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Reducing the Traffic in the Control Loop for the Robot Arm (OS+PBL)

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Contents
Reducing the Traffic in the Control Loop for the Robot Arm

1 Introduction
1.1 The Reason to reduce the Traffic

1.1.1 A lot of redundant information the class franka::RobotState [1]

— All the members in the class franka::RobotState, the size is more than 2000 Bytes.

O_T_EE	F_x_Cload	tau_J	cartesian_contact	O_ddP_EE_c
O_T_EE_d	m_total	tau_J_d	joint_collision	theta
F_T_EE	I_total	dtau_J	cartesian_collision	dtheta
EE_T_K	F_x_Ctotal	q	tau_ext_hat_filtered	current_errors
m_ee	elbow	**q_d**	O_F_ext_hat_K	last_motion_errors
I_ee	elbow_d	dq	K_F_ext_hat_K	control_command_success_rate
F_x_Cee	elbow_c	dq_d	O_dP_EE_d	robot_mode
m_load	delbow_c	ddq_d	**O_T_EE_c**	time
I_load	ddelbow_c	joint_contact	O_dP_EE_c	

1 Introduction
1.1 The Reason to reduce the Traffic

1.1.1 A lot of redundant information the class franka::RobotState [1]
— The libfranka provide ways to control the robot, in the offical examples there are only 2 members are used.

Joint Positions - robot_state.O_T_EE_c (desired joint position)

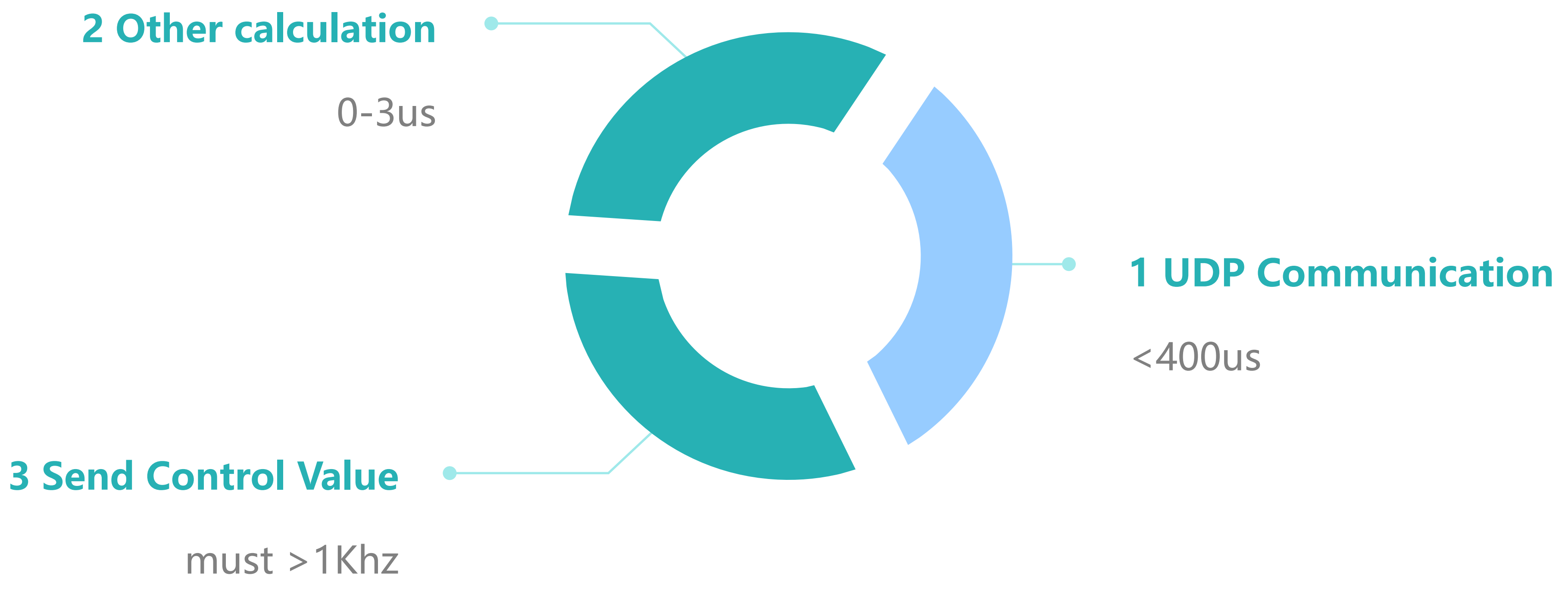
Joint Velocity

Cartesian Pose - robot_state.q_d (cartesian position)

Cartesian Velocities

1 Introduction
1.1 The Reason to reduce the Traffic

1.1.2 The limit of time consumption of UDP communication in control loop



1 Introduction
1.2 Two ways of Reducing the traffic

1.2.1 Extracting the useful data to reduce the sending/receiving data

More than 2000 Bytes

136 Bytes

1 Introduction
1.2 Two ways of Reducing the traffic

1.2.2 Improve the perfromance of UDP communication

A Using boost library [2]

B Based on C UDP [3]
Low level programing

C Asynchronous UDP communication

2 Data Processing
2.1 Data Extraction

2.1.1 Extracting the useful data

— Convert the useful data to a chary array

```
uchar8t *mStrCpy(uchar8t *&pre, uint32t copy_length, const uchar8t *dst)
{
    for (uint32t i = 0; i < copy_length; i++)
        *pre++ = *dst++;
    *(pre) = '\0';
    return pre;
}

uchar8t *string_process_position;
template <class T>
uchar8t *SPAddData(T &robot_state)
{
    return mStrCpy(string_process_position, sizeof(robot_state), (uchar8t *)(&robot_state));
}
```

2 Data Processing
2.1 Data Extraction

2.1.1 Extracting the useful data

— Convert the useful data to a chary array

```
uint32t length;
uchar8t *send_data;

DPInit();
SPAddData(robot_state.O_T_EE_c);
SPAddData(robot_state.q_d);
......
GetSendData(send_data, length);
```

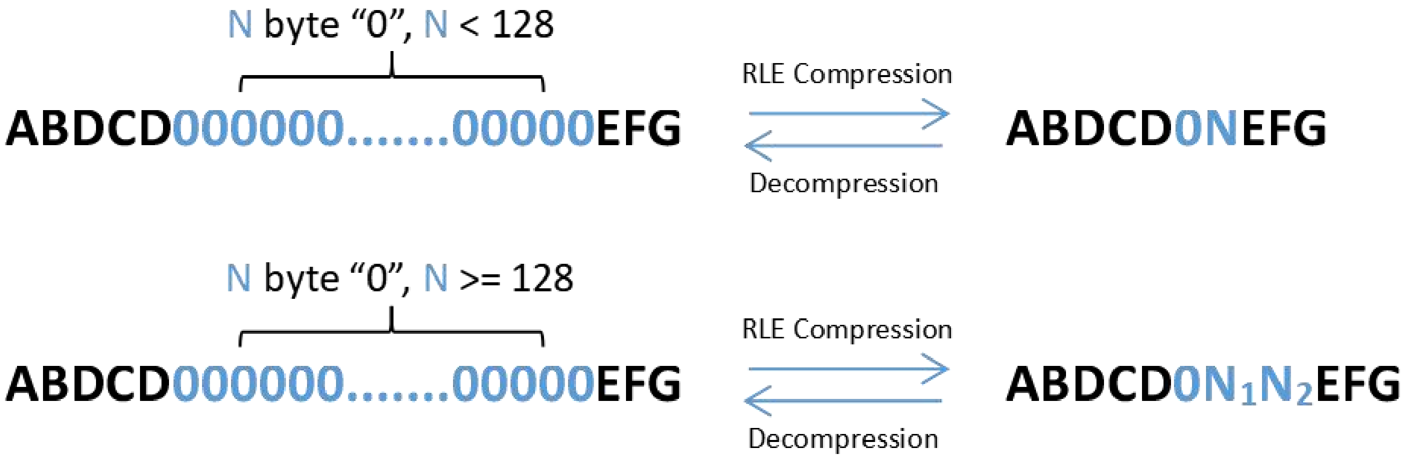
The **send_data**, **length** can be directly used by UDP communication.

2 Data Processing
2.2 Fast RLE Compression

2.2.1 The fast run-length Encoding Compression

- Further reduce the amount of data sent through the UDP

- N_1 = (N % 128) | 0x80
- N_2 = N / 128
- N is the number of zeros.



