Detection and Classification of Cracks on Transportation Infrastructure using UAV Based Aerial Imagery

Design Document

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Executive Summary

Development Standards & Practices Used

Software -

- PyTorch - library for machine learning

Hardware -

- UAV - for taking photographs of the pavement
- UAV mounted photography equipment - for taking photographs of pavement

Standards -

- IEEE 12207 - Software life-cycle processes

Summary of Requirements

- UAV can take photographs of pavement
- Photos will be taken on sunny or overcast days with no precipitation
- Software will be able to detect cracks in asphalt
- Software will be able to detect cracks and joints within concrete
- Software will be able to correctly classify cracks and joints

Applicable Courses from Iowa State University Curriculum

- COMS 309
- COMS 311

New Skills/Knowledge acquired that was not taught in courses

- Machine learning
- Image processing
- Knowledge of how concrete with joints crack

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UAV - Unmanned Aerial Aircraft; a drone that can fly via remote control

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1 Introduction

1.1 Acknowledgement

Our team would like to acknowledge our client for the assistance he has provided throughout the project. At the beginning, Ahmed has been proactive in assisting our team with design specifications, equipment, and initial data. Throughout the project, Ahmed was available to answer questions and was willing to help us in whatever manner he could.

1.2 Problem and Project Statement

Problem Statement: Due to the weather fluctuations in Iowa and throughout the midwest, concrete and other road surfaces are constantly changing causing potholes, cracks, and other problems that create hazardous and at times, undrivable road conditions.

Project Statement: The purpose of our project is to provide a way to identify cracks and their classifications in pavement via an Unmanned Aerial Vehicle (UAV).

This will be accomplished by using a UAV, artificial intelligence, and image processing. The UAV will take photos of various roads which will be run through through image processing which will teach artificial intelligence to identify cracks.

By being able to identify cracks and their classifications, any department charged with fixing and maintaining roads will be able to identify roads in the most critical conditions. As a result, crews will be able to prioritize their work and create safer driving conditions.

1.3 Operational Environment

The main operational environment for this project will consist of days with clear or overcast skies and no precipitation. While the overcast conditions will alter the pictures will still be able to run through image processing whereas precipitation could alter the photos beyond our capabilities. In addition, the UAVs that are used in this project will only fly with no precipitation.

1.4 Requirements

Economic -

- Software cost will be kept minimal (use free/open source software)
- The cost to operate the UAV will stay to a minimum

Environmental -

- UAV flights will not impact the surrounding environments
- Conditions for flight must be taken into account when flying

Outcome -

- Software will be able to detect cracks within concrete and asphalt roads
- Software will be able to detect different surface areas (concrete, asphalt, gravel)
- Software will be able to categorize different cracks (joints vs. cracks)

1.5 Intended Users and Uses

This project is intended to be used by professionals as an additional resource to evaluate existing infrastructure including roads and bridges. This will assist in prioritizing repairs and maintenance to roads and bridges in critical conditions in order to ensure they stay safe and drivable.

1.6 Assumptions and Limitations

Assumptions -

- Initial data will be provided to us (client has notified us that data is available)
- Surfaces will have cracks to identify (most surfaces have some form of crack or joints)

Limitations -

- UAV flying must be planned and will not always be available for use (FAA laws since ISU is within 5 miles of an airport)
- UAV can only fly to a certain height for picture to be useful (photo equipment limitation)
- UAV flight cannot be continuous (UAV hardware limitations)

1.7 Expected End Product and Deliverables

The expected end product and deliverable to the client will be a software that can intake photographs of roads and identify and classify cracks and joints. This software can be used to help those assessing infrastructure conditions and help prioritize roads for maintenance and repair. The software will be delivered in two phases. The first phase will be delivered by December 13, 2019 and will be a software that identifies any type of cracking in pavement or asphalt. The second phase will be delivered no later than May 1, 2020 and will be a software that, in addition to phase 1, will also be able to classify the cracks into different types.

2. Specifications and Analysis

2.1 Proposed Design

We have decided that our project will use machine learning to identify cracks in the pavement. After looking at a few options, we decided upon using PyTorch due to its ease of use and extensive documentation. Since it is open source, it is also free to use. This meets our economic requirement of our project, as it will dramatically reduce man-hours previously required to examine every picture, and there is no cost associated with using the software.

2.2 Design Analysis

After looking at different options for machine learning algorithms, we decided that PyTorch would be a better option than its closest competitor TensorFlow. This is because of PyTorch being easier to use and also having more documentation. We have also created a Python script that crops images down so that they can be easily analysed by the software.

2.3 Development Process

We will follow an Agile-like development process. As the majority of our project revolves around the machine learning algorithm, most of our tasks will involve removing errors and improving its accuracy. Working in 2 week sprints will also allow us to always have something new to present to our client.

2.4 Design Plan

For our design plan, we will make a flowchart that illustrates the process we will be taking for this project. This flowchart will contain the data collection process, the machine learning algorithm and how we train it to correctly identify cracks in concrete. Then if need be, we will use the trained algorithm to predict cracks in video footage of concrete.

