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# Requirements and analysis of Multispectral Volume Scattering Meter

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# 1. Introduction (Sissejuhatus)

## 1.1 Purpose (Eesmärk)

The volume scattering function (VSF), which describes the angular distribution of light scattered from an incident beam, is a fundamental inherent optical property of the aquatic environment. Despite its fundamental nature, there is little known about the range of variability in the VSF in the aquatic environment. This is mainly because the measurements of the function are difficult to perform. A lot of currently used radiate transfer models are based on a very limited set of measurements, which are made over 20 years ago. For the correct calculations of the radiate transfer, it is essential to know the variations of the phase function. Instruments, which have previously been used for measuring VSF, were complicated, bulky and most importantly: they are not able to take measurements of the function in full angular range [1].

The purpose of this document is to describe the system requirements specifications of a Multispectral Volume Scattering Meter (MVSM). Document describes a new instrument for measuring the volume scattering function of seawater and other natural waters across a hemispheric angle range. System requirements and analysis is put together following modern methodology and standards [2].

The measurement principles implemented in the device, are based on static scatter approach. Photomultiplier tube (PMT) is used to detect scattering light at different angles. Device's mechanistic approach involves a use of a special periscope prism and a novel light shadow method.

## 1.2 Business Context (Äriline kontekst)

The documentation in hand is for one of the sub-projects of Plan for European Cooperating State (PECS). The requirements are for the device, which is going to be used in optical radiometry applications for aquatic environment (ORAQUA). ORAQUA is aiming at establishing Nordic reference testing center for optical parameters of aquatic environment, relevant for remote sensing applications. The services include support to whole chain of ground measurements starting with instrument development, ensuring quality control and validation satellite products.

## 1.2 Scope (Ulatus)

Requirements and specifications established in this documents are going to be used to design and build a working device, which is intended to measure volume scattering function of different waters. The second part of the document describes the general requirements for the system and the third part describes the functional and physical requirements.

## 1.3 User Characteristics (Kasutuse iseloomustus)

Scientists who study the radiation and volume scattering function in the aquatic environment will use the device in question. VSF measurements can be performed in two configurations: laboratory water samples and hydrographic deploying. The device is easy to operate by a computer in the laboratory conditions, or by a special control pad in the field conditions. It takes one user to operate the device. The deploying of the device into the water environment can be done by a special crane mechanism attached to the vessel or by hand.

## 1.4 Glossary (Mõisted)

ASCII (American Standard Code for Information Interchange) – Character-encoding scheme based on the ordering of the English alphabet [3].

LED (Light-emitting diode) – An electronic semiconductor device that emits light when an electric current passes through it [4].

Light scattering – Process in which light energy changes direction without loss of energy [1].

MVSM (Multispectral Volume Scattering Meter) – Instrument that measures the volume scattering function of the aquatic environment [5].

PMT (photomultiplier tube) – A sensitive light detector providing current output directly proportional to light intensity [6].

RTOS (Real-time operating system) – Operating system (OS) intended to serve real-time application requests [7].

Static light scattering – Technique that measures the total scattered intensity of a light as a function of angle, concentration, or both [8].

UI (User interface) – Part of a program that controls a display for the user (usually on a computer monitor) and that allows the user to interact with the system [9].

UML (Unified Modeling Language) – Visual language for specifying, constructing and documenting the artifacts of systems [10].

VSF (volume scattering function) – Function that describes the directional dependence of light scattering [1].

## 2. General System Description (Süsteemi üldine kirjeldus)

### 2.1 System Context (Üldkontekst)

Device consists of three hermetically sealed separated sections mutually oriented at 90° – Light Housing, Prism Housing and Photomultiplier (PMT) Housing as well as Measurement Chamber where rotating prism is located and real volume scattering measurements take place. The figure 1.1 gives an overview of the system and defines all significant sections and interfaces.