2 Data Processing
2.2 Fast RLE Compression

2.2.2 The performace of fast run-length Encoding Compression

— Tested data (std::array<double, 16>):

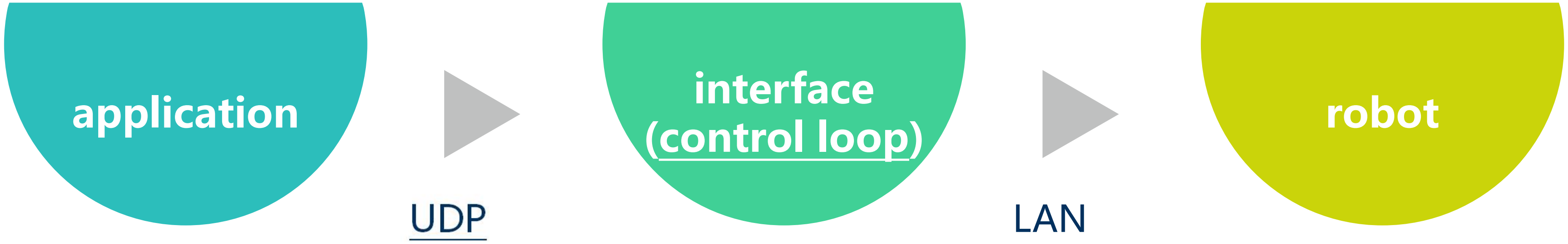
robot_state.O_T_EE_c = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -0.999023, 0, -0.00810967, 0, 0};

Compress method		Quicklz[4]	Zlib[5]	Snappy[6]	RLE
Size (bytes)	Original	128			
	Compressed	41	33	41	**24**
Time (us)		101	203	26	**1**

3 UDP Communication
3.1 The UDP Communication in the Whole System

3.1 How to improve the performance of UDP communication

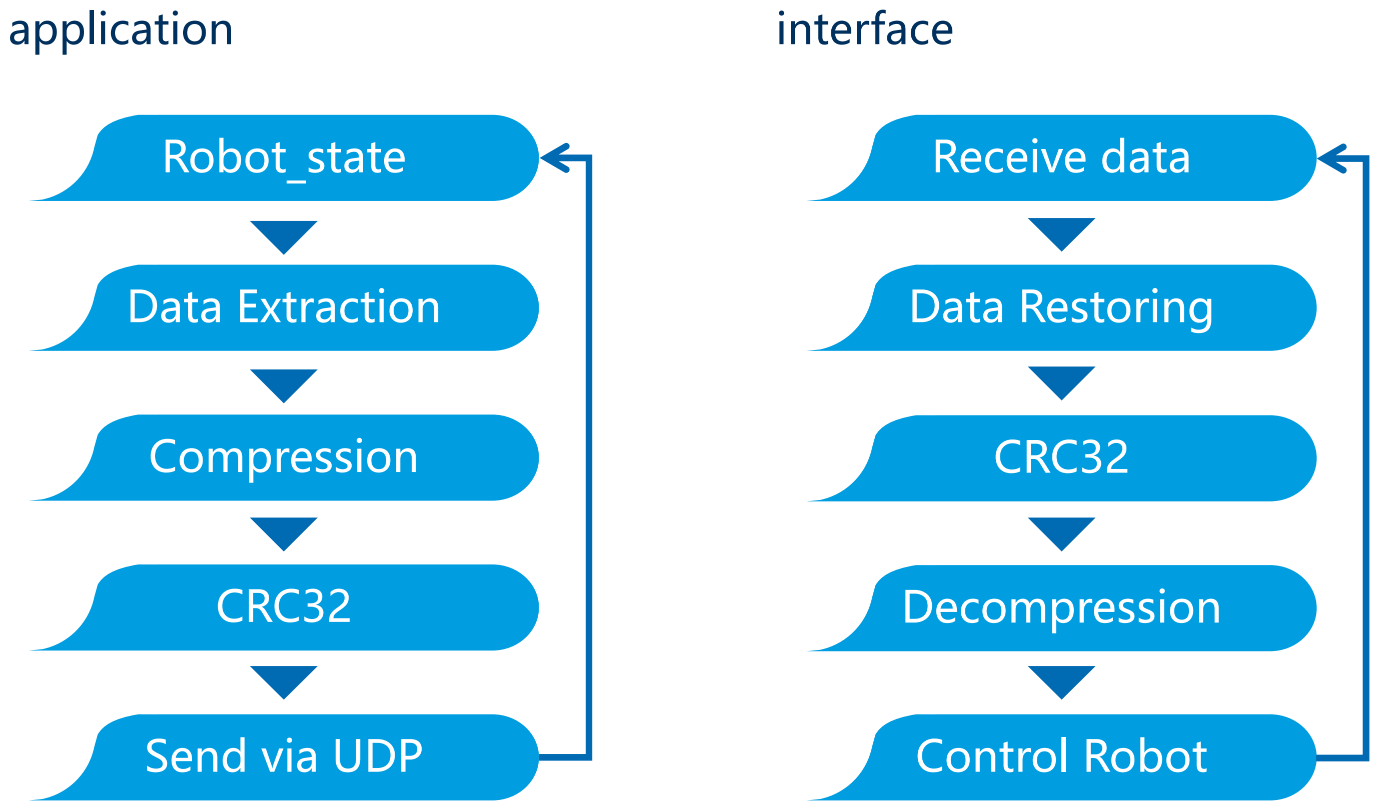
- 1. UDP communication between Application and Interface
- 2. Time consumption in the control loop



3 UDP Communication

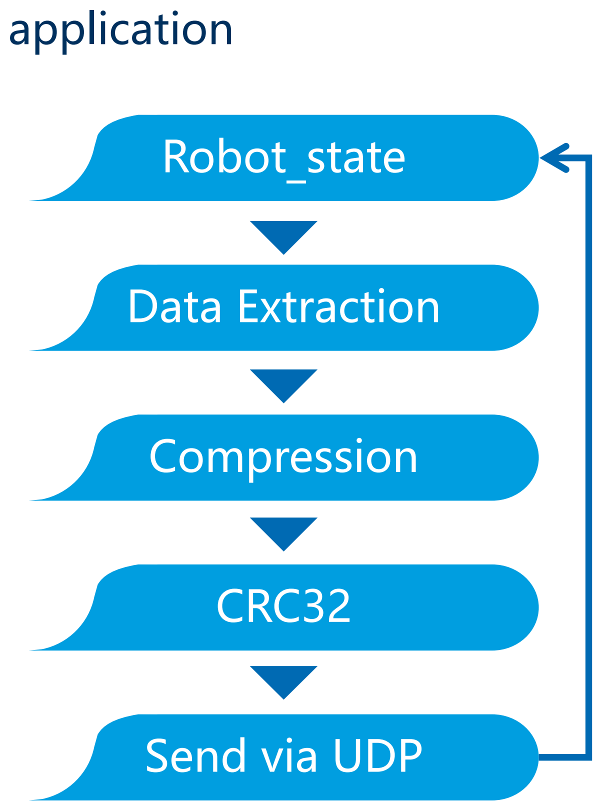
3.2 The first synchronous UDP Communication

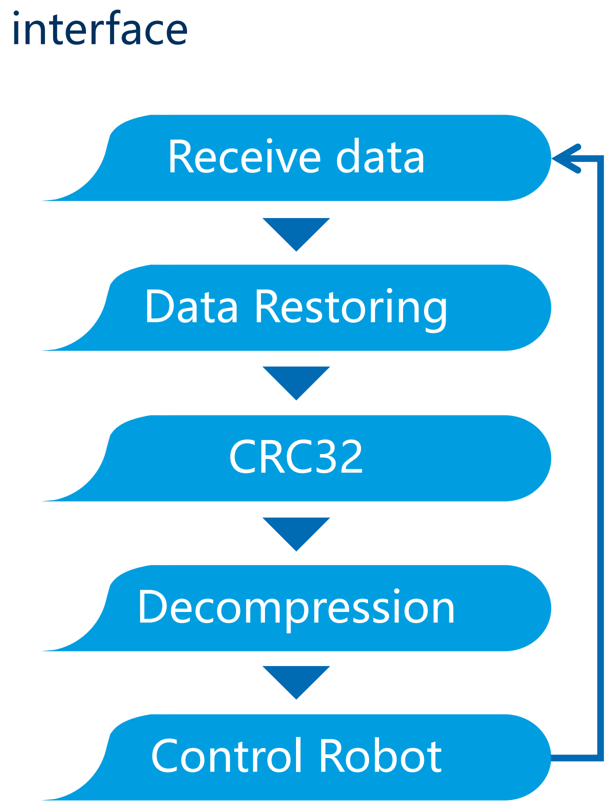
3.2.1 Structure of the first synchronous UDP commnuication



3 UDP Communication
3.2 The first synchronous UDP Communication

3.2.1 Structure of the first synchronous UDP commnuication





Advantage:

small quantity of the sent data

data reliability

Easy to set up Communication

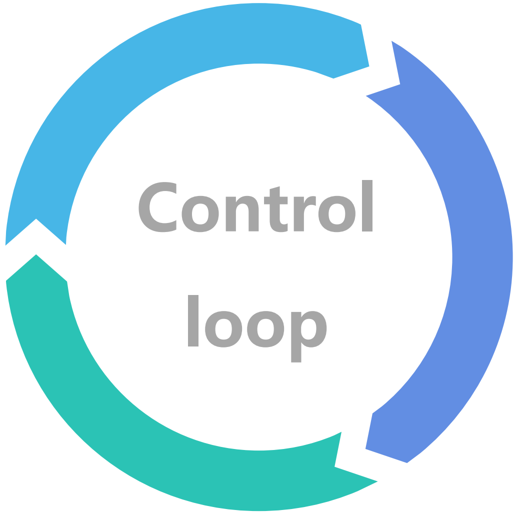
Disadvatage:

Computational complexity

3 UDP Communication
3.2 The first synchronous UDP Communication

3.2.2 Time consumption in the control loop for the robot am

1. Receive the data (400-1000us)



2. Send data (32-200us)

3. Control the Robot

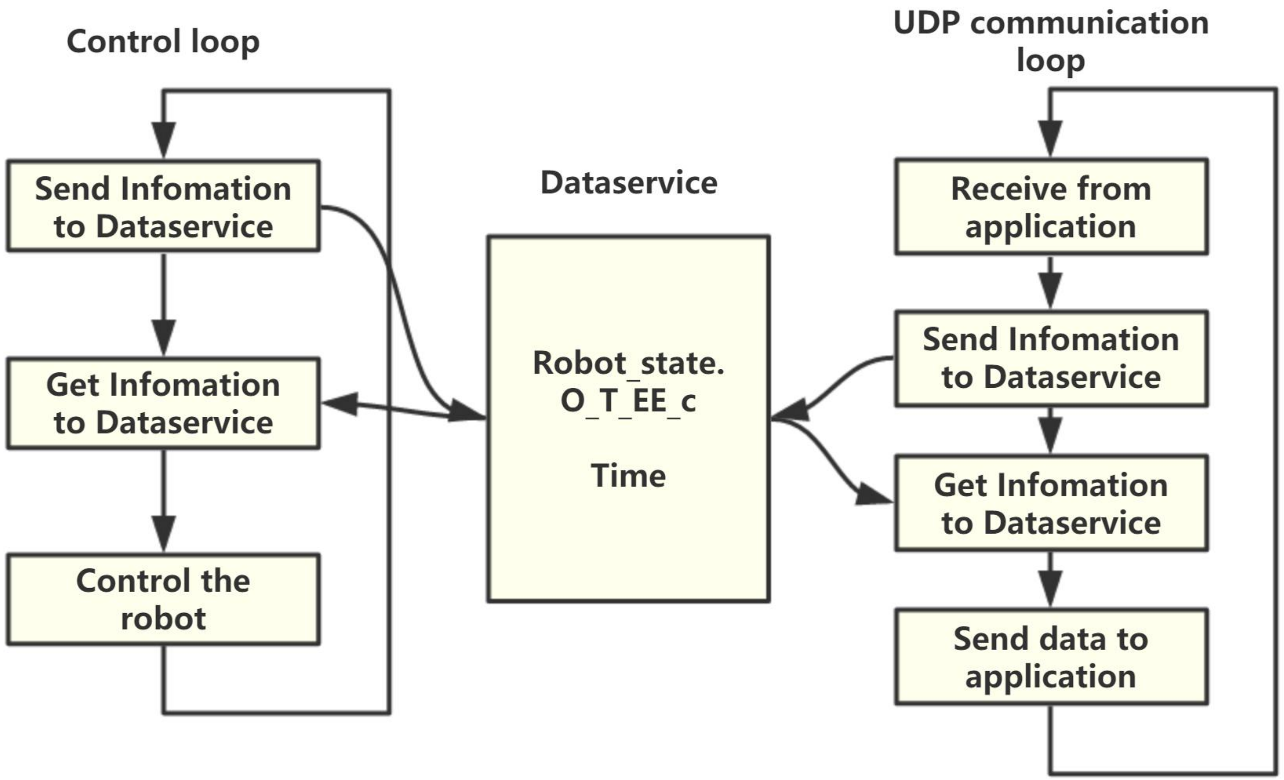
3 UDP Communication
3.2 The first synchronous UDP Communication

3.2.3 The results

- The robot arm aborted
- Reason: The receiving and sending spend too much time in the control loop.
- **Next Step:** Using asynchronous UDP communication

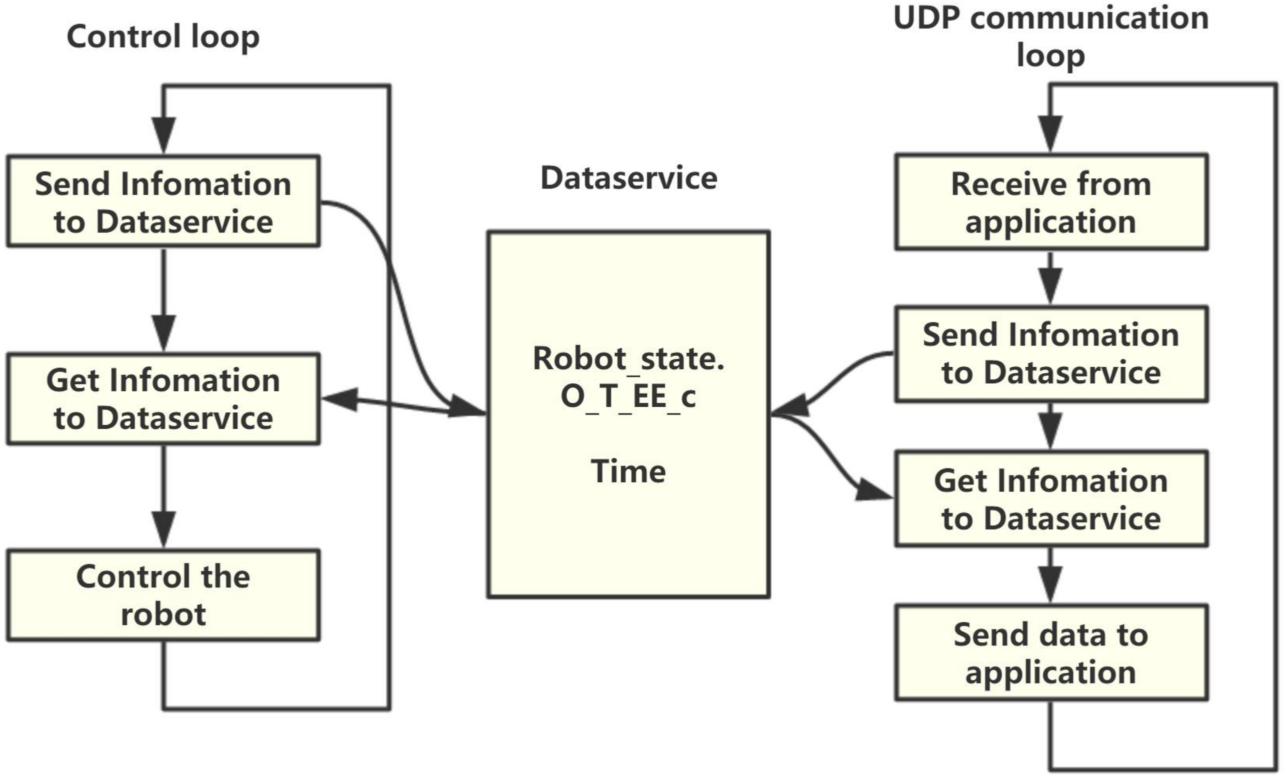
3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.1 Structure of the asynchronous UDP commnuication - 1
— The structure of the interface program



3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.1 Structure of the asynchronous UDP commnuication - 1
— The structure of the interface program



Advantage:

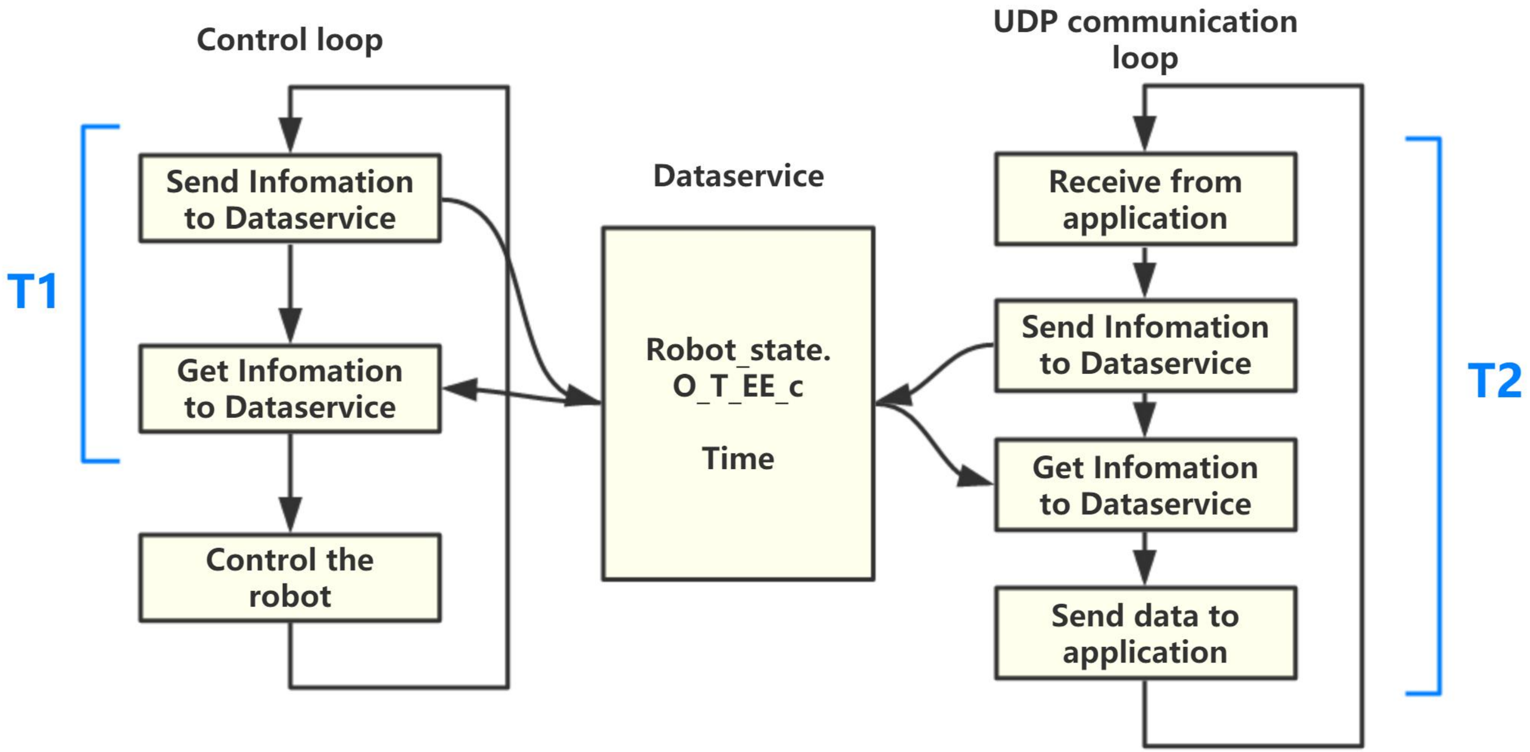
small latency in the control loop

Disadvatage:

large latency of the data through the UDP

3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.2 Performance of the asynchronous UDP commnuication - 1
— Test the values of T1, T2



3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.2 Performance of the asynchronous UDP commnuication - 1

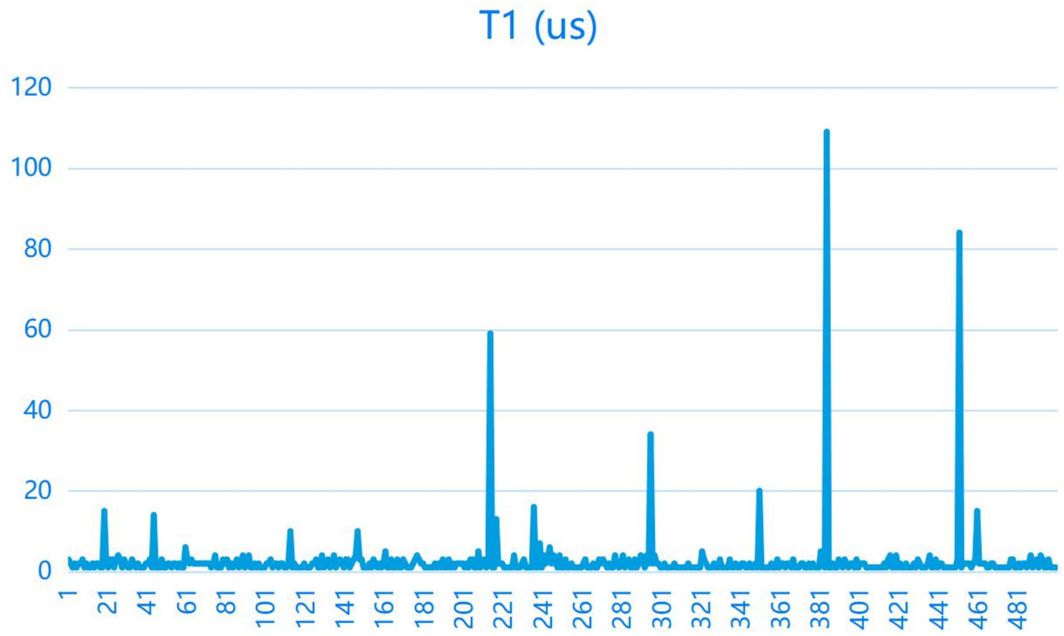
— T1, the time consumption in control loop
— T2, the time consumption communcation loop

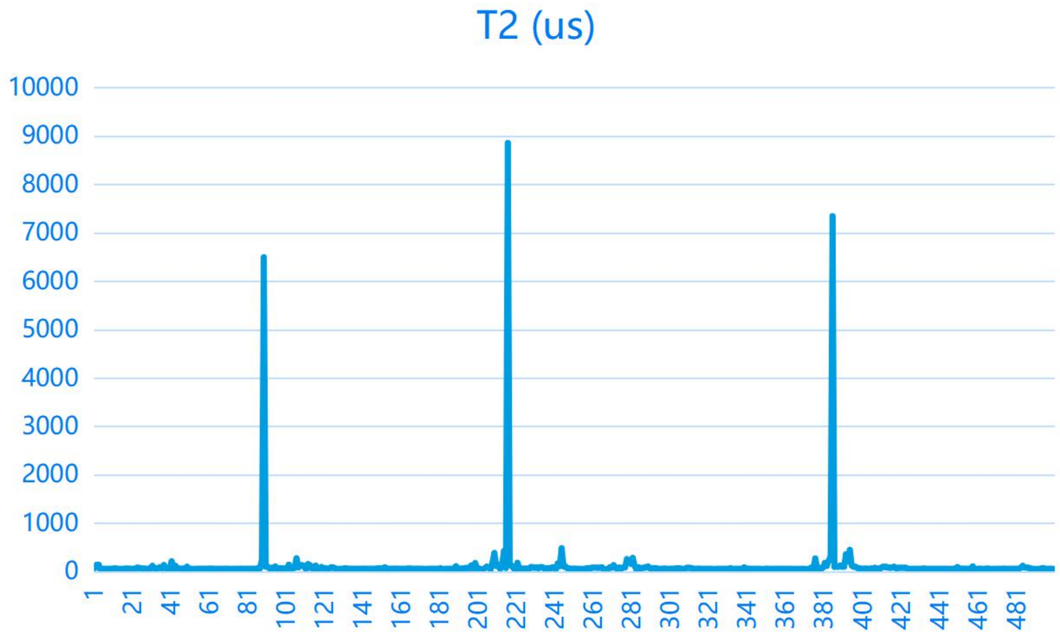
— The sample size is 500.

Time (us)	T1	T2
Average	2.508	119.798
Max	109	8854
Min	1	35

3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.2 Performance of the asynchronous UDP commnuication - 1
— T1, the time consumption in control loop
— T2, the time consumption communcation loop
— The sample size is 500.





3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.3 The results

— The robot arm aborted

— Reason: The discontinuity of acceleration, may be caused by the delay of the command

3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.3 The results

— The code of control loop in the **example**

```
robot.control([&time, &DS](const franka::RobotState &robot_state,
                           franka::Duration period) -> franka::CartesianPose {
    time += period.toSec();
    if (time == 0.0)
    {
        initial_pose = robot_state.O_T_EE_c;
    }
    new_pose = function(time , initial_pose)
    return  new_pose;
});
```

3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.3 The results

— The code of control loop in the **interface application**

```
robot.control([&time, &DS](const franka::RobotState &robot_state,
                           franka::Duration period) -> franka::CartesianPose {
    time += period.toSec();
    if (time == 0.0)
    {
        Dataservice.Init( robot_state.O_T_EE_c, time );
        Dataservice.run();
    }
    Dataservice.UpdateSendData( robot_state.O_T_EE_c, time );
    return  Dataservice.RecvState();
     // The received pose is calculated by the  "time"  updated in the previous control loop
});
```

