., STENSLAND, H. K., GADDAM, V. R., GRIWODZ, C., ET AL.Bagadus: an integrated system for arena sports analytics: a soccer case study. In Proceedings of the 4th ACM Multimedia Systems Conference (2013), ACM, pp.48–59.

[12] KING, K., PERKINS, N. C., CHURCHILL, H., MCGINNIS, R.,DOSS, R., AND HICKLAND, R. Bowling ball dynamics revealed by miniature wireless mems inertial measurement unit. Sports Engineering 13, 2 (2011),95–104.

[13] KUMAR, S., GIL, S., KATABI, D., AND RUS, D. Accurate indoor localization with zero start-up cost. In Proceedings of the20th annual international conference on Mobile computing and networking (2014), ACM, pp.483–494.

[14] LANGLEY,R.B.Dilution of precision.GP S world 10,5(1999),52–59.

[15] LEFFERTS, E. J., MARKLEY, F. L., AND SHUSTER, M. D.Kalman filtering for spacecraft attitude estimation. Journal of Guidance, Control, and Dynamics 5, 5 (1982),417–429.

[16] LIANG, W. Y., MIAO, W. T., HONG, L. J., LEI, X. C., ANDCHEN, Z. Attitude estimation for small helicopter using extended kalman filter. In Robotics, Automation and Mechatronics, 2008IEEE Conference on (2008), IEEE, pp.577–581.

[17] MADGWICK, S. An efficient orientation filter for inertial and inertial/magnetic sensor arrays. Report x-io and University of Bristol (UK)(2010).

[18] MAHONY, R., HAMEL, T., AND PFLIMLIN, J.-M. Nonlinear complementary filters on the special orthogonal group. IEEETransactions on Automatic Control 53, 5 (2008),1203–1218.

[19] MCELROY, C., NEIRYNCK, D., AND MCLAUGHLIN, M. Comparison of wireless clock synchronization algorithms for indoor location systems. In 2014 IEEE International Conference on Communications Workshops (ICC) (2014), IEEE, pp.157–162.

[20] MCGINNIS, R. S., AND PERKINS, N. C. A highly miniaturized, wireless inertial measurement unit for characterizing the dynamics of pitched baseballs and softballs. Sensors 12, 9(2012), 11933–11945.

[21] NICULESCU, D., AND NATH, B. Ad hoc positioning system (aps) using aoa. In INFOCOM 2003. Twenty- Second Annual Joint Conferences of the IEEE Computer and Communications. IEEE Societies (2003), vol. 3, Ieee, pp.1734–1743.

[22] NIKE. Footwear having sensor system. Patent US 8676541B2.

[23] PFLIMLIN,J.M.,HAMEL,T.,ANDSOUERES`,P.Nonlinearattitudeandgyroscope'sbiasestimation for a vtoluav. International Journal of Systems Science 38, 3 (2007),197–210.

[24] RAI, A., CHINTALAPUDI, K. K., PADMANABHAN, V. N., ANDSEN, R. Zee: zero-effort crowd sourcing for indoor localization. In Proceedings of the 18th annual international conference on Mobile computing and networking (2012), ACM, pp.293–304.

[25] SEO, Y., CHOI, S., KIM, H., AND HONG, K.-S. Where are the ball and players? soccer game analysis with color-based tracking and image mosaic. In International Conference on Image Analysis and Processing (1997), Springer, pp.196–203.

[26] SIOURIS, G. M., CHEN, G., AND WANG, J. Tracking an incoming ballistic missile using an extended interval kalman filter .IEEE Transactions on Aerospace and Electronic Systems33,1(1997),232–240.

[27] SWANSON, E. Geometric dilution of precision. Navigation 25, 4(1978),425–429.

[28] TSAI, N.-C., AND SUE, C.-Y. Stability and resonance of micro machined gyroscope under nonlinearity effects. Nonlinear Dynamics 56, 4 (2009),369–379.

[29] VASISHT, D., KUMAR, S., AND KATABI, D. Decimeter-level localization with a single wifi access point. In 13th USENIX Symposium on Networked Systems Design and Implementation (NSDI16) (2016), pp. 165–178.

[30] WANG, H., SEN, S., ELGOHARY, A., FARID, M., YOUSSEF,M., AND CHOUDHURY, R. R. No need to war- drive: unsupervised indoor localization. In Proceedings of the 10th international conference on Mobile systems, applications, and services (2012), ACM, pp.197–210.

[31] XIONG, J., AND JAMIESON, K. Array track: a fine-grained indoor location system. In Presented as part of the 10th USENIX Symposium on Networked Systems Design and Implementation (NSDI 13) (2013), pp. 71–84.

[32] YANG, L., CHEN, Y., LI, X.-Y., XIAO, C., LI, M., AND LIU,Y. Tagoram: Real-time tracking of mobile rfid tags to high precision using cots devices. In Proceedings of the 20th annual international conference on Mobile computing and networking (2014), ACM, pp.237–248.

[33] YOUSSEF, M., AND AGRAWALA, A. The horuswlan location determination system. In Proceedings of the 3rd international conference on Mobile systems, applications, and services (2005),ACM, pp. 205– 218.

[34] YU, X., XU, C., LEONG, H. W., TIAN, Q., TANG, Q., ANDWAN, K. W. Trajectory-based ball detection and tracking with applications to semantic analysis of broadcast soccer video. In Proceedings of the eleventh ACM international conference on Multimedia (2003), ACM, pp.11–20.

[35] ZHOU, B., KOERGER, H., WIRTH, M., ZWICK, C., MARTINDALE, C., CRUZ, H., ESKOFIER, B., AND LUKOWICZ, P. Smart soccer shoe: monitoring foot-ball interaction with shoe integrated textile pressure sensor matrix. In Proceedings of the 2016 ACM International Symposium on Wearable Computers (2016), ACM,pp.64–71.

[36] ZHOU, P., LI, M., AND SHEN, G. Use it free: instantly knowing your phone attitude. In Proceedings of the 20th annual international conference on Mobile computing and networking(2014),ACM,pp.605–616