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Master's Thesis
on the topic

LPWAN: Deriving the theoretical and practical limitations, and design of an application/ technology matching algorithm

by

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Declaration

I confirm that I have written this thesis unaided and without using sources other than those listed and that this thesis has never been submitted to another examination authority and accepted as part of an examination achievement, neither in this form nor in a similar form. All content that was taken from a third party either verbatim or in substance has been acknowledged as such.

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Kurzfassung

Abstract

Introduction to an abstract thesis about the flow of space-time during the creation of any thesis.

Abbreviations and Acronyms

CEA Controlled Environment Agriculture

PAR Photosynthetically Active Radiation

PPFD Photosynthetic Photon Flux Density

DLI Daily Light Integral

Contents

Chapter 1

Introduction

Lorem ipsum ... This is some sample text.
This is more sample text :). And I have even more sample text. Test.

Figure 1.1: Image caption

Lorem ipsum ...

1.1 Motivation

In the last two centuries human civilization has seen tremendous growth, a rise in global interconnectedness and urbanization. These trends are posed to continue at a rapid rate and provide mankind with prosperity never imaginable to our ancestors. Unfortunately as everything in life these developments also come with significant drawbacks we as a society need to address.

One, interconnectedness comes at the cost of reliance. The division of labor on a global scale has produced the curious situation where some nations are not able to provide food for their own people. needs ref. An arrangement which previously has taken down not only nations but entire civilizations. Something as basic as food supply should be the upmost priority for a government serving its people. However now, agricultural highly productive nations such as Ukraine are exporting much of their produce, providing a stable food supply to the world. But with this we can see multiple problems. On the one hand climate conditions and regions may shift significantly in the future which would result in previously very productive areas becoming less fertile.

On the other hand in a global economy every nation is its own actor. Recent history has revealed that overdependence on an entity you have no control over or which safety you can not control, can lead to catastrophic consequences. But not only autocracies with their agenda pose a risk to this configuration.

Second, higher prosperity has led to higher resource usage and an exploitation of our environment. Especially cities are drivers of incredible economic prosperity as they provide a dense and efficient network of people, equipment and services. What has traditionally be lacking in these urban environments however is food production. And so humans still need to rely on area and water intensive traditional agriculture in rural regions to produce their food.

Higher interconnectedness comes at the cost of increased reliance on other global actors and autocrats. And as we have seen in the last years with the attack on Ukraine, heavy reliance on non democratic regimes food safety is still an issue in the world - famines have played significant role in downfall of civilizations in the past.

The motivation for this work is threefold. One, crafting ideal human environment in the context of smart city. - Taking advantage of synergies. Two, resilience and national autonomy of food supply. - Preparedness for shifting climate. Three, most important to the author, global sustainability of human civilization. - water use - pesticide use and water ?artrification? - local food production - freeing up area for natural ecosystems

?Mehr auslegen einer Vision? - Imagine the future city. Clean green walls dampen the sound of cars, provide cooling in the hot summer months. More people in cities. More sustainable production systems needed. Land use of agriculture precise value. Water use of agriculture precice value. Greenhouse Gas emissions of agriculture precise value. Good sources in this paper https://doi.org/10.3390/horticulturae10020117.

1.2 Problem Statement

The last decade has seen the advent of a novel approach to agriculture to tackle these problems. Controlled Environment Agriculture (CEA) and in particular urban vertical farming want to control the plants environment more fully to lessen the reliance on climate. This method has a number of benefits over traditional agriculture. - less area needed - significantly less water use - no water ?atrification? - no dependence on climate conditions - no need for pesticides and therefore clean food - more regional food production If we want to tackle the problems posed above Introduce benefits of vertical farming

Companies such as ... and ... try to seperate the plants completely from the elements and control the environment they are in fully. This of course is great for reproducibility and quality. However as we will show later in 3 current commercially operating farms with this approch have one main problem. Energy consumption. This makes them economically less competitive to traditional agriculture and shifts the resource usage from water and land area to energy. Not ideal for Germany, a country which still relies to ... % on fossil fuels for its energy production ref for concrete number.

From the three main motivations laid out before we can extract the main problems of these areas. One - Air quality - disconnection from nature - buildings not properly insulated, taking advantage of synergies. Two - Reliance on a few agricultural plentiful areas in the world to sustain the hunger of the human population - These might change as climate patterns will shift. Three - High resource use of cities. Uncertainty of future climate. This section laid out a number of different problems. This work can not adress all, but tries to connect

Let us first examine current CEA and vertical farming approaches to get a better understanding of the solution methods and shortcomings. Current solutions try to achieve high degree of automation and full control over the environment. This results in high energy

1.3 Solution Proposal

This work will introduce a plant irrigation system in the form of panels. These panels shall be mounted on building facades and be protected from the elements by an additional layer of glass. With this we can provide all of the benefits over traditional agriculure which have been discussed before. Simultaneously this arrangement addresses the main problem of present vertical farming systems by not relying on a completely artificial environment and instead using existing resources to cultivate the plants. Namely natural lighting by the sun and vertical area of city infrastructure.