3 UDP Communication
3.3 The asynchronous UDP Communication - 1

3.3.3 The results

- The robot arm aborted by the discontinuity of acceleration

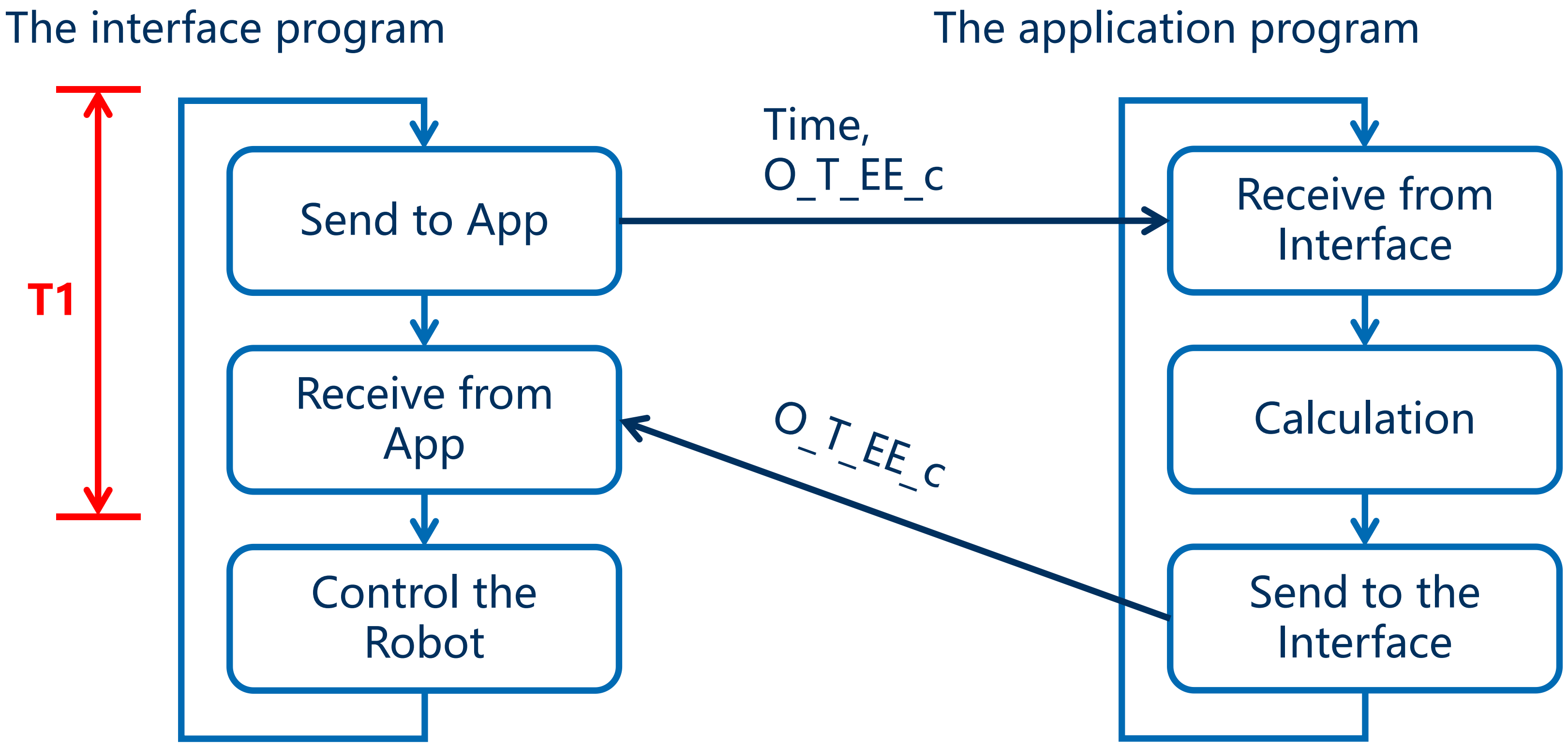
- Reason:
- 1. delay of the command
- 2. period.toSec() is not a constant

- **Next Step:** The simplest and fastest synchronous UDP Commmunication, finisched in one control loop

3 UDP Communication

3.4 The simplest and fastest synchronous UDP Commmunication

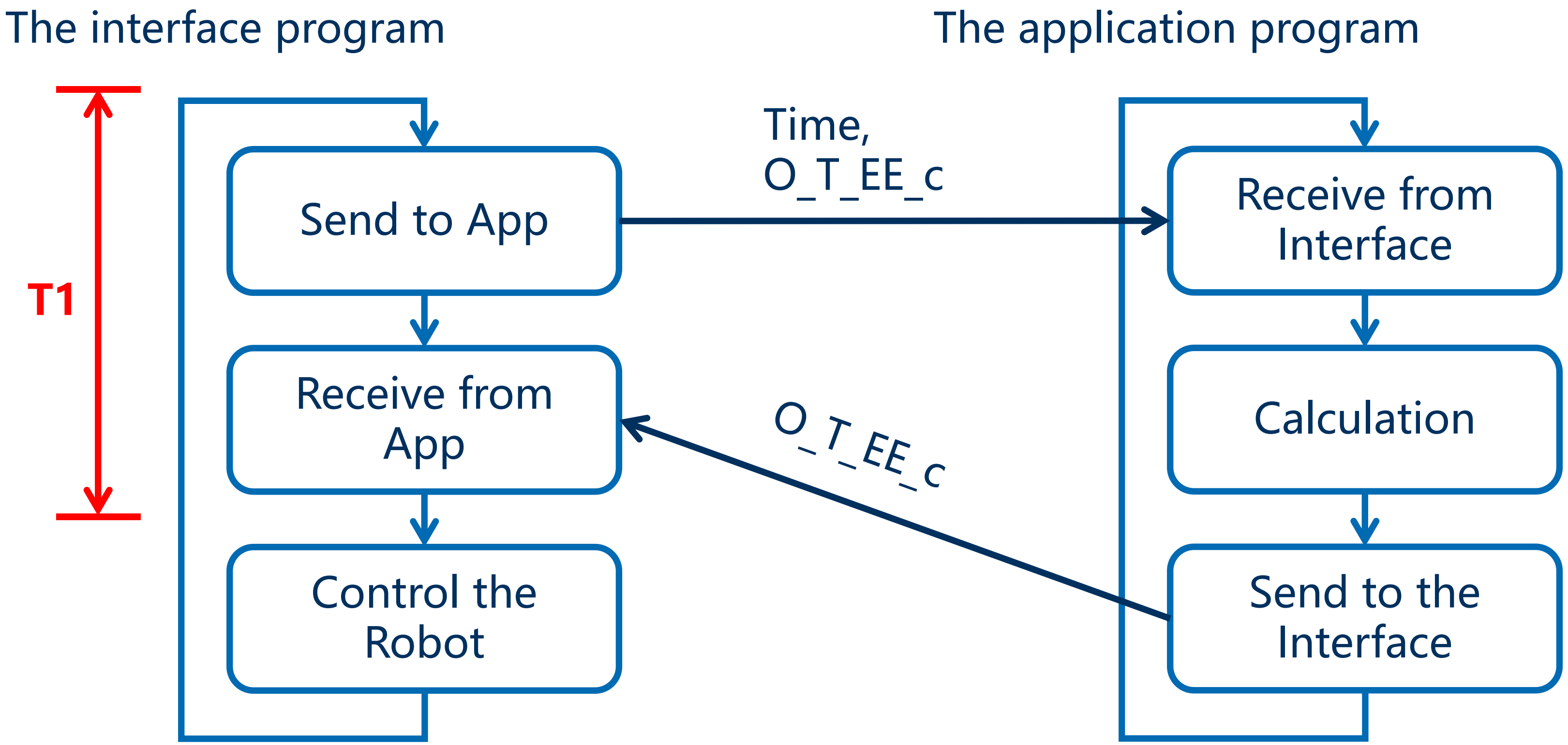
3.4.1 Structure of the simplest and fastest UDP commnuication



3 UDP Communication

3.4 The simplest and fastest synchronous UDP Commmunication

3.4.1 Structure of the simplest and fastest UDP commnuication



Advantage:

fastest way of UDP communication

Disadvatage:

Unstable

3 UDP Communication
3.4 The simplest and fastest synchronous UDP Commmunication

3.4.2 Performance of the simplest and fastest UDP commnuication

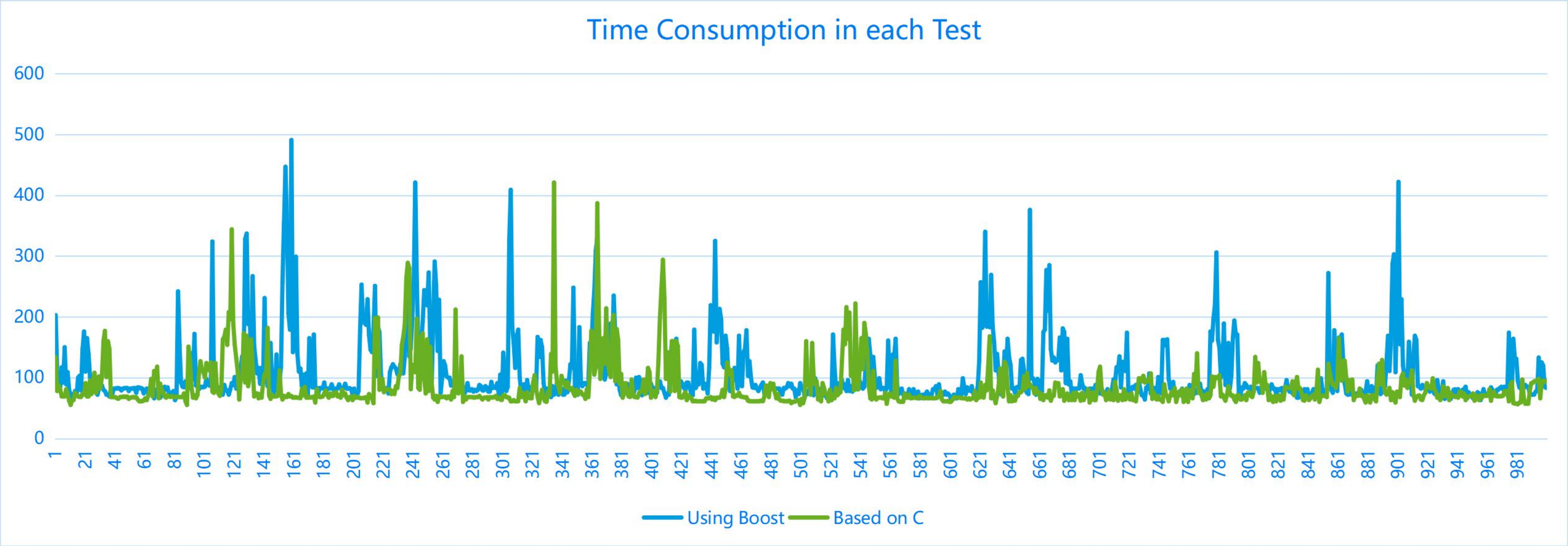
— T1, the time consumption in control loop
— The sample size is 1000.

