IoT Sports Analytics for Baseball

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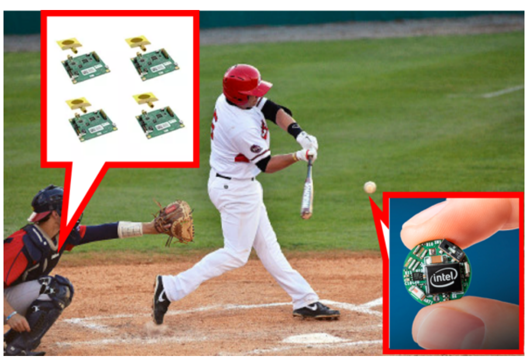
1. Research Problem Statement

Sports analytics is a thriving industry in which motion patterns of balls, bats, and players are being analyzed for coaching, strategic insights, and predictions. The data for such analytics are usually sourced from expensive, high-quality cameras installed in stadiums, and processed at powerful backend cloud platforms. Those high-end equipment are only feasible for live game broadcasts, and such a high cost barrier prevents the pervasive applications of truly real-time sports analytics anytime and anywhere. To this end, there is a need for a low-cost real-time sports analytics solution.

This project follows a growing excitement in Internet of Things (IoT) based sports analytics. Sensor-enabled football helmets, aimed at detecting concussions and head injuries, are already in the market. Nike is prototyping Inertial Measurement Unit (IMU) embedded shoes [1], while multiple startups are pursuing ideas around camera-embedded jerseys [2], GPS-enabled soccer balls [3], and Bluetooth frisbees [4]. Researchers have investigated approaches to bringing IoT to Cricket field [5]. MLB has already promoted IoT-based analytics by contracting with a startup company Blast Motion who serves as MLB's official bat sensor technology provider [6]. However, we have not found research effort to characterize 3D ball motion for Baseball.



In this undergraduate research project, our primary objective is to develop Baseball analytics solutions to track: 1) a ball's 3D trajectory, 2) player's movement, and 3) the motion of the bat, with low-cost sensors and radios embedded in the ball and bat. Our education plan aims to increase our community's understanding of the Internet of Things technology and the close relationship between Ubiquitous Computing and our daily life (***Yes! Embedding intelligence is into everyday objects***). Students participating in this project will gain hands-on experience in computer programming, wireless sensing, data analytics, physics, and statistics modeling, etc.

2. Research Projects

We propose to design and implement a Baseball tracking prototype system by using embedded sensing and IoT technology. By leveraging low-cost embedded microcontroller modules with Inertial Measurement Unit (IMU) sensors and Ultra Wide-band (UWB) radio, the prototype can be used to obtain sensing data of ball flight and players' motion. We envision ***a R&D project that involves entry-level computer programming, entry-level embedded hardware engineering, and sensing data analytics processing and modeling***. The project consist of the following 4 major phases: 3D trajectory tracking, player tracking, and bats tracking, and analytics modeling & processing. We briefly describe the details of each phase in the following.

- **Phase#1: Bats tracking.** Sensors e.g. accelerometers will be embedded in bats in order to track bat's motion. The bat's location data will be combined with ball-bat contact time, which serves as a bouncing point to help facilitate ball's 3D trajectory tracking.
- **Phase#2: Ball 3D-trajectory tracking.** A number of UWB antenna MIMO radio anchors will be built and deployed on the ground. The IMU sensors embedded in the ball send POLL signals to the anchors, which send back RESPONSE signals. The ball responses with a FINAL packet. Using the two round trip times, students can estimate the ball's flight time, and ball's range (by multiplying the speed of light). Students will use bats sensor (described in Phase#1) to determine the time the ball reaches the batsman. With a number of UWB antenna MIMO radio anchors deployed on the ground or on catcher's chest gear, students can develop techniques to estimate the ball's approximate trajectory range.
- **Phase#3: Player tracking.** Player tracking can be done using e.g. clip-on UWB devices. To further increase the tracking accuracy, students can explore wearable techniques such as using a wearable accelerometer sensor to detect when a player is running. Students will also build motion models, which will be combined with the UWB ranging estimates developed in ball's trajectory tracking (Phase#2).
- **Phase#4: Analytics modeling and processing.** In the final phase, students will leverage scripting programming languages such as Python to develop a tool to automate the data collection and backup process. The collected dataset will be eventually sync'ed and backed up in reliable remote cloud such as Amazon Web Service (AWS) cloud storage. Students will also develop programs to automate the post-processing, analyzing, and plotting on the collected dataset, to generate useful and interesting insights, *which, to the best of our knowledge, the known literature has not studied before*.

3. Expected Products and Learning Outcomes

Students will be exposed to the cutting-edge Internet of Things and Edge Computing research by participating the proposed project. After accomplishing the project, students are expected to build an effective and intelligent IoT sports analytics solution using embedded system programming techniques, motion physics modeling, hardware engineering, and data analysis and processing techniques with emerging cloud platform. The anticipated product deliverable consists of: (1) a ***low-cost*** research prototype system that includes: (a) UWB radio anchors connecting to a series of sensors in the ball, on player, and bats, etc., (b) simple embedded programs driving motion sensing, and (c) computer program tools that automate data processing and plotting; and (2) a ***first of its kind*** Baseball sports analytics dataset collected from experiments.

