



**mmCESim**

<https://mmcesim.org>

# MMCESIM DOCUMENTATION & TUTORIALS

## TASK-ORIENTED MMWAVE CHANNEL ESTIMATION SIMULATION

Version 0.1.0

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The latest edition of this document (mmCESIM DOCUMENTATION & TUTORIALS) can be freely accessed online at <https://pub.mmcesim.org/mmCEsim-doc.pdf>.

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mmCEsim Website: <https://mmcesim.org>

Source of This Document: <https://github.com/mmcesim/mmcesim-doc>



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# Preface

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mmCEsim documentation & tutorials are under development!

I would like to thank Jinwen Xu for designing the elegant L<sup>A</sup>T<sub>E</sub>X template beaulivre, which empowers this document.

WUQIONG ZHAO  
Nanjing, China  
January 2023





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I

## PRELIMINARY

Make preparations before we start.



# Preview 1

Before diving into documentation details, let's first have a preview of mmCEsim. Maybe you are not sure whether your research or study need this powerful tool, then read this chapter to have a glimpse of mmCEsim.

## 1.1 Introduction

The application is dedicated to simulate millimeter wave (mmWave) channel estimation:

$$\text{mmCEsim} = \text{mmWave} + \text{Channel Estimation} + \text{simulation},$$

where reconfigurable intelligent surface (RIS), also known as intelligent reflecting surface (IRS) [1] is supported for multiple input multiple output (MIMO) systems.



Figure 1.1: mmCEsim banner.

We offer a task-oriented simulation software for researchers to focus on algorithms only without being bothered by coding.

## 1.2 Features

Here is a list of basic features of mmCEsim:

- Task-oriented mmWave channel estimation formulation;
- Customizable system model;
- Extendable algorithms with our designed ALG language;
- Multiple RISs support;
- Automatic report generation (in plain text and  $\text{\LaTeX}$  PDF);
- Well-written documentation with examples and tutorials.

### 1.3 Algorithm Background

The task-oriented channel estimation for (RIS-assisted) mmWave MIMO systems is implemented with compressed sensing (CS), which exploits the sparsity of mmWave channels.

### 1.4 Software Implementation

Based on the algorithm background, we implement this software with command line interface (CLI), graphic user interface (GUI), web application and a VS Code extension.



# Installation | 2

So far, there is no built binary for mmCESim since it is still under development. However, you may clone the GitHub repository and compile it yourself.

---

```
1 git clone https://github.com/mmcesim/mmcesim.git --recurse-submodules
2 cd mmcesim
3 cmake .
4 make
```

---





## DOCUMENTATION

Every syntax and option in details.



# CLI Application | 3



# GUI Application | 4





# Web Application | 5

The example web app page is shown in Fig. 5.1.

The screenshot displays a web browser window with the address bar showing `app.mmcesim.org`. The page title is "mmCESim Web App" with a subtitle "Task-oriented Millimeter Wave Channel Estimation Simulation". Navigation links for "About", "Website", "GitHub", and "v0.0.1" are in the top right. A light blue notification bar at the top states: "The web app is currently under development." Below this is a horizontal menu with icons and labels for "Project", "System", "Channels", "Estimation", "Simulation", and "Report". The "Project" tab is active. The form includes three main sections: "Project Name" with a text input field containing the placeholder "Project name (also output file name)"; "Author Name (Optional)" with a text input field containing the placeholder "Author name"; and "Descriptions (Optional)" with a large text area containing the placeholder "You may describe your project here." At the bottom right of the form are three buttons: "Cancel", "Generate" (highlighted in green), and "Save Config". A footer at the very bottom reads: "Developed, designed and hosted by Wuqiong Zhao. © 2022 Wuqiong Zhao (Teddy van Jerry), Southeast University".

Figure 5.1: Web app interface.



# ALG Language

# 6

## 6.1 Data Type

### 6.1.1 Why Need Data Type

Languages Python and Matlab/Octave are weakly typed which can be convenient for writing the code. However, that is problematic for implementation. The efficiency is not satisfactory compared to C++, and sometimes you may encounter ambiguous error information in Matlab. Therefore, for the sake of efficiency and generality, ALG language is designed to be **strongly typed**.