— 2 Methods of UDP communication: boost library, C

Time T1 (us)	Using boost	Based on C
Average	106.083	83.957
Max	491	421
Min	63	55

3 UDP Communication
3.4 The simplest and fastest synchronous UDP Commmunication

3.4.2 Performance of the simplest and fastest UDP commnuication



3 UDP Communication
3.4 The asynchronous UDP Communication - 1

3.4.3 The results

- The robot arm aborted
- Reason: The discontinuity of acceleration und velocity.
- **Next Step:** To find out the maximum acceptable constant delay in the original example

3 UDP Communication
3.4 The asynchronous UDP Communication - 1

3.4.3 The results

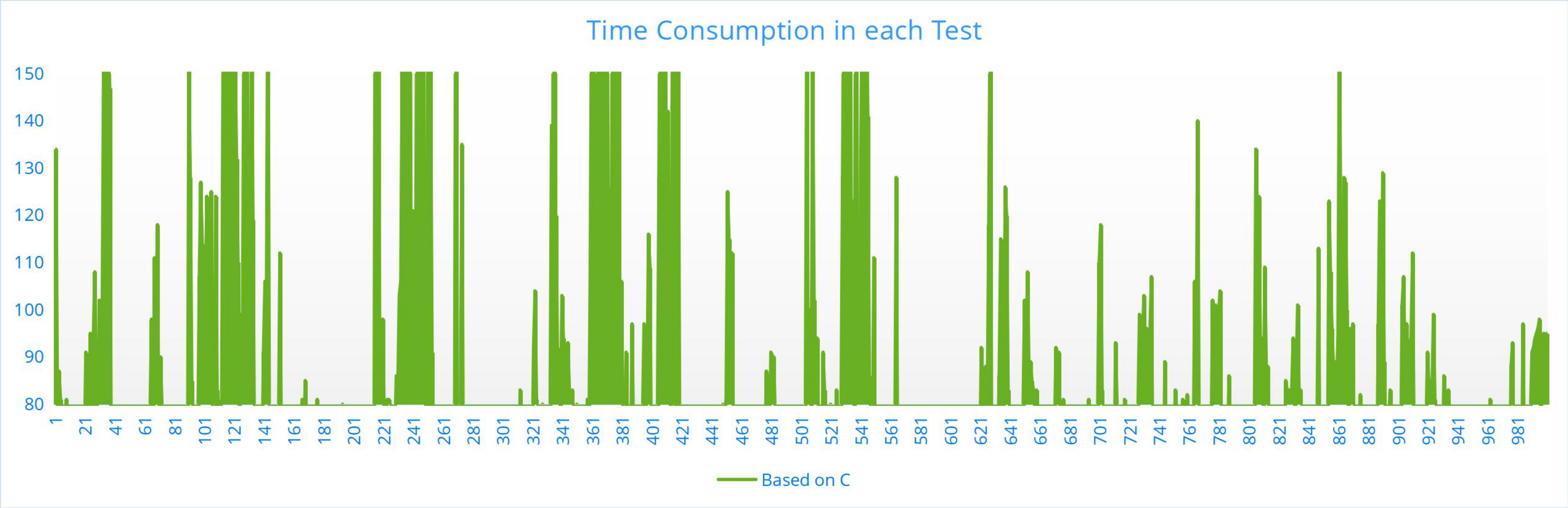
— The code of control loop in the **example**

```
robot.control([&time, &DS](const franka::RobotState &robot_state,
                          franka::Duration period) -> franka::CartesianPose {
    time += period.toSec();
    delayus(80); //The maxium acceptable value is only 80us !!!
    if (time == 0.0)
    {
        initial_pose = robot_state.O_T_EE_c;
    }
    new_pose = function(time , initial_pose)
    return  new_pose;
});
```

3 UDP Communication
3.4 The asynchronous UDP Communication - 1

3.4.3 The results

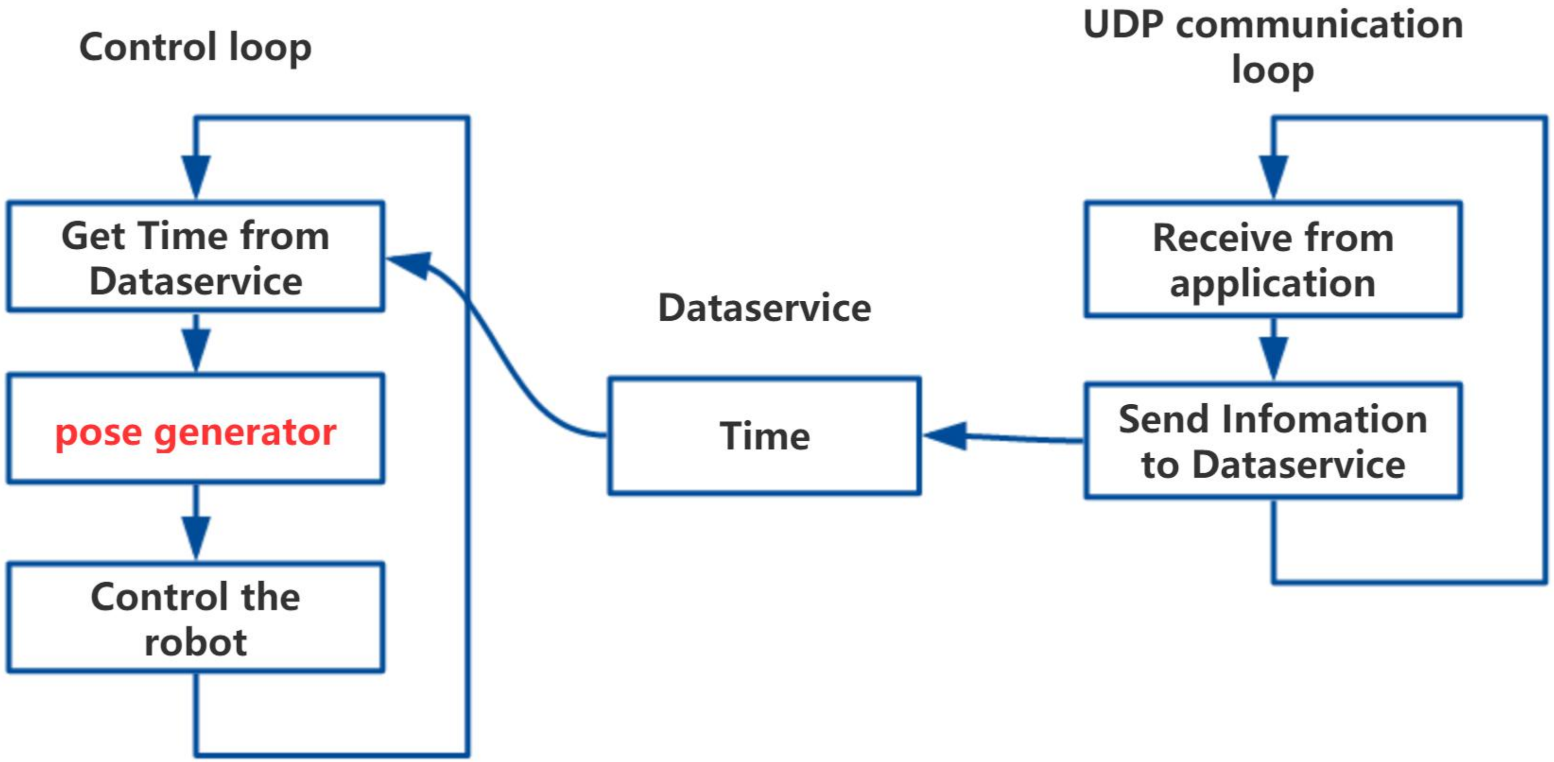
— The delays sometimes have exceeded 80us for a while (more than 20 cycle), which may cause the error.