Students involved in this project will achieve the following learning outcomes. (1) Students will have the chance to learn and grasp hands-on skills such as programming skills, embedded system and wireless networking knowledge, data analysis techniques etc., and to build and improve critical thinking skills and creative thinking abilities. (2) Since this is, to the best of our knowledge, the very first attempt in the field to apply emerging IoT techniques to Baseball sports analytics, students will be exploring the solution space for an important research problem, with the goal of finding out the most suitable approach which has the potential of advancing the state of the art (i.e., Computer Science and sports analytics). (3) The research methodology, developed prototype, experimental results, and collected dataset will be presented in the form of a published conference poster, workshop paper, and/or prototype demo's. Students' communication and presentation skills will be enhanced as well.

4. Sustainability and Funding Plans

National research funding agencies such as NSF strongly encourage research efforts that focus on IoT and Edge Computing. The proposed project can be easily extended on top of its current scope and footprint, and has great potential to be supported by external grant funding. For example, NSF's Computer and Network Systems (CNS) core program recently lists three highlighted and strategic areas including "Embedded and Real-time Systems" and "Edge Computing" [7]. Our proposal is in many aspects well aligned with the core areas emphasized by NSF's core program. Besides external grant funding sources, the proposed project has the potential to benefit communities such as Mason's sports teams including the Baseball team. Therefore, we will seek possible opportunities to establish collaboration partnerships with them as well.

5. Faculty Mentor Roles

We have two faculty mentors included in the proposed project. **Prof. Yue Cheng** has strong expertise in cloud systems, designing computer systems software for emerging platforms such as IoT, data and storage management, and big data analytics. **Prof. Song Min Kim** has expertise in IoT sensing and wireless technologies, with extensive experience in physical testbed prototyping, deployment, and analysis. The faculty mentors' synergistic experience across computer systems, wireless networks, and embedded systems well qualifies them to lead the proposed research. The faculty mentors will provide detailed guidance to the participating students throughout the entire course of the project – e.g., formulating research problems, computer programming, and use of the cloud resources – which will be given through weekly and on-demand meetings throughout the summer.

6. Diverse Student Recruiting Plan

The proposed project will facilitate the efforts of the two faculty mentors on attracting and mentoring undergraduate and underrepresented students in research. The faculty mentors have a track record of working with undergraduate students and underrepresented minorities. In the past few years, Prof. Cheng has mentored one undergraduate student (Yoonjin Kim), and three female students (Yoonjin Kim, Richa Sinha, and He Feng). Prof. Kim is currently mentoring a research project team of five George Mason undergraduate students including two females, Layanne Hazim and Totcheme Soufiano.

7. Project Timeline

The proposed project is anticipated to involve 6 undergraduate student researchers. The planned project timeline is shown as follows:

- **Week 1 (05/28-06/01):** Introductory week: Meetings with students to discuss background, overall goals, and project plan. Assign readings for literature survey, distribute sensors for students to familiarize themselves with embedded sensors and devices. Decide team composition.
- **Week 2 (06/04-06/08):** Bootcamp week: Meetings with students. Basic knowledge about embedded system programming, device usage etc. skill development for project warmup.
- **Week 3-4 (06/11-06/22):** R&D weeks 1: Regular meetings with students to check on progress. Students develop sensor modules for balls, bats, and players, and build UWB radio anchors.

- **Week 5-6 (06/25-07/06):** R&D weeks 2: Regular meetings with students to check on progress, troubleshooting, etc. Students design, develop, and test embedded computer programs to enable motion sensing and data collecting in balls, bats, and players.
- **Week 7-8 (07/09-07/20):** Evaluation weeks: Regular meetings with students to check on progress. Field trips with students to conduct experimental evaluation on the hardware-software prototype build by students. Students develop program tools to backup data in remote cloud storage, and automate data processing and plotting.
- **Week 9 (07/23-07/23):** Wrap-up week: Finalizing project, analyzing data, and preparing research posters and demos.
- **Week 10 (07/30-08/03):** Show time: Meetings with students to discuss next-step plan, e.g., preparing a draft for a workshop or conference poster submission. Presenting at Celebration of Student Scholarship on August 3rd, 2018.

8. Budget Plan

<table>
<tr><th colspan="2">Category</th><th>Amount</th><th>Note</th></tr>
<tr><td colspan="2">Faculty (2)</td><td>$6,000</td><td></td></tr>
<tr><td colspan="2">Undergraduate researcher (6)</td><td>$24,000</td><td></td></tr>
<tr><td rowspan="6">Supplies/ Resources</td><td>Embedded device with IMU (10)</td><td>$500</td><td>Intel CurieNano with IMU</td></tr>
<tr><td>UWB RF node (10)</td><td>$300</td><td>Decawave Limited DWM1000 UWB RF chipset</td></tr>
<tr><td>4-antenna UWB Anchor (2)</td><td>$2,300</td><td>Decawave Limited TREK1000 UWB radio development kit</td></tr>
<tr><td>Laptop</td><td>$800</td><td>Laptop for data collection and processing</td></tr>
<tr><td>AWS cloud service</td><td>$500</td><td>Amazon Web Services for data storage and processing</td></tr>
<tr><td>Baseball equipment</td><td>$200</td><td>Baseball bats, balls, and chest gear for testbed</td></tr>
<tr><td colspan="2">Total</td><td>$34,600</td><td></td></tr>
</table>

Bibliography

[1] Nike, "Footwear Having Sensor System". US Patent US20120234111 A1, 2012.

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[5] M. Gowda, A. Dhekne, S. Shen, R. R. Choudhury, X. Yang, L. Yang, S. Golwalkar and A. Essanian, "Bringing IoT to Sports Analytics," in *NSDI 2017*.

[6] "Blast Motion," [Online]. Available: https://blastmotion.com/.

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