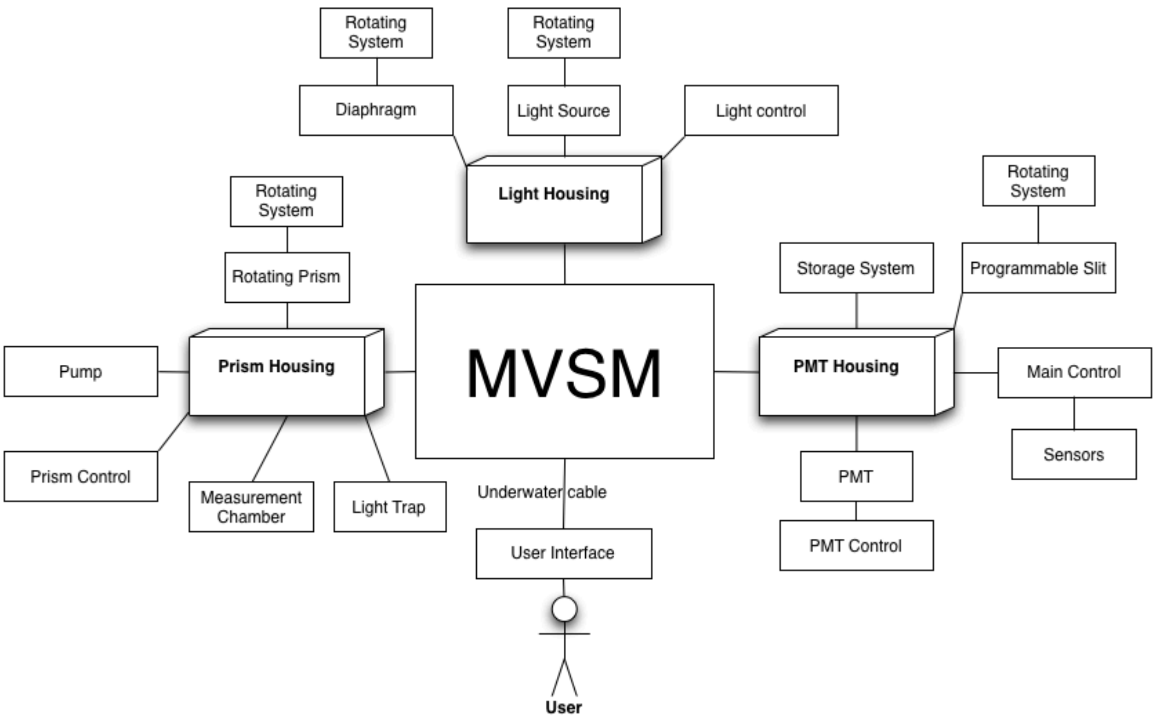


*Figure 1.1: System Context*

There is a light source in the Light Housing of the device, which provides the device with light. The light source and lens, mounted in front of the light source, create a controlled and collimated light beam, which passes the objective-window and penetrates to the Measurement Chamber where the sample volume is situated. A changeable diaphragm controls the width of the light beam. In the Measurement Chamber the special periscope prism collects the scattered light and directs it to the Photomultiplier Tube in the Photomultiplier Housing. The scatter light is collected continuously, as the periscope turns over 360 degrees.

Because all measurements are taken underwater, there are certain requirements that have to be met. All connections between the different parts of the device have to be protected from the effects of water. The only part of the device, which contains water, is the Measurement Chamber, where the sample volume is situated.

## 2.2 System Modes and States (Süsteemi moodid ja olekud)

### 2.2.1 Deploying (Kasutamine)

Upon deployment, the instrument is lowered to just below the water's surface and then turned on. The boot up mode of hardware and software is described in the next paragraph. Then the device is lowered to a depth of 10–20 meters or lower, if the depth of the water body is sufficient. After that the device has to run for a warm up period (3–5 minutes) to allow the motor controller to stabilize, the measurement chamber to clear and the instrument to achieve temperature equilibrium with the water.

After the warm up period, the device is has to be raised to just below the surface and data collecting, which is described in section 2.2.3, may begin. The initial sinking depth will be dependent on the natural surface conditions and the amount of bubbles that the ship itself is generating. The instrument can be then steadily lowered through the water column.

### 2.2.2 Booting (Alglaadimine)

On the boot up of the device, it has to initialize all the components. All the moving parts have to return to their zero positions. In addition, the device has to check if the communication between different parts is working. If there are any problems with the communication or connections, the device has to inform the user and stop the boot up sequence. If the boot up is successful, and all the initializations are done, the user has to be notified.

### 2.2.3 Data collecting (Andmete kogumine)

When the user initializes the data collection mode, the instrument starts collecting data. The scattered light from different angles and wavelengths is measured. After each program cycle the device calibrates itself, like described in section 2.2.4. After data is collected and processed by the main controller, it is stored onto an internal storage device.

### 2.2.4 Calibrating (Kalibreerimine)

After scanning over all the angles, the Instrument has to check the zero position settings. The device compares the measured light intensities and chooses the peak amplitude. This is defined as an optical zero position for the prism. Mechanical and optical zero position difference is analyzed to estimate mechanical displacement of the periscope prism – this is important information to perform measurements correctly in the forward (0°-10°) and backward (170°-180°) angle regions.

### 2.2.5 Data transfer and storing (Andmeedastus ja salvestamine)

When device is connected to a personal computer, measurement files can be transferred from the internal storage device to a computer and stored in database.

### 2.2.6 Test sequences (Testimine)

In addition to the measurement sequences, user can choose to run a test sequence on the device to test that everything is working correctly. The measurements, acquired in the Test sequences, are not stored in the internal storage device as these are merely used for testing and calibrating of the device.

## 2.3 Major System Capabilities (Süsteemi võimalused)

### 2.3.1 Measurement capabilities (Mõõtmiste võimalused)

The device is able to take measurements in up to twelve different spectral ranges. Spectral range selection depends of the available LED peak wavelengths – wavelength distribution should be maximally uniform over the wavelength range of visible light (eq. nearest wavelengths to 410, 440, 470, 500, 530, 560, 590, 620 nm in case of only eight different wavelengths are in use).

Volume scattering function measurements are carried out across the entire 0° to 180° range in the forward (small, 0°-10°), general (10°-170°), and backward (large, 170°-180°) angle regions. VSF measurements can be performed in two configurations: laboratory water samples (sample volume 1.5 l) and hydrographic deploying up to 30 m.

### 2.3.2 Control (Juhtimine)

Users can control the device via a special external controller. The default program is set up to run measurements for all installed wavelengths from blue to red and repeat a second cycle for iteration. User can also change the number of wavelengths measured, the wavelength sequence, or the number of repeat cycles.

### 2.3.3 Data storing (Andmete hoidmine)

Device is able to store raw measurement data and processed data to an internal storage device. Storage device uses its own file system and is externally accessible when the device is connected to a PC. From the PC the data is backed up to a database for further analysis. This requires an importing and backup system as well.

### 2.3.4 Water flow (Vee ringlus)

There are three options of how the water flow can be controlled. First option is illustrated on Figure 2.1. Here water comes freely through five input tubes when MVSM is moving down. The water is slowly stirred within the chamber by rotation of the periscope prism.

