# Indoor Localization for Navigation in an Unfamiliar Environment: A Capstone Course Design Process Case Study

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## Abstract

A public-domain design process from the National Aeronautics and Space Administration was used as a template to design a capstone process that can be performed over two semesters. The process was designed to practice proposing technical solutions to relevant problems, formally plan activities prior to execution, and present results in both written and varied oral forms. That process is detailed here and connected to the public-domain template. A student project performed under the process is detailed to provide an example of the outcomes and experiences of students. The student work focuses on the navigation of indoor environments through the use of Wi-Fi power measurements. The method of estimating location was then evaluated for accuracy and bias and validated at a number of locations throughout the test area. Finally, feedback taken from course surveys is provided as a means of gauging student reaction to the course as a whole and the process itself.

## Introduction

Educating undergraduate students in the fields of engineering and technology requires reflection and vigilance. In a brief four years the students must grow to understand the principles of their field as well as the culture in which they will apply those principles. Given the breadth of topics studied in that short time a balance must be struck between the two. The students in the Computer Engineering Technology (CET) program at Central Connecticut State University (CCSU) study the principles and the process of engineering design. The work presented here details the balance struck between the two during the senior capstone classes in that program. A student project is used to examine the output of the process over the course of two semesters in the Fall of 2015 and Spring of 2016.

A comprehensive review of capstone project classes was performed by Dutson et al.[3] and updated by many works since. That review was concerned with the level of faculty involvement, types of projects, and industrial involvement in undergraduate capstone courses. Additionally, the formation of teams and evaluation of the courses themselves was also discussed. All of those concerns continue to be addressed by current literature such as Dym et al.[4] Additional discussion and a clear set of guidelines are also provided by Rasul et al.[13]

Mckenzie et al.[7] surveyed and interviewed faculty to determine the most common course lengths and methods of evaluation used in senior capstone courses. The conclusions of that work reveal that the CCSU CET capstone course falls within common and acceptable parameters as they relate to an undergraduate degree in engineering or technology. Since the length of time required of the capstone project at CCSU is difficult to increase beyond the current two semesters, designing a process to maximize the educational benefit of the experience is a worthy pursuit.

Paretti et al. discuss the balance between process and product at length.[10] The extreme cases are introduced first where a functional product is the sole focus of the capstone experience forgoing any attention to a formal design process. It is likely in this scenario that little to no formal design process is introduced and will certainly lack emphasis. The students may succeed in the immediate case but will be ill-prepared to participate in larger, more complex design activities. The scenario that represents the other extreme puts all focus on the process of design with no weight on the final product. This exposes the students to a formal process but the lack of functional product undermines the lesson that such processes lead to successful outcomes. The two semesters of capstone classes at CCSU aim to find the middle way with respect to these two extreme scenarios.

## CCSU Computer Engineering Technology Capstone Process

Involvement of industrial partners serves to maintain relevant work for the students and was of detail discussion in the works previously cited. Industry in the State of Connecticut centers around the design and manufacture of aerospace and submarine applications. Both industries require adherence to structured design processes. A study of such processes was performed in order to structure the capstone process to introduce the students to the design culture they will likely join upon graduation. As many processes are proprietary to the companies which use them, a suitable public-domain process was sought. The procedural requirements[8,9] of the National Aeronautics and Space Administration (NASA) served as a template for the CCSU CET Capstone Process. The formal structure of the NASA process prepares the students for work on any number of aerospace and/or military design projects.

The shorter span of the two semester capstone projects and the focus on learning outcomes rather than spaceflight necessitate adjustment of the NASA process. The NASA process is summarized in Figure 1. This process can span multiple decades and employ a large team of engineers and scientists. Furthermore, it is solely focused on robotic and manned spaceflight.

In contrast, senior CET capstone projects at CCSU span two semesters comprised of the courses CET 497 and CET 498. The nature of the projects is often as diverse as the students performing them. Students have explored topics related to computer systems ranging from audio signal processing to mobile robot navigation. Therefore the process must be simplified and generalized to accommodate the shorter time-frame and broader scope of design work performed.