3 UDP Communication
3.5 The asynchronous UDP Communication - 3

3.5.1 The structure of the asynchronous UDP Communication - 3

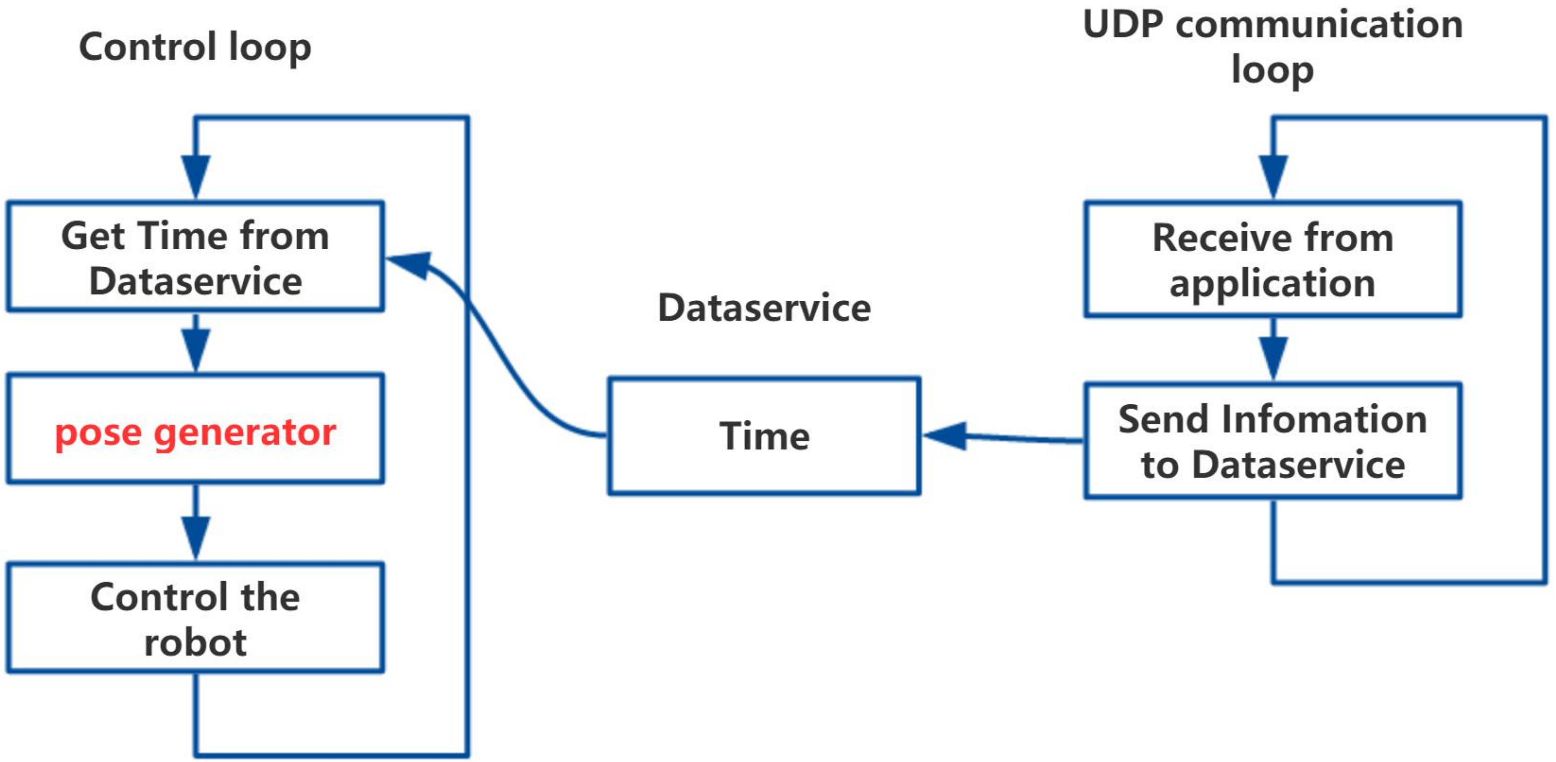
— The structure of the interface program



3 UDP Communication
3.5 The asynchronous UDP Communication - 3

3.5.1 The structure of the asynchronous UDP Communication - 3

— The structure of the interface program



Advantage:

small latency in the control loop

Disadvatage:

large latency of the data through the UDP

Performance:

Similar to the asynchronous UDP Communication - 1

3 UDP Communication
3.5 The asynchronous UDP Communication - 3

3.5.1 The structure of the asynchronous UDP Communication - 3

```
— robot.control([&time, &DS](const franka::RobotState &robot_state,
—                            franka::Duration period) -> franka::CartesianPose {
—     time_period = period.toSec();
—     command_time=DS.RecvCommand();
—     TimeGenerator(current_time, command_time, time_period);
—     double angle_x = M_PI / 4 * (1 - std::cos(M_PI / 5.0 * current_time));
—     double delta_x = kRadius * std::sin(angle_x);
—     std::array<double, 16> new_pose = initial_pose;
—     new_pose[12] += delta_x;
—     new_pose[14] += delta_z;
—     DS.UpdateSendData(current_time,robot_state.O_T_EE_c);
—     return new_pose;
—   });
```

3 UDP Communication

3.5 The asynchronous UDP Communication - 3

3.5.1 The structure of the asynchronous UDP Communication - 3

```
void TimeGenerator( double &current_time, double target_time, double period )
{
    double time_interval = target_time - current_time;
    if( time_interval > period )
    {
        current_time += period;
    }
    else if( -time_interval > period )
    {
        current_time -= period;
    }
}
```

3 UDP Communication
3.5 The asynchronous UDP Communication - 3

3.5.1 The Results

— This may be the only program that can “run” with the robot.

— Problem is that

— Only run successfully when the application send a large command time to the interface at first

— When the value of current time of the robot grows or decreases close to the value of command time, the robot will abort by the acceleration.

— **Why always the acceleration ?!!**

4 Problem Discussion
To find out the acceleration problem

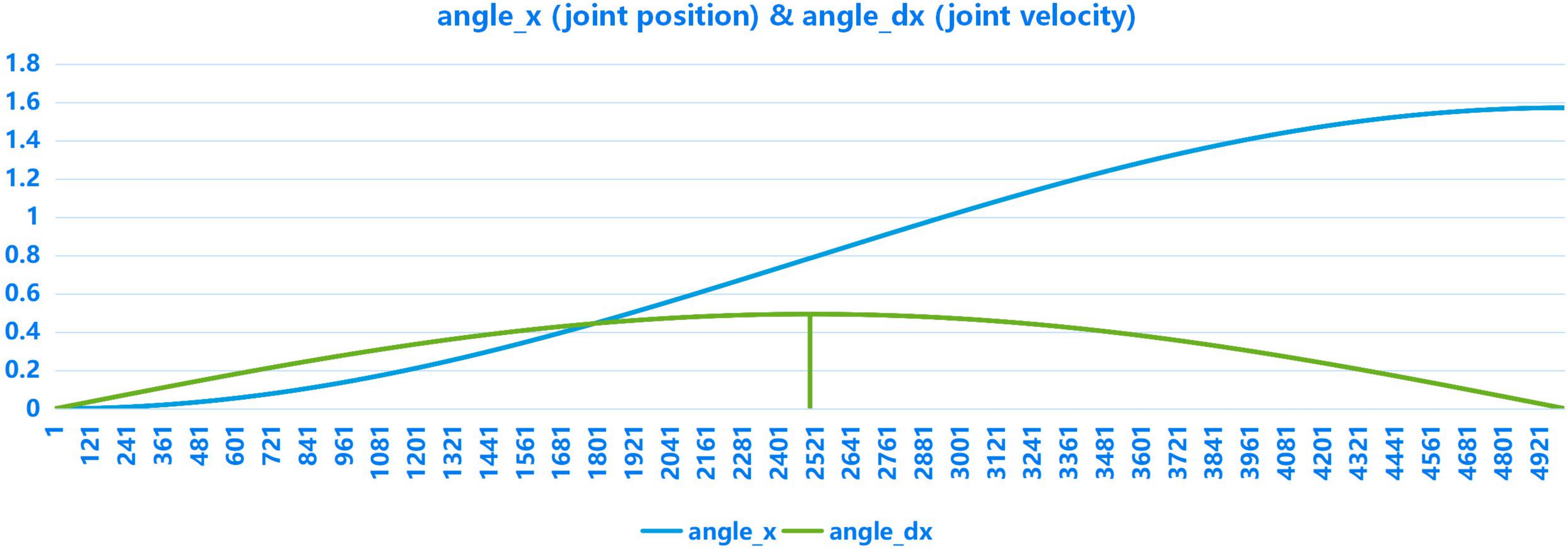
4.1 Simulate the change of the robot's motion parameters