### 6.1.2 Structure

The type specification is very simple, because ALG language concentrates on matrices. Basically, the structure of ALG language is

**prefix + dimension + suffix.**

For example, f2c means a matrix (dimension is 2) with data type as float and property as a constant.

### 6.1.3 Specifiers

#### 6.1.3.1 Prefix

**Basic Type Prefix** Basic type just names the element type. They are shown in Table 6.1.

Table 6.1: ALG variable basic type prefix.

Prefix	Type	C++ Type	Python Type	MATLAB/Octave Type
c	Complex	<code>cx_double</code>	<code>complex</code>	<code>complex</code>
f	Float	<code>double</code>	<code>double</code>	<code>double</code>
i	Integer	<code>int</code>	<code>int</code>	<code>int64</code>
u	Unsigned Integer	<code>uword</code>	<code>uint</code>	<code>uint64</code>
b	Boolean	<code>bool</code>	<code>bool</code>	<code>logical</code>
s	String	<code>std::string</code>	<code>str</code>	<code>string</code>
h	Character	<code>char</code>	<code>char</code>	<code>char</code>

Table 6.2: ALG variable alias prefix.

Alias Prefix	Type	Equivalent Two-character Type
v	(Column) Vector	c1
r	Row Vector	c2
m	Matrix	c2
t	Tensor	c3
d	Double	f0

**Alias Prefix** Alias prefixes not only set the element type, but also the dimension. They are the one character alias for a two-character type. A list of alias prefixes is shown in Table 6.2.

! v, r, m and t are all for **complex** types. For a non-complex type, you need to use the normal two-character way.  
 ! Row vector (r) is actually regarded as a matrix for simplicity, so its dimension is still 2. Only column vector (c) is the real vector. But there can be differences in terms of **INIT**, so it should not be confused with m.

#### 6.1.3.2 Dimension

Dimensions range from 0 to 3. Details are shown in Table 6.3.

Table 6.3: ALG variable dimension.

Dimension	Type	C++ Type
0	Scalar	—
1	Vector	Col
2	Matrix	Mat
3	Tensor	Cube

! Dimension for a scalar can not be omitted.

Please note that matrices are stored in **column major** order, which is the default order in C++ (Armadillo) and Matlab/Octave. In Python (NumPy), it is equivalent to the option `order='F'`.

! You should always remember the column **major order**, especially if you use are accustomed to Python.  
 ! The order will make a big difference to matrix reshape and vectorization.

#### 6.1.3.3 Suffix

All suffixes of ALG variables are shown in Table 6.4.

Table 6.4: ALG variable suffix.

Suffix	Meaning	C++	Python	MATLAB/Octave
c	Constant	<code>const</code>	(None)	<code>persistent</code>
r	Reference	<code>reference</code>	(None)	(None)

#### TIP

Two suffixes cannot be used together and there is also no need to do so. The use of `r` is mainly in function, allowing a parameter to be changed inside the function body.

## 6.2 Function

### 6.2.1 Syntax Basics

The initiative of proposing a new programming language for algorithm implementation is based on the multi-backend design of mmCEsim. The language is specially designed so that it can be exported to C++ (with Armadillo), Python (with NumPy) and MATLAB/Octave easily.

Every line of ALG language calls a function. Let's first have a look at its basic structure before we cover its details.

```
1 ret1::type1 ret2 = FUNC param1 param2::type2 key1=value1 key2=value2::type3 # com.
```

It may look like an assembly language at the first glance, due to all parameters are separated by space. But it is actually much more convenient. Here are some basic rules:

- All tokens are separated by space.
- Function names are in all upper cases, like `CALC`, `WHILE`.
- Indentation does not matter. Blocks are ended with `END`.
- The function line is mainly composed of three parts: **return values**, **function name**, **parameters**, in the left to right direction.
- Some functions may not have return values, and you may also omit the return values. If there are return values, there is a `=` between return values and function names.
- Function name is the first word on the right of `=` (if there are return values) or the first word of line (if there is no return value).
- Like Python, parameters can be passed in by two ways:
  - 1) **value in position**: Like `param1` and `param2` in the above example. Parameters in different positions correspond to different usages in the function. This is the only way in C++.
  - 2) **key and value**: Parameters can also be specified using key and its corresponding value. `value1` and `value2` are passed in using this method. It should be noted that there should be no space around the `=` between key and value.