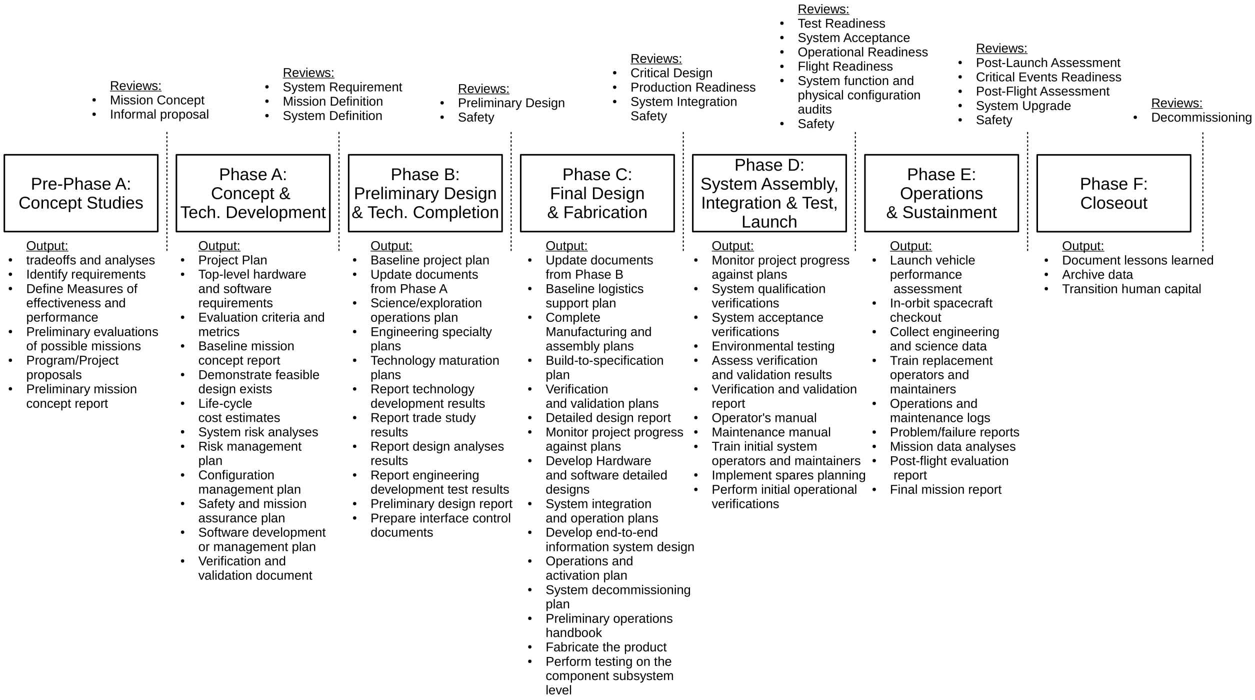

Figure 1: Summary of the Systems Engineering process used by the National Aeronautics and Space Administration

Examining the outputs of the NASA process reveal varied types of output in all of the stages. The outputs of that process can be broadly grouped into the following headings:

1. Proposal of Program/Project Goals
2. Development of Requirements
3. Formation of Planned Activities
4. Documentation of Results

Each design phase culminates in a set of formal reviews. The formal design reviews are ubiquitous in engineering design and are often overlooked in other areas of engineering and technology education. The CCSU process aims to cover the types of output produced throughout all design phases and introduce the students to the work flow around formal design reviews. The CCSU process is summarized in Figure 2.

The primary goal of the CCSU process is education rather than spaceflight. To that end the modes of output are more varied than seen in the NASA process. The students must demonstrate effective written and oral communication.

The CCSU process is broken into four distinct stages detailed here:

1. **Concept Development:** Covers approximately the first half of CET 497, the first semester of the capstone project. Incorporates tasks similar to that in the NASA process Pre-Phase A and Phase A Concept Development. Students practice defending the relevance of their