- The value of period.toSec() is specially defined as 0.001, all the initial values are 0

```
for(int i=0;i<5000;i++)
{
    angle_x1 = M_PI / 4 * (1 - std::cos(M_PI / 5.0 * time));
    if(i!=2500)time+=0.001;  //          time+=0.001; - ideal case
    angle_dx1 = (angle_x1-angle_x2)/0.001;
    angle_x2 = angle_x1;
    angle_ddx1 = (angle_dx1-angle_dx2)/0.001;
    angle_dx2 = angle_dx1;
    angle_dddx1 = (angle_ddx1-angle_ddx2)/0.001;
    angle_ddx2 = angle_ddx1;
}
```

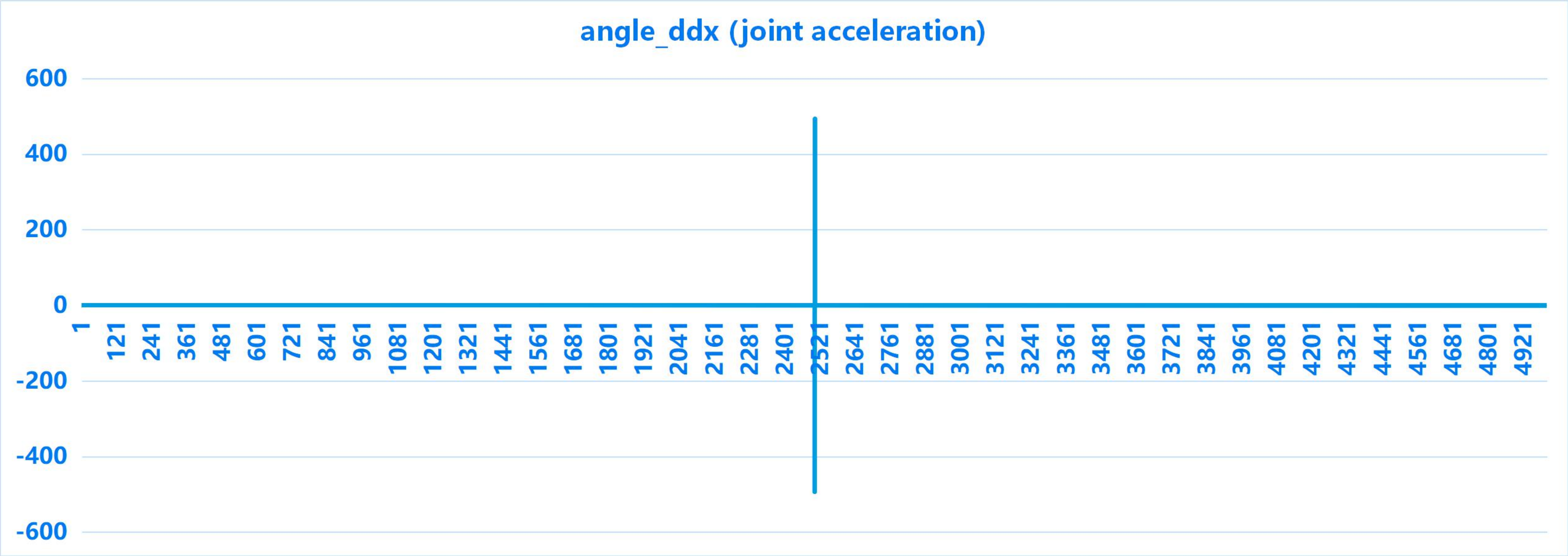
4 Problem Discussion
To find out the acceleration problem

4.3 Change of the robot's motion parameters - lost a command in one control loop



4 Problem Discussion
To find out the acceleration problem

4.2 Change of the robot's motion parameters - lost a command in one control loop

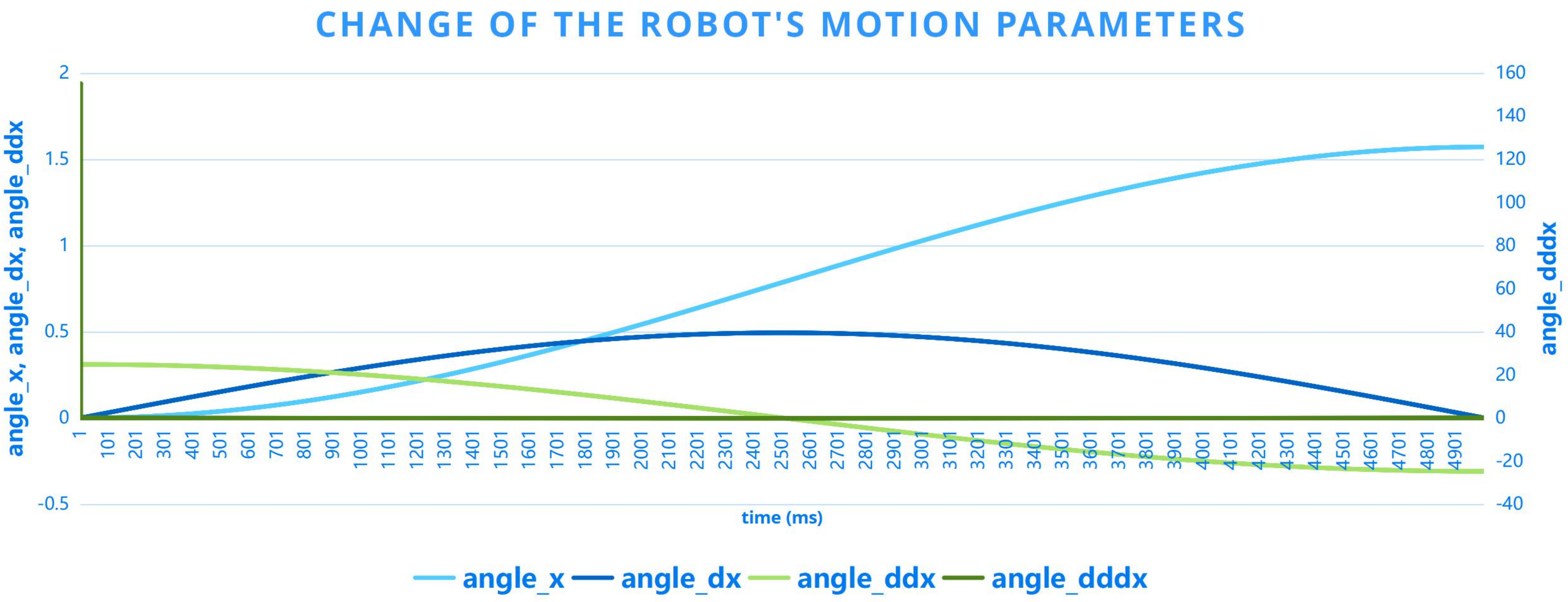


4 Problem Discussion
To find out the acceleration problem

4.2 Change of the robot's motion parameters - lost a command in one control loop

4 Problem Discussion
To find out the acceleration problem

4.3 Change of the robot's motion parameters - ideal case



4 Problem Discussion
To find out the acceleration problem

4.4 Compare to the limit of the official website [7]
— The results in the 4.2 greatly exceed the limit

Name	Translation	Rotation	Elbow
$\dot{p}_{max}$	$1.7000\ \frac{\mathrm{m}}{\mathrm{s}}$	$2.5000\ \frac{\mathrm{rad}}{\mathrm{s}}$	$2.1750\ \frac{rad}{\mathrm{s}}$
$\ddot{p}_{max}$	$13.0000\ \frac{\mathrm{m}}{\mathrm{s}^2}$	$25.0000\ \frac{\mathrm{rad}}{\mathrm{s}^2}$	$10.0000\ \frac{rad}{\mathrm{s}^2}$
$\dddot{p}_{max}$	$6500.0000\ \frac{\mathrm{m}}{\mathrm{s}^3}$	$12500.0000\ \frac{\mathrm{rad}}{\mathrm{s}^3}$	$5000.0000\ \frac{rad}{\mathrm{s}^3}$

5 Conclusions
Of reducing the Traffic in the Control Loop for the Robot Arm

5.1 Three Tips for the UDP communication in the interface application

— 1. A synchronous UDP Communication because of its unstable and delay could not be directly used in the robot control loop.

— 2. The robot can’ t directly controlled by a determined pose, by which, the lost of the packets could cause large acceleration and jerk exceed the limit.

— 3.It is important to make the robot mildly speed up and slow down, because the limit of the robot is very strict.

5 Conclusions
Of reducing the Traffic in the Control Loop for the Robot Arm

5.2 Solution for acceleration probem

- **In the example:**
- time += period.toSec();
- double angle_x = M_PI / 4 * (1 - std::cos(M_PI / 5.0 * time));

- **Now, the new pose should be calculated by the velocity instead of the time**

- velocity = function(v(x-2), v(x-1), desired angle from application);
- double angle_x += period.toSec() * velocity;

- where v(x-2), v(x-1) is the previous velocity, and the function will according to the limit and the desired angle to calculate the optimal speed

5 Conclusions
Of reducing the Traffic in the Control Loop for the Robot Arm

5.3 Solution for acceleration probem

- **In the example:**
- time += period.toSec();
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References
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[7] Robot and interface specifications, Franka Emika GmbH, Retrieved February 24, 2019, from : https://frankaemika.github.io/docs/control_parameters.html

Thank you!