There are some special cases that parameters are viewed as a whole, for example `COMMENT` and `CALC`.

- If a parameter contains space or special characters, you need to use the double quotes like "param with space" and escape special characters as in C++ and Python.
- You may optionally specify the type of return value and parameters with `::` after the value. For example, in the above example `dtype1`, `dtype2` and `dtype3` are type specifications for `ret1`, `param2` and `value2`, respectively. For more information about data type, please refer to [data type of ALG language](#).
- Like Python, the backslash (`\`) at the end of the line can be used for continuing the function on next line.
- Comments start with the hash (`#`) like Python.

! There should be no space around the `=` between key and value for parameters. For example, `key=val` is valid while `key = val` is forbidden.

Special rules may be applied for different functions. Please refer to the specific documentation for each function.

### 6.2.2 BRANCH

Declare start of the scope of job algorithms.

#### Explanations

This is useful in estimation. Contents between `BRANCH` and `MERGE` will be repeated for different algorithms. So you need to place compressed sensing estimation `ESTIMATE` and `RECOVER` inside.

#### Example

Example of OFDM OMP.

### 6.2.3 BREAK

Break from a block (for `FOR`, `FOREVER`, `LOOP`, `WHILE`).

#### Explanations

The same as `break` in C++, Python and MATLAB/Octave. This function takes no parameter.

#### Example

Example with `FOREVER`.

### 6.2.4 CALC

Make arithmetic calculations.

#### Explanations

There are two kinds of `CALC` usage: **inline** and **standalone**:

- **inline**: The contents to be calculated are placed in a set of dollar signs, like  $\text{\LaTeX}$  syntax:  $\$some\ operations \rightarrow to\ be\ calculated\$$ .
- **Standalone**: This is like a normal function, with function name as `CALC`. You may also omit the function name `CALC` since it is the default function name if nothing is specified. Therefore, `result = CALC your expression` is equivalent to `result = your expression`.

For more information about the `CALC` syntax, please refer to §6.3.

! For safety, you should not use anything other than ANSI characters in `CALC` functions. Otherwise, there can be undefined behaviour.

If you want the calculation result to be a new variable, you may use function `NEW`.

#### Example

##### EXAMPLE 6.1 (Example of CALC)

```
1 a = CALC b + 2 # explicit CALC function
2 a = \sin(b) @ c # implicit CALC function
3 a = b^H + c^{-1} # conjugate transpose and inverse
4 c = b_{2, 3} # get element of a matrix
5 c = \abs{b_{:, 3}} + \pow(b_{}, 2) # use : in subscript & use {} for function
6 \exp2(a + c .* d) ./ e^T -f_{:,3,1:index} # element-wise operator and
   \rightarrow subscript : range
```

##### Equivalent C++ Code

```
1 a = b + 2;
2 a = arma::sin(b) * c;
3 a = b.t() + c.i();
```

```

4 c = b(2, 3);
5 c = arma::abs(b(arma::span::all, 3)) + arma::pow(b, 2);
6 arma::exp2(a + c % d) / e.st() - f(arma::span::all, 3, arma::span(1, index));

```

### 6.2.5 CALL

Call a custom function defined by **FUNCTION**.

### 6.2.6 COMMENT

Place a line of comment in the exported code.

#### Explanations

All contents after the function keyword **COMMENT** are considered as comments.

#### Example

##### EXAMPLE 6.2 (Example of COMMENT)

```
1 COMMENT Hi, this is a comment!
```

##### Equivalent C++ Code

```
1 // Hi, this is a comment!
```

##### Equivalent Python Code

```
1 # Hi, this is a comment!
```

##### Equivalent MATLAB/Octave Code

```
1 % Hi, this is a comment!
```

### 6.2.7 CPP

Write standard C++ contents.

#### Explanations

All contents after the **CPP** keywords are copied to exported codes. For backend other than C++, this function is ignored.