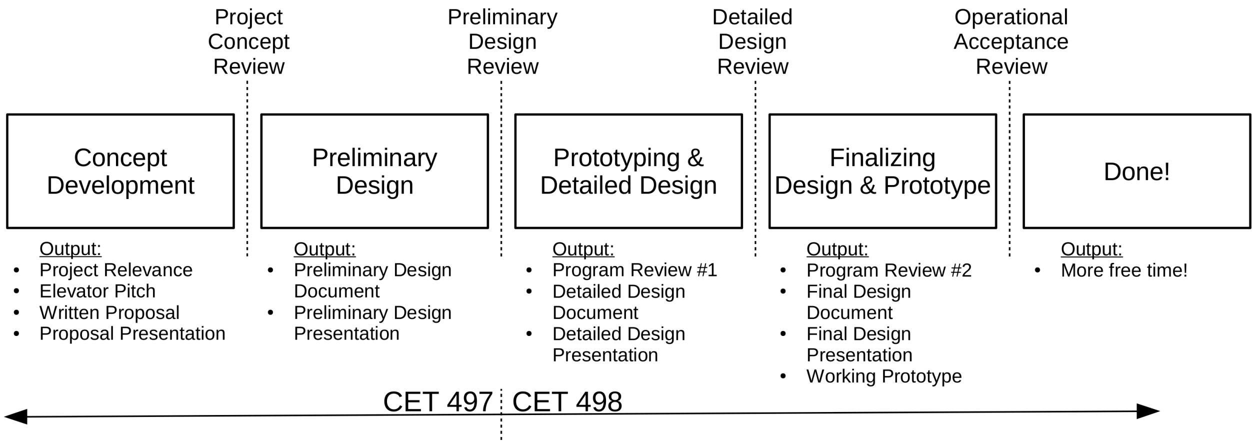

Figure 2: Overview of the capstone process used by the Computer Electronics & Graphics Technology Department at Central Connecticut State University

project in written and oral forms. The scope, schedule, and budget of the project are developed and culminate in a formal proposal document and presentation. Faculty and students review the exit criteria as part of the Project Concept Review.

2. **Preliminary Design:** Covers the remainder of CET 497. Incorporates tasks similar to the NASA process Phase A Technology Development and Phase B Preliminary Design. Students practice proper documentation of design appropriate to their project. This phase results in a set of plans to solve the problem identified during Concept Development. The students prepare a preliminary design document and presentation. Faculty and students review the exit criteria as part of the Preliminary Design Review.

3. **Prototyping & Detailed Design:** Covers approximately the first half of CET 498, the final semester of the capstone project. Incorporates tasks similar to the NASA process Phase B Technology Completion and Phase C Final Design. This phase involves prototyping of individual subsystems and revision of the preliminary design based on the results. Students practice presentation of project progress through formal Program Reviews. The students prepare a detailed design document and presentation. Faculty and students review the exit criteria as part of the Detailed Design Review.

4. **Finalizing Design & Prototype:** Covers the remainder of CET 498. Incorporates tasks similar to the NASA process Phase C Fabrication and Phase D System Assembly, Integration, and Test. Students continues program reviews and focus on the fabrication and assembly of a working prototype. The students prepare a final design document and presentation. Faculty, students, and engineers from local industry review the exit criteria as part of the Operational Acceptance Review.

## Case Study: Using Wi-Fi in Indoor Localization

The inclusion of a capstone project intends to collect the disparate topics covered over the course of the CET degree program and apply them to a single project. The students often develop a sense of completion and confidence through their performance on such a project. Furthermore, capstone projects afford the opportunity for students to study advanced topics. The study of advanced topics is crucial for technology students in particular given the ever-changing state of technology. This section documents one such project as it relates to the CCSU CET Capstone Process.

## Design Phase: Concept Development

The students focused on navigating unfamiliar environments in the absence of the Global Positioning System (GPS). Nicholas Copernicus Hall at CCSU serves as the primary academic building for the School of Engineering, Science, and Technology. The layout of the building is inherently confusing to visitors and students. 87% of students polled have been lost in the building. 61% of those students have had to stop and ask for directions. The layout of a single floor of the six-floor building contains rooms located within other rooms and an unintuitive numbering system.

The students defined the objective of their work to provide a navigational aide to building visitors and automated guidance systems throughout the building. Wi-Fi access points report the signal power received by a remote receiver such as a user's smart phone or a mobile robotic platform. In both cases the magnitude of the power measurements are dependent on the location of the receiver within the building. The students endeavored to use measurements from Wi-Fi access points (AP) to estimate location in the building to provide such a navigational aide. This is a well studied problem with as many solutions as people who have studied it.[1,5,6,11,15]

Other applications of similar technology have gained footing in more complex applications requiring a higher-level of technology.[2,12,14] These works demonstrate that the work performed by these students may serve only as a stepping stone to more advanced research.

During the Project Concept Review faculty and student peers determined that:

1. The problem was clearly defined and supported with appropriate references or data.
2. A clear benefit to a population was made clear, the visitors to Copernicus Hall in this case.
3. Adequate work was required of all team members.
4. New knowledge was required in addition to knowledge from across the CET curriculum

## Design Phase: Preliminary Design

During the Preliminary Design Phase students acquire and organize the knowledge necessary to begin their design. This stage results in a "best guess" that rarely survives the design process to become the final design. Adjustments are made as prototyping, fabrication, and integration are performed.