If the water exchange is not sufficient, it is possible to use a water pump. In this configuration, like illustrated on Figure 2.2, water enters from upper ring hole, then goes through measuring chamber, and leaves with a help of a pump using five tubes.

For work in laboratory, all chamber ports are blocked with stoppers except the one under the light trap. Sample water enters through light trap into chamber, and then runs out slowly from ring hole on the top, to avoid turbulence (Figure 2.3). When the chamber is full, sample water exits the chamber through the top ring around the prism rotation plate. Valves or clamps are used to regulate the flow. It helps to slow down the water flow or stop it when the chamber is full [5].

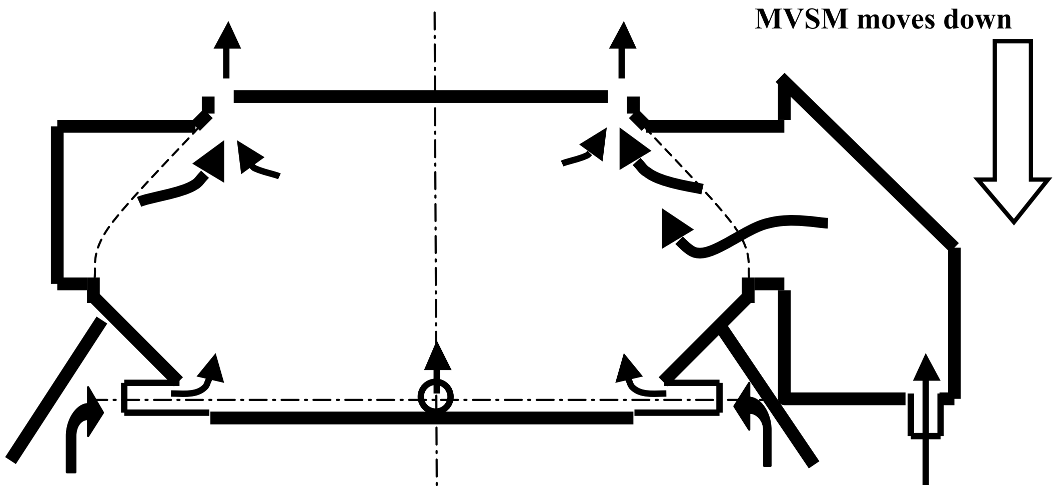


*Figure 2.1: Deploying*

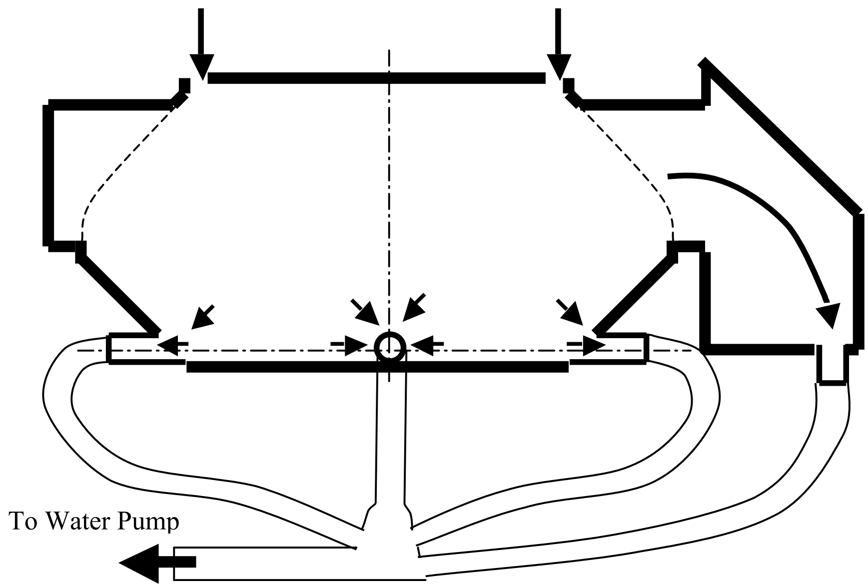


*Figure 2.2: Using Pump with Deploying*

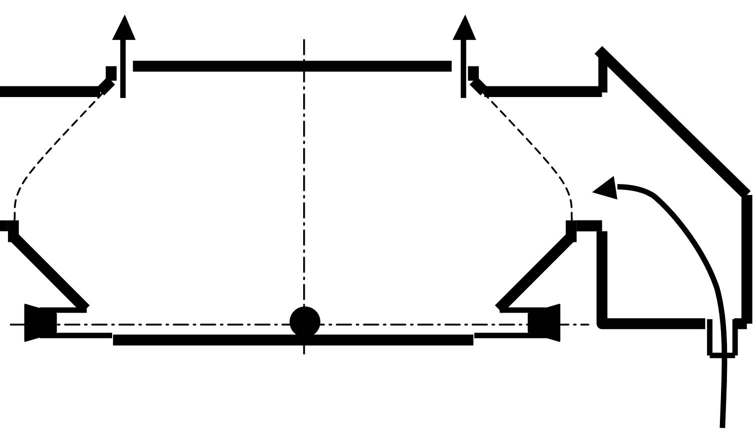

*Figure 2.3: Laboratory work*

## 2.4 Major System Conditions (Süsteemi kasutamistingimused)

### 2.4.1 Temperature (Temperatuur)

By decreasing the temperature of a photomultiplier tube, dark current originating from thermionic emission can be reduced. Sensitivity of the photomultiplier tube also varies with the temperature. In the ultraviolet to visible region, the temperature coefficient of sensitivity usually has a negative value, while near the long wavelength cut-off it has a positive value. Figure 2.4 shows temperature coefficients vs. wavelength of typical photomultiplier tubes classified by photocathode materials. Since the temperature coefficient change is large near the long wavelength cutoff, temperature control may be required in some applications [11].