#### Example

##### EXAMPLE 6.3 (Example of CPP)

```
1 CPP std::cout << "Standard C++ Language!" << std::endl;
```

##### Equivalent C++ Code

```
1 std::cout << "Standard C++ Language!" << std::endl;
```

For Python, MATLAB/Octave, nothing will happen with the **CPP** function.

### 6.2.8 ELSE

Used in **IF** blocks.

### Explanations

This function implements as `else` in C++, Python and MATLAB/Octave. There is no parameter for the `ELSE` function.

### Example

Example with `IF`.

#### 6.2.9 END

End of a block for `ELSE`, `ELIF`, `FUNC`, `FOREVER`, `IF`, `LOOP`, `WHILE`.

### Explanations

In C++, this functions as `}`, in Python it is the indentation goes back for one block. In MATLAB/Octave, it is the `end` specification.

### Example

Example with `FOR`, `FOREVER`, `IF`, `LOOP`, `WHILE`.

#### 6.2.10 ESTIMATE

`CALL standard ALG functions` to estimate the sparse channel with compressed sensing (CS).

#### 6.2.11 FUNCTION

Start a function definition.

### Explanations

The function requires an `END` to mark the end of the function.

#### 6.2.12 IF

Conditional statement.

## 6.3 Calculation (CALC)

## 6.4 Macro

## 6.5 ALG Library



# III

## TUTORIALS

Step-by-step guide on using mmCEsim.



# Millimeter Wave Channel Estimation



Millimeter wave channel estimation for multiple input multiple output (MIMO) systems techniques are discussed in [2].



## CLI Application Tutorials





## GUI Application Tutorials







# Web Application Tutorials | 10



## VS Code Extension Tutorials

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## APPENDIX

Additional information about mmCEsim.



# Additional Resources



## A.1 Publications

A brief introduction of mmCEsim is given in the [poster](#) at the 2022 National Postdoc Seminar in Nanjing, which I attend as the only undergraduate student, and got the Honorable Mention award.

This document is also published online at <https://pub.mmcesim.org/mmCEsim-doc.pdf>.

## A.2 Websites

### A.2.1 For Users

If you are the user of mmCEsim and wants to know more, you may find the following websites in Table A.1 useful.

Table A.1: Websites for users.

Website	URL
Homepage	<a href="https://mmcesim.org">https://mmcesim.org</a>
Web Application	<a href="https://app.mmcesim.org">https://app.mmcesim.org</a>
Blog	<a href="https://blog.mmcesim.org">https://blog.mmcesim.org</a>
Publications	<a href="https://pub.mmcesim.org">https://pub.mmcesim.org</a>
VS Code Extension	<a href="https://marketplace.visualstudio.com/items?itemName=mmcesim.mmcesim">https://marketplace.visualstudio.com/items?itemName=mmcesim.mmcesim</a>

### A.2.2 For Developers

If you are a developer and maybe want to contribute to the mmCEsim project, you can find additional websites in Table A.2.

Table A.2: Websites for developers.

Website	URL
GitHub Organization	<a href="https://github.com/mmcesim">https://github.com/mmcesim</a>
C++ Dev Documentation	<a href="https://dev.mmcesim.org">https://dev.mmcesim.org</a>
CLI App Wiki	<a href="https://github.com/mmcesim/mmcesim/wiki">https://github.com/mmcesim/mmcesim/wiki</a>





# Change History | B

**B.1 HEAD** ..... 2023/01/04

**B.2 v0.1.0** ..... 2022/10/16

## New Features

- Basic mmWave MIMO systems channel estimation support;
- Design of ALG language;
- Export of code with Armadillo library;
- Auto simulation ([#5](#)).

**B.3 v0.0.1** ..... 2022/07/27

Though the app has not been fully developed, the task-oriented concept has already been established.



# Bibliography

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- [1] Q. Wu and R. Zhang, "Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network", *IEEE Commun. Mag.*, vol. 58, no. 1, pp. 106–112, Jan. 2020.
- [2] J. Lee, G.-T. Gil, and Y. H. Lee, "Channel estimation via orthogonal matching pursuit for hybrid MIMO systems in millimeter wave communications", *IEEE Trans. Commun.*, vol. 64, no. 6, pp. 2370–2386, Jun. 2016.



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