The student team planned to survey the Wi-Fi signals in the building for use as a training dataset for the developed algorithm. Power levels from all MAC addresses were to be recorded over a period of time at 120 fixed and known locations on the first floor of Copernicus Hall. These training data points effectively sampled a multidimensional function relating the received MAC powers to locations within the building. The students learned the k-nearest neighbor method of regression and intended to use it to make estimates of position based on the training data power survey. Briefly, the k-nearest neighbor algorithm calculates the distance from a new data point, in this case a set of power measurements at an unknown location, to all of the training data points from the survey. The algorithm then averages the locations within the building of the k-nearest training data points. Figure 4 depicts a two dimensional example of this algorithm. This is a simplified example as two power measurements would be insufficient to determine location in the three dimensions of the building. In this example k is set to 2. The physical locations of TD2 and TD3 would be averaged to find the estimate. The value of k allows for tuning of the algorithm.

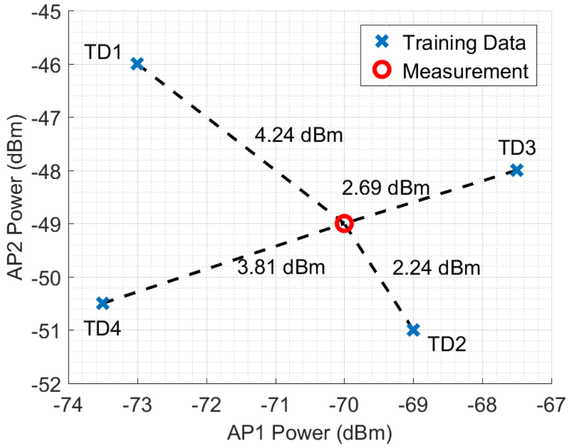

Figure 3: Estimation of position in the ideal case during Preliminary Design

The proposed plan demonstrated an understanding of a possible solution that spanned multiple courses in the CET curriculum, required development of new knowledge in support of life-long learning, and provided a reasonable path to successfully addressing the problem identified previously.

## Design Phase: Prototyping & Detailed Design

The students began data collection and development of the algorithm in the first part of CET 498 during the Spring semester of 2016. In addition to the 120 points planned for the training data set the students collected an additional 15 points at uniformly random locations within the same area spanned by the training data. A naive implementation of the k-nearest neighbor algorithm was applied to the validation dataset and estimates were evaluated against the known locations of those points. Examination of the results revealed estimates with unacceptable error, sometimes exceeding 30 meters. The results proved unacceptable given the surveyed area of the building is approximately 30.7 meters squared. The “best guess” developed during preliminary design did not survive the design process. However, it did provide a path for inquiry and led to a successful outcome.

The student team determined that signal dropout caused the error. If an access point was too far from the receiver to provide a power measurement they had elected to ignore that dimension of the function input. Figure 4 graphically demonstrates the consequences of this approach.

The two plots in Figure 4 depict the same set of measurements. The top plot shows the case where all dimensions are considered, two in this simplified example. The two blue crosses indicate training data points located 3.16 dBm and 4.12 dBm from the current set of power measurements, depicted as a red circle. If the k parameter is 1, the algorithm would select the first point as the nearest.

In the bottom plot shows the case where AP2 does not report a power measurement. Ignoring the dimension associated to that access point projects the data points onto a single dimension. In this case the blue crosses indicate that same data points though the distances have changed. The points are located 3 dBm and 1 dBm away from the current set of power measurements. Again, with the k parameter set to 1, the second point is now selected as the nearest. The incorrect selection of the data point caused the error in the estimates seen in the validation data set. During the Detailed Design Review faculty and students determined that sufficient prototyping was performed by the team. Issues with the preliminary design had been identified and a sufficient plan existed to address those deficiencies. The team updated all documents to reflect the necessary changes and maintained sufficient focus on the problem identified in the Concept Development phase.

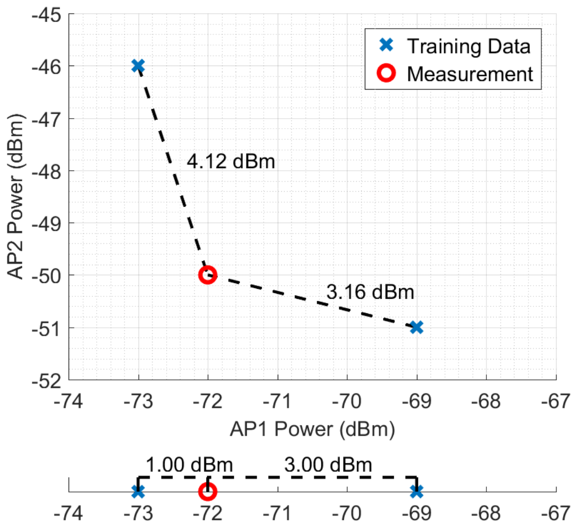

Figure 4: An illustration of deficiencies found during prototyping. 2 dimensional example of measurement space. (top) Projection of that same space onto 1 dimensional space. (bottom)