Additionally it provides even more benefits resulting from the tight integration into its environment and distributed nature of deployment. double use as building insulation.

This work will introduce a urban farming concept providing clean, regional food while simultaniously providing insulation to existing buildings and improving city climate. The solution presented consists of panels which can be retrofitted on existing building Let us imagine a future city where old buildings have been retrofitted with insulating tiles. These tiles shall - improvement of quality of life factors inside cities such as improved air quality, beautifying building facades and creating awareness for plants and human food production - providing clean, regional food for cities - insulate existing buildings for more energy efficiency and sound isolation - help with regulating city climate during heat waves

Chapter 2

Fundamentals

2.1 Heat Transfer

2.1.1 Types of Heat

Heat can be classified into two different forms. There is sensible heat which directly causes a temperature change in a material. And there is latent heat which is responsible for the phase change of a material. During the phase change, there is no temperature change from heat added into or substracted from the system. Total heat transfered during a process is denoted by Q and the rate at which this happens is signified with $\dot{Q}$ carrying the unit Watt. This heat transfer rate $\dot{Q}$ is what we will look at next.

2.1.2 Types of Heat Transfer

@cengel2003 Heat transfer can fundamentally occur in three different forms. Conduction, Convection and Radiation.

Conduction refers to heat moving through a material. It is characterised by the heat conductivity k specific to the substance in question and can be modeled by Fourier's law

$$\dot{Q}_{cond} = -k\frac{A}{L}\Delta T$$

, where A is the area through which the conduction takes place, L is the distance and ΔT is the temperature difference. *Convection* is heat transfered on the boundary between a solid and a fluid. The characteristic value for this interaction is the convection heat transfer coefficient h while the mathematical description is given by Newton's law of cooling

$$\dot{Q}_{conv} = hA\Delta T$$

, with A being again the area, and ΔT the temperature difference. *Radiation*

To be able to understand the implementation of the simulation discussed later in needs ref, we first need to introduce the basics of heat transfer. There are three different forms in which heat transfer can occur. First Conduction, which describes heat moving through a solid material. This property can be characterised by the heat conductivity k for the specific material. The mathematical model equation will be introduced later with the heat capacity in 2.1.3. Second we have Convection. This is heat transfer which happens between the surface of a solid material and a fluid. Last the transfer can occur via radiation. As the name implies this is basically heat energy transmitted with electromagnetic rediation. These will all be modeled seperately later. How about heat transfer via mass transfer? some sources also have advection - what's that? Difference between sensible and latent heat flow.

2.1.3 Other important thermodynamic properties

Explain Heat Capacity.

2.2 Systems Modelling Approach

2.3 Agricultural and CEA Basics

In the center of CEA stands the plant. The environment is crafted to provide optimal conditions.

2.3.1 Irradiance

Irradiance on a tilted surface

Solar spectrum and photosynthesis

When assessing the optimal lighting conditions for plant growth, several factors need to be illuminated. Pun intended. Light spectrum, Instantenous light intensity, Cumulative light amount and Photoperiod

For quantifying *spectrum* and *instantenous intensity* we will introduce Photosynthetically Active Radiation (PAR) and Photosynthetic Photon Flux Density (PPFD). As discussed before we want to How do we quantify the solar irradiance Plants use solar radiation in the spectrum from 400 nm to 700 nm needs ref for photosynthesis. This is only a portion of the actual solar radiation which is hitting earth. For the *natural* solar radiation in the context of plant growth, the concept of PAR is most often used. This describes the solar radiation which lies inside the aforementioned range for photosynthesis and can be calculated with a simple conversion factor @reis2020.

Meanwhile when using *artificial* lighting, PPFD is used to describe the relevant radiation. PAR and PPFD quantify *light spectrum* and *instantenous intensity*. They both carry the same unit and except for their natural or artificial origin, can be treated the same.

To quantify the *cumulative light amount* and *photoperiod* for a whole day, we simply accumulate PAR and PPFD over one day. This is called Daily Light Integral (DLI).

LEDs are chosen because of their high efficiency and possibility to adjust the light spectrum granuarly.

2.3.2 Irrigation

Soilless Agriculture - Hydroponics - Aeroponics

Aeroponics and specially fogponic system is chosen because of the lightweight nature and ease of deployment.

2.3.3 Atmosphere

Vapor pressure - VPD CO2 concentrations

Chapter 3

Theoretical Analysis and Architectural Approach

3.1 Energy Analysis

3.2 Presentation of the General Concept

Metrics to evalute feasibility of the concept:

- The energy consumption can be met through a solar installation covering at most the area on the roof.
- Yield can offset investment costs in a reasonable timeframe.
- Farm provides measurable insulation increase in comparison with the 'naked' building.

3.3 Energy System Architecture

Chapter 4

Showcase of Example Unit and Simulation

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