3. Statement of Work

3.1 Previous Work And Literature

Include relevant background/literature review for the project

– If similar products exist in the market, describe what has already been done

– If you are following previous work, cite that and discuss the **advantages/shortcomings**

– Note that while you are not expected to “compete” with other existing products / research groups, you should be able to differentiate your project from what is available

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

3.2 Technology Considerations

Highlight the strengths, weakness, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

3.3 Task Decomposition

In order to solve the problem at hand, it helps to decompose it into multiple tasks and to understand interdependence among tasks.

3.4 Possible Risks And Risk Management

As with any project, there will be an inherent risk. Below are the identified risks and mitigations to reduce the risk to the lowest possible severity.

Risk: UAV Flight -- Flying UAVs require a specific skill set that not everybody on the team has. UAVs must adhere to FAA laws and since Iowa State University is within 5 miles of an airport, flight plans must be submitted in advance.

Mitigation: This risk is highly mitigated by our clients ability and experience flying UAVs. Our client has both the resources, skills, and knowledge to safely operate a UAV and has had 9 years experience in UAV photography.

3.5 Project Proposed Milestones and Evaluation Criteria

The following major milestones will be used as a project guide to determine progress:

Collect Relevant Research Information - Collect all initial information needed for project such as purpose, scope, resources, background information, etc. This is considered finished when the major tasks for the project have been identified and a timeline can be developed.

Develop Timeline - Establish a plausible timeline for each identified major stage of the project. This will be considered complete when all major tasks are identified, a rough timeline has been established, and the final timeline is discussed with and approved by the client.

Begin Algorithm Training - Start to train the algorithm using an open source data set. This is considered completed when the training begins to work.

Crack Detection - The algorithm is able to detect cracks on the pavement. This is considered complete when at least 8/10 cracks have been correctly identified.

Pavement Detection - The algorithm is able to identify if the crack is on pavement or asphalt. This is considered complete when at least 8/10 surfaces have been correctly identified.

Crack Classification - The algorithm is able to classify cracks based on the type taking into account shape, crack pattern, and pavement. This is considered complete when at least 8/10 cracks can be correctly classified on the correct pavement.

3.6 Project Tracking Procedures

As stated above, our team will use an agile-like development process. Tools that will be used to track project progress will be as follows:

Discord - Used for team member communication

WhatsApp/Text Message - Used to communicate with client

Email - Used to communicate between group and client

GitLab/GitIssues - Repository for all code. Git Issues will be used to track all “fixes” that need to happen

Trello - Since we are following an agile process, we will use trello to track tasks, their progress, and completion.

Other relevant tools will be used as needed.

3.7 Expected Results and Validation

The desired outcome for the projects will be in two stages: the identification of cracks, and the classification of cracks.

Crack Identification - The desired results for this will be that after the algorithm has been trained, it will be able to identify all cracks in concrete or asphalt. At this stage, the identification of cracks will not be dependent on the type of crack, but whether one is present there or not. To test our algorithm, we will use a series of pictures we currently have as well as new ones that we can take once the algorithm has been accurate with the current photos. At a high level, we will confirm the algorithm works when it can correctly identify at least 8/10 cracks in the photos. Once we get to this accuracy, we will begin to move towards the next step while continuing the training of the algorithm to 10/10 cracks.

Crack Classification - The desired result for this stage will be the algorithm being able to recognize the difference between a crack and a joint in concrete. As a stretch goal, the algorithm will also be able to identify different types of cracking patterns within concrete. To test the algorithm, we will use the same process as stated for crack identification. At a high level, we will confirm the algorithm works once it is able to correctly identify 8/10 cracks and then refine the process to 10/10 cracks.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

The full project timeline is attached as Appendix 2.

The major factor impacting this schedule is the group members course load, schedule, and client's availability. Each of these factors will determine how timely we will be able to finish tasks. We also are trying to account for the time necessary to troubleshoot and debug code.

4.2 Feasibility Assessment

This project should be able to be completed in the time given. Given the stages of the project, we project to have the crack detection portion finished at the end of the semester. In the spring semester, we will continue to work on identifying and classifying different types of cracks. The degree to which we are able to do this will be dependent on identifying patterns within the datasets.

4.3 Personnel Effort Requirements

Task	Time Estimate	Time Estimate Justification
Collect Relevant Research Information	20 Hours	The 20 hours needed to do initial research will include meetings with the client, research done individually by the team, and follow on research based on the initial findings.
Develop Timeline	3 Hours	These 3 hours will be used to develop the timeline, meet with the client about the proposed timeline, and allow for adjustments and modifications
Begin Algorithm Training	40 hours	This includes the time needed for each group member to set up the work space, become familiar with the PyCharm, write the algorithm, troubleshoot/debug algorithm

Crack Detection	40 hours	This includes the time needed for the dataset to train, correct, and modify the algorithm as necessary to complete the task. This is considered complete when at least 8/10 cracks have been correctly identified.
Pavement Detection	30 hours	This includes the time needed for the dataset to train, correct, and modify the algorithm as necessary to complete the task. This is considered complete when at least 8/10 surfaces have been correctly identified.
Crack Classification	40 hours	This includes the time needed for the dataset to train, correct, and modify the algorithm as necessary to complete the task. This is considered complete when at least 8/10 cracks can be correctly classified on the correct pavement.