## Design Phase: Finalizing Design & Prototype

Recognizing the issue with their initial approach the team chose to reduce the training data set used to generate each estimate. In the naive implementation of the k nearest algorithm similarity is determined solely by the distance to each point in the measurement space. The team chose to first consider similarity by examining how many and which dimensions those measurements existed within. As a result the team implemented the algorithm as follows:

1. Reduce training set by selecting training data points with power measurements within ±10 dBm of the new measurements.
2. Calculate distance in measurement space to remaining points
3. Sort remaining training points by distance
4. Use up to k (the algorithm parameter) points that share at least half of the power measurement in the current set of measurements
5. Average the physical location of the remaining training data points to form an initial estimate
6. Address outliers in training data by reconsidering the training data points used to form estimate if the location of that point is greater than 6 meters from the estimate.

The modified algorithm was evaluated against the 15 point validation dataset. The resulting estimates were compared in physical space to the known locations of those validation data points.

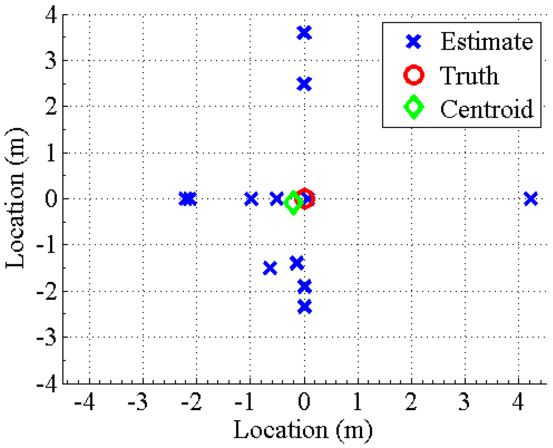

Figure 5: Estimate error compared against the validation dataset

The team generated and documented estimates that were clearly superior to those generated in previous design phases. Figure 5 shows the error in each estimate over the validation data set. The resulting estimates have a mean error of less than 1.5 meters. Additionally, the bias was near zero meters over the validation data set in a two dimensional plane. These results are suitable for the two platforms targeted by this work.

## Discussion

While the accuracy of the estimates was acceptable the team made several observations that must be addressed by future capstone students. The sensitivity of the algorithm to obstructions was left uncharacterized but nonetheless should be examined and addressed. Common events such as the opening of a door or the presence of human bodies (big bags of salt water in the electromagnetic sense) disturbed the estimates adding several meters to the error. This phenomena was observed and reported with a subjective eye but will prevent successful implementation without further study.

Another observation the team made was the effect of latency on the estimate accuracy. If the receiver was in a static position the estimate quality matched that which was reported above. However, if the receiver was moving within the building the power reported by each access point did not necessarily correspond to the current position of the receiver. Without the ability to move the receiver within the building there is little need to estimate position. Future students will need to address this through stochastic methods and sensor fusion, topics which are beyond the scope of an undergraduate degree in Computer Engineering Technology.

## Conclusion

The faculty of the Computer Electronics & Graphics Technology Department at CCSU developed the capstone process summarized above with the intention of exposing students to the rigid design processes they will face in industry while leaving room for genuine technological inquiry resulting in a successful outcome. The need to balance student success with the process of design lies in reinforcing the purpose and efficacy of rigidly structured design processes.

The student work presented here, as well as other student work, was guided by the CCSU CET Capstone Process. In following the process student awareness of design processes was improved without hindering the outcome of the work. The practice of proposing relevant technological solutions, planning for successful outcomes, and documenting both successful and unsuccessful attempts at realizing those solutions was practiced.

The immediate reception of the class was positive as evidenced by student responses on a course survey. Most responses from the small sample size were encouraging including:

- "Overall this course was great"
- "one of the best classes I've taken"
- "I enjoyed the course and truthfully gained a better understanding of everything"

A more detailed response included "...approach was more valid for this particular class." when contrasting the approach to class-based projects in other courses.

Underlying the attention to balancing process and product is the desire to ease the transition of the students from graduation to employment. In the future a survey will be made of alumni addressing that underlying goal as more alumni have performed their capstone projects in this way.

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