One option is to use metal mounting fixture as heat sink, but for best heat dissipation, a special thermoelectric cooler module can be used. Thermoelectric coolers improve signal to noise ratio (S/N) of PMT measurement because of reduction of thermal electrons, which are emitted from PMT photocathode, and minimization of external noise by a built-in electrostatic and magnetic shield.

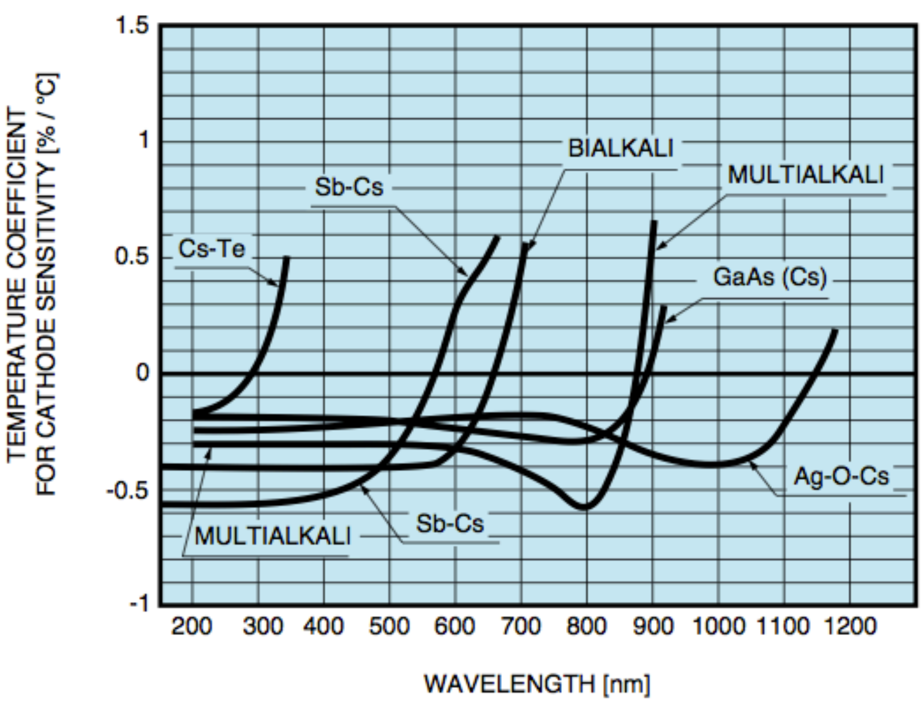

*Figure 2.4: Temperature coefficients of different photocathode materials commonly used in PMT-s*

### 2.4.2 Power supply and energy managing (Võimsustarve ja energiakasutuse juhtimine)

In the laboratory measurements, there are no limitations to power consumption. In the field works the device is used in the conditions, where there are power limitations. The input voltage is 12V, which is supplied by a twenty ampere per hour battery pack. The supposed biggest energy consumers are the light system and the pump, if it is applied. Taking this in encounter, it is important to use a spectral light source with low power consumption (eq. LEDs), which would waive from interference filters in front of the measuring input.

Careful analysis and testing has to be carried out for the energy consumption of the systems components and optimizations made if necessary. This should be done starting from the presumably larger consumers, such as motors and converters – as well as thermoelectric coolers, which may be used for cooling the photomultiplier and/or the light source.

The most noise critical part of the system is the PMT module. To reduce the noise generated by the power fluctuations, the PMT power supply should be electrically separated from the main power supply using low noise power converters. There could also be problems managing the energy needed for the thermoelectric cooling of the PMT.

## 2.5 Major System Constraints (Süsteemi piirangud)

The volume scattering function, $\beta(\theta)$, is radiometrically defined with a formula:

$$\beta(\theta) = \frac{dI(\theta)}{EdV} \quad (m^{-1} sr^{-1}). \tag{1}$$

where *I* is radiant intensity, deriving from a volume element in a given direction *(θ)*, per unit of incident irradiance *(E)* and per unit volume *(V)*.

If we integrate the light emitted over all directions, we obtain the total scattering coefficient, *b* *($m^{-1}$)*. The VSF divided by the total scattering coefficient is called the phase function

$$\bar{\beta}(\theta) = \frac{\beta(\theta)}{2\pi \int_{\theta=0}^{\pi} \beta(\theta)\sin(\theta)\,d\theta} = \frac{\beta(\theta)}{b}(sr^{-1}) \tag{2}$$

which provides information about the relative angular distribution of the scattering. The total scattering coefficient can be divided into forward, $b_f$, and backward, $b_b$, components [12]:

$$b_f = 2\pi \int_{\theta=0}^{\frac{\pi}{2}} \beta(\theta)\sin(\theta)\,d\theta \quad \text{and} \quad b_b = 2\pi \int_{\theta=\frac{\pi}{2}}^{\pi} \beta(\theta)\sin(\theta)\,d\theta \tag{4}$$

$$b_t = b_b + b_f \tag{5}$$

Like mentioned in section 2.3.1, VSF measurements are carried out in small, general and backwards angles. These angular ranges arise different problems and require different instrumental approaches. The small angle problem relates to the high level of background light generated by the direct beam, whose magnitude is several orders greater than that of the measured scattered light. The leading problems of the general angle scattering (10°< θ <170°) are the large dynamic range of measured scattered radiance (>$10^7$) and a very low signal of scattered light at angles near 90 degrees. Low light level and insufficient and undetermined scattering volume near angles in the range of 180° also creates problems [1].