Table 1.1

This table gives an estimate of the total number of hours needed for the project. Each task has been determined by the amount of hours approximately each group member will need to spend per/week on the project and then multiplied by the number of people in the group. Most of the algorithm tasks time will be used by making manual corrections to the algorithm to improve accuracy. These numbers are approximations and will be adjusted as needed either adding or subtracting the necessary time to ensure a quality product will be delivered to the client.

4.4 Other Resource Requirements

Outside of financial resources, our project will need access to a UAV, a High Performance Computing (HPC), and a dataset to train the model. Our client has provided us access to the UAV photography he has previously taken and has offered the ability to take more photos should we need it. The HPC will be available through a cluster provided by the Department of Electrical and Computer Engineering. Lastly, the dataset and library we will be using are both open source.

4.5 Financial Requirements

The financial resources for this project are limited. The products we are using are open source and the high performance computing cost will be covered by the Department of Electrical and Computer Engineering.

5. Testing and Implementation

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or a software library

Although the tooling is usually significantly different, the testing process is typically quite similar regardless of CprE, EE, or SE themed project:

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study for functional and non-functional requirements)
2. Define the individual items to be tested
3. Define, design, and develop the actual test cases
4. Determine the anticipated test results for each test case 5. Perform the actual tests
6. Evaluate the actual test results
7. Make the necessary changes to the product being tested 8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you've determined.

5.1 Interface Specifications

– Discuss any hardware/software interfacing that you are working on for testing your project

5.2 Hardware and software

- Indicate any hardware and/or software used in the testing phase
- Provide brief, simple introductions for each to explain the usefulness of each

5.3 Functional Testing

Examples include unit, integration, system, acceptance testing

5.4 Non-Functional Testing

Testing for performance, security, usability, compatibility

5.5 Process

– Explain how each method indicated in Section 2 was tested

– Flow diagram of the process if applicable (should be for most projects)

5.6 Results

– List and explain any and all results obtained so far during the testing phase

- – Include failures and successes
- – Explain what you learned and how you are planning to change it as you progress with your project
- – If you are including figures, please include captions and cite it in the text

• This part will likely need to be refined in your 492 semester where the majority of the implementation and testing work will take place

-**Modeling and Simulation**: This could be logic analyzation, waveform outputs, block testing. 3D model renders, modeling graphs.

-List the **implementation Issues and Challenges**.

6. Closing Material

6.1 Conclusion

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 References

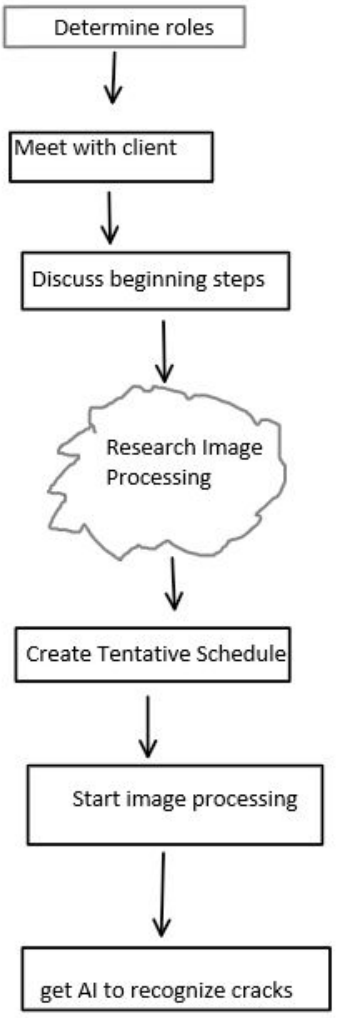
This will likely be different than in project plan, since these will be technical references versus related work / market survey references. Do professional citation style(ex. IEEE).

6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar that does not directly pertain to the problem but helps support it, include that here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc. PCB testing issues etc. Software bugs etc.

Appendix 1 - Project Plan Flow



9/10 Determine group roles for admin

9/12 Met with client initially

Meeting on 9/26 to start processing data

9/26-10/23 Research image processing and data collection
This will be continuous as needed for the project

9/28 - Script made to break down images

10/3 Begin creating schedule for the rest of the year

10/9 - begin to process the images and train AI to recognize cracks

The group will work on the project and continue to have meetings with the client about specifications and necessary project changes

12/6 - Get first half of senior design finished;
next steps: data processing to recognize types of cracks

Appendix 2 - Detailed Project Schedule

Administration - 9/30/2019*

Course work administration and group setup - 8/28/2019*

Client initial meeting - 9/12/2019*

Begin project planning - 9/26/2019*

Research - 10/23/2019*†

Client initial meeting - 9/12/2019*

Data processing initial research - 10/15/2019*

Project Start - 09/30/2019*

Script to break down images - 9/28/2019*

Algorithm training start - 10/09/2019*

Crack Detection - 12/03/2019

Pavement Detection - 02/07/2019

Crack Classification - 05/27/2019

* completed

† initial research completed on 10/23/2019. Research will be continuing throughout the project as needed