## 2.6 Assumptions (Eeldused)

Since we are dealing with a measuring device, it is important that there are no unwanted factors, which can alter the measuring results. This puts certain restrictions to the components, which the instrument is built from.

If possible, using fans should be avoided, because they create unnecessary noise and vibration, which can disturb the photomultiplier measurements and measuring environment. In addition to that, fans have mechanical parts like bearings, which wear out over time.

## 2.7 Operational Scenarios (UML diagrammid ja tööstsenaariumid)

The figures below describe the measuring process of the MVSM using the latest version of the industry-standard for modeling - Unified Modeling Language 2.0 (UML) [10]. Figure 2.1 shows the activity diagram of the measurement. Figures 2.2 and 2.3 illustrate the PMT measurement and dark current adjusting in more detail.

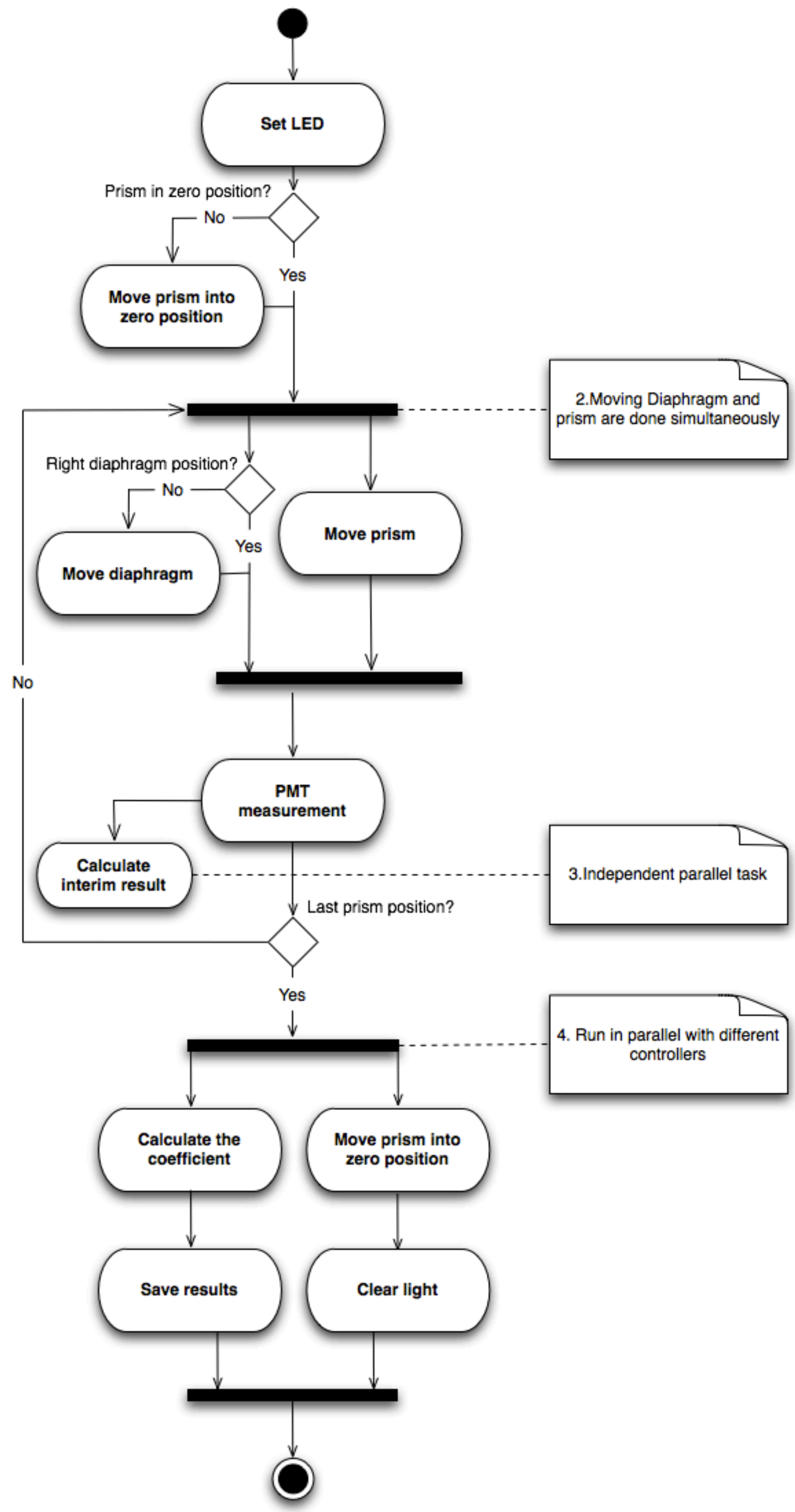


*Figure 2.1: Measurement Activity Diagram*


*Figure 2.2: PMT Measurement Activity Diagram*

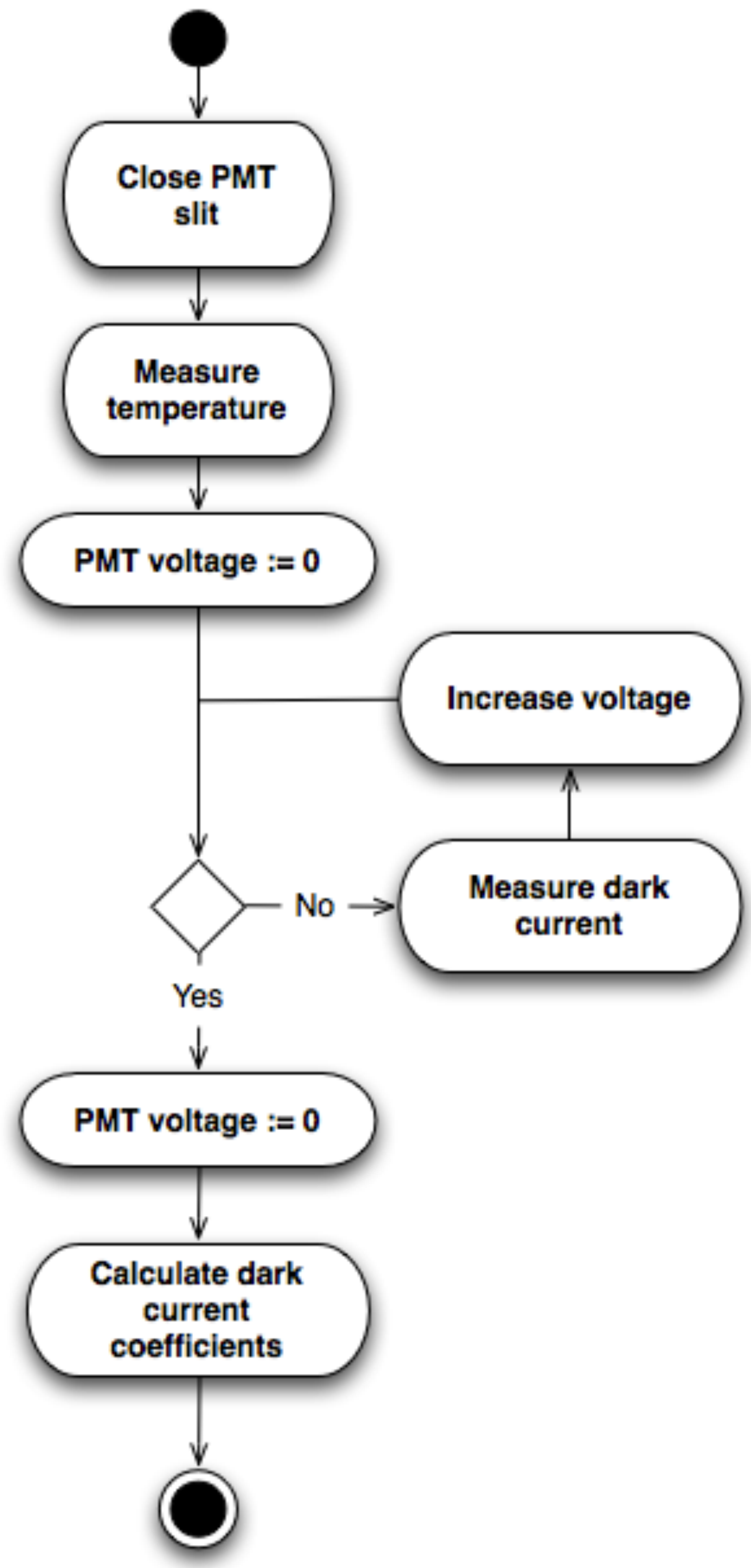


*Figure 2.3: Dark Current Adjustment Activity Diagram*

# 3. System Capabilities, Conditions, and Constraints (Süsteemi võimalused, tingimused ja piirangud)

## 3.1 Functional Requirements (Funktsionaalsed nõuded)

This chapter describes the functions of the system and its components. A function is described as a set of inputs, the behavior, and outputs. All functions are presented as use cases to specific functionality that defines what a system is supposed to accomplish.

### 3.1.1 Boot up (Alglaadimine)

#### 3.1.1.1 Boot up Purpose (Alglaadimine - eesmärk)

Boot up sequence is needed to initialize all components of the instrument. In order to work properly, the boot up sequence has to be a success.

#### 3.1.1.2 Boot up inputs (Alglaadimine - sisendid)

- The person operating the device starts it.
- To start and control the device, a special external controller is used.
- Control logic is done with two microcontrollers.
- Instrument uses motors to operate moving components.
- As the device is in a closed capsule, we cannot determine the initial positions of the moving parts by sight. For that purpose, photo detectors are used for detecting initial positions.
- To monitor conditions, sensors are mounted inside the package.

#### 3.1.1.3 Boot up input Operations (Alglaadimine - sisendoperatsioonid)

- Controller sends initiation commands to components and tests all connections for any errors.
- All the components are retrieved to their initial positions and are prepared for the measuring process. Photo detectors register the zero position of the moving parts.

- Temperature and pressure sensors are used to monitor the instrument components.

#### 3.1.1.4 Boot up Outputs (Alglaadimine - väljundid)

- Instrument messages are displayed to the operator via a small display on the remote external controller.

- The boot up process takes about 10 seconds, but for optimum stability, the instrument has to warm up for 3…5 minutes before data acquisition. While this is not an absolute requirement, it is good for the instrument's electro-optics to have an initial stabilization period.

#### 3.1.1.5 Boot up Use Case (Alglaadimine - kasutusmall)

*Table 3.1: Boot up use case*

| | |
|---|---|
| Use Case | 1 |
| Name | Boot up sequence |
| Actor | Operator |
| Pre-conditions | All connections between the device modules are connected. |
| Post-conditions | Device is ready for taking measurements. |
| Trigger | Operator pushes the power on button on the external controller. |
| Outcome | All lights on the external controller light up and the ready message is put on the display. |
| Scenario | 1. Operator pushes the "Power on" button.<br>2. Power LED and display light up.<br>3. The device starts up and "Initializing..." is displayed onto the screen.<br>4. After about 20 seconds "Warming up…" is displayed on the screen.<br>5. When the warm up is finished, "Ready" is displayed on the screen. |

| | |
|---|---|
| Alternative scenario 1.1 | 1. Operator pushes the "Power on" button.<br>2. Power LED and display light up.<br>3. The device starts up and "Initializing..." is displayed on the screen.<br>4. After about 20 seconds "Warming up…" is displayed on the screen.<br>5. Operator cancels the warm up period.<br>6. "Ready" is displayed on the screen. |
| Alternative scenario 1.2 | 1. Operator pushes the "Power on" button, but nothing happens.<br>2. LED does not light up.<br>3. Display does light up.<br>4. Device does not start. |
| Alternative scenario 1.3 | 1. Operator pushes the "Power on" button, light and display lights up, but "Initializing…" is not displayed on the screen.<br>2. Device does not start. |
| Alternative scenario 1.4 | 1. Operator pushes the "Power on" button, the LED lights up, but the display does not.<br>2. Device does not start. |

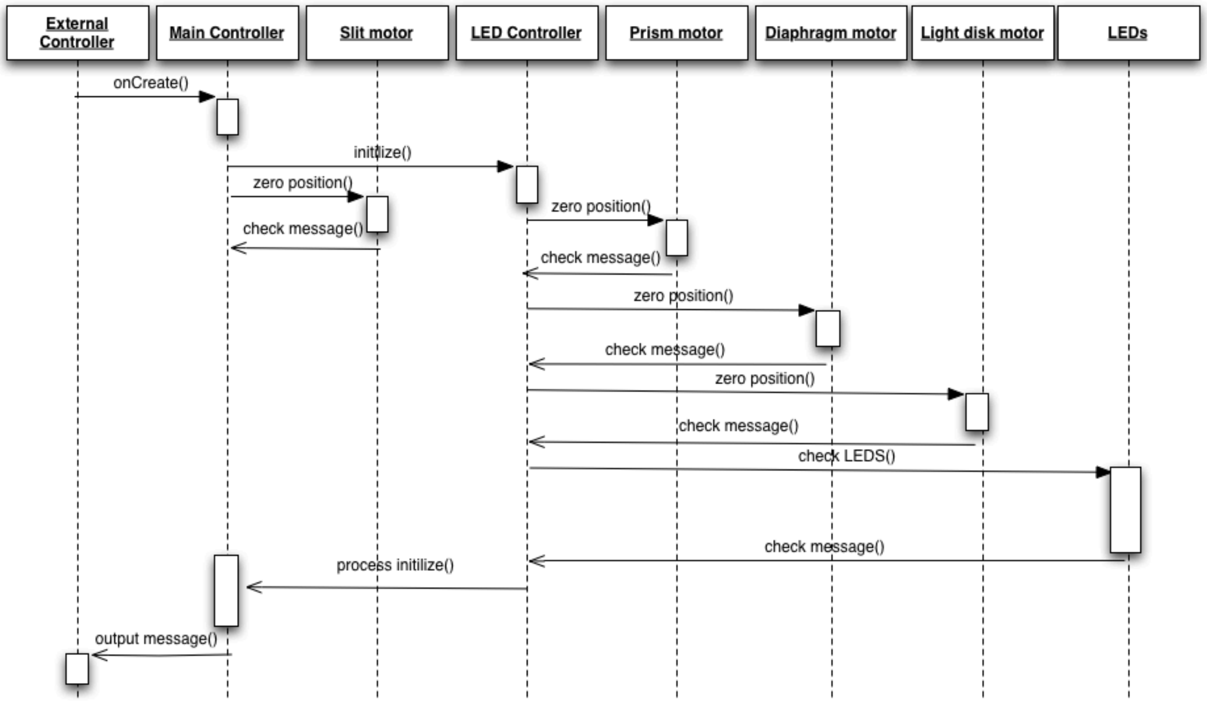


*Figure 2.1: Boot sequence*

### 3.1.2 Light scattering (Valguse hajumine)

#### 3.1.2.1 Light scattering (Valguse hajumine)

The purpose of light scattering is to collect the scattered light from the incident light beam and redirect it to the PMT Housing for measuring.

#### 3.1.2.2 Light scattering inputs (Valguse hajumine - sisendid)

- Light generated by the light source.
- To start and control the device, a special external controller is used.
- Control logic is done with two microcontrollers.
- Instrument uses motors to operate moving components.
- Rotating prism is used to collect the scattered light at different angles.
- Changeable diaphragm is used to control the light beam width.

- To monitor operating conditions, sensors are mounted inside the package.

#### 3.1.2.3 Light scattering inputs Operations (Valguse hajumine – sisendoperatsioonid)

- Controller sends initialization commands to components and tests all connections for any errors.
- All components are retrieved to their initial positions to start the measuring process. Photo detectors register the zero positions of the moving parts.
- Operator uses external control panel to start the desired measuring process.
- Controllers direct the commands to the device's components.
- Temperature sensors are used to monitor the temperature of the instrument components.

#### 3.1.2.4 Light scattering Outputs (Valguse hajumine – väljundid)

- Scattered light is directed to the Photomultiplier Tube in the Photomultiplier Housing.
- If any errors occur, then user is notified by displaying messages on the external controller display.
- During measuring process the currently used wavelength is showed on the display.

#### 3.1.2.5 Light scattering sequence Use Case (Valguse hajumine - kasutusmall)

*Table 3.2: Light scattering use case*

| | |
|---|---|
| Use Case | 2 |
| Name | Light Scattering |
| Actor | Operator |
| Pre-conditions | Device is turned on and boot up sequence was successful. Light source control mechanics is working correctly. |

| | |
|---|---|
| Post-conditions | Scattered light is successfully directed to the PMT. |
| Trigger | Operator chooses the desired measuring mode and starts measurements. |
| Outcome | Measuring sequence is started and information is put onto the display. |
| Scenario | 1. Operator pushes the "Start" button.<br>2. The wavelength information and prism positions are displayed on the screen.<br>3. Measuring sequence is started. |
| Alternative scenario 2.1 | 1. Operator pushes the "Start" button.<br>2. Error message is prompt onto the display.<br>3. Measuring sequence is not started. |
| Alternative scenario 2.2 | 1. Operator starts the measuring sequence.<br>2. Nothing happens and display is empty.<br>3. Measuring sequence is not started. |

### 3.1.3 PMT measurements (PMT mõõtmised)

#### 3.1.3.1 PMT measurements Purpose (PMT mõõtmine - eesmärk)

The purpose of PMT measurements is to measure the intensity of the scattered light and control the dark current of the PMT.

#### 3.1.3.2 PMT measurement Inputs (PMT mõõtmine - sisendid)

- Scattered light from the light source.
- PMT measurements are controlled from the external controller, which gives commands to the Main controller.
- Temperature sensor is used to monitor the device condition.
- Programmable slit is used to control the light beam width.

#### 3.1.3.3 PMT measurement input Operations (PMT mõõtmine - sisendoperatsioonid)

- The user starts measuring process using the external controller device attached to the device.
- User can also choose to run a test sequence on PMT measuring.
- PMT current and dark current are continuously measured in the process.
- The width of the light beam is changed depending on the measurement region.
- PMT voltage is set continuously depending on the measured current.

#### 3.1.3.4 PMT measurement Outputs (PMT mõõtmine - väljundid)

- The size of the light slit in front of PMT is checked during the measurement process and warning flags are set when it is minimal or maximal.
- The PMT high voltage value is checked during the measurement process and warning flag is set if voltage value is at the limits.
- When the measuring process in completed, the user is notified by displaying "Measurement Completed" on the external controller's display.
- The PMT current, PMT slit size and the last measured scattering factor is outputted onto the display while the measurement process is in progress.
- If an error is encountered the error message is prompted to external controllers display.
- On completion of a test run, either a success or failure and error message is displayed on the screen.

### 3.1.3.5 PMT measurement Use Case (PMT mõõtmine - kasutusmall)

*Table 3.3: PMT measurement use case*

| | |
|---|---|
| Use Case | 3 |
| Name | PMT Measurement |
| Actor | PMT controller |
| Pre-conditions | Wavelength is set and measurement sequence is started. |
| Post-conditions | Measurements are stored onto a storage device. |
| Trigger | Main controller sends Start measurement command. |
| Outcome | Measuring sequence is completed successfully. |
| Scenario | 1. PMT controller measures PMT current value using ADC.<br>2. Processes the reading and calculates the results.<br>3. PMT controller sends measuring information to the Main controller.<br>4. Info is outputted to the external controller's display.<br>5. Measuring data is stored on the internal storage device. |
| Alternative scenario 3.1 | 1. PMT current value is measured.<br>2. Error message is put to the display.<br>3. Measurement sequence is stopped. |
| Alternative scenario 3.2 | 1. PMT current value is measured.<br>2. Nothing happens and no info is displayed.<br>3. Measuring sequence is stopped. |

## 3.2 Physical Requirements (Füüsikalised nõuded)

### 3.2.1 Construction (Konstruktsioon)

The chassis of the instrument has to be made from stainless steel to protect it from the effects of the salty seawater. The hermetical packaging should withstand to the pressure up to 5 bars.

Because the working environment of the instrument is underwater, the outer device connections and cabling should be reduced to minimal. The device chassis connections have to be waterproof to avoid corrosion and short-circuiting the device. The sea cable has to also withstand to the pressure which aquatic environment applies. One option to reduce the cabling and connectors is to use the same wires for power and data transmission.

The functionality of a system is implemented with a set of interconnected system components, such as application-specific integrated circuits (ASIC's), memories, CPU's, buses etc. There are two problems to be solved, when designing a system: allocation – selecting a set of system components and partitioning - grouping the system's functionality among these components. Partitioning separates the objects into groups, where each group represents relatively independent system component. It helps to improve the device's computing speed and efficiency. The final implementation has to satisfy a set of design constraints, such as cost, performance and power consumption [13].

#### 3.2.1.1 Main Control Module (Juhtmoodul)

As pointed out in above the device is divided into tree subsystems. When dealing with subsystems it is much simpler to control and manufacture the device. There is a main control module in the device, which deals with storage, data analyzing and calculations, and communication between the other subsystems. It also coordinates the communication between the user interface and the device and passes user commands to other parts. The module consists of a controller and internal storage device. The controller has to have peripherals to communicate with other subsystems and the user interface. There are also sensors connected to the main controller, which monitor the working conditions of the device. There is an option to connect a pump to the device – the main controller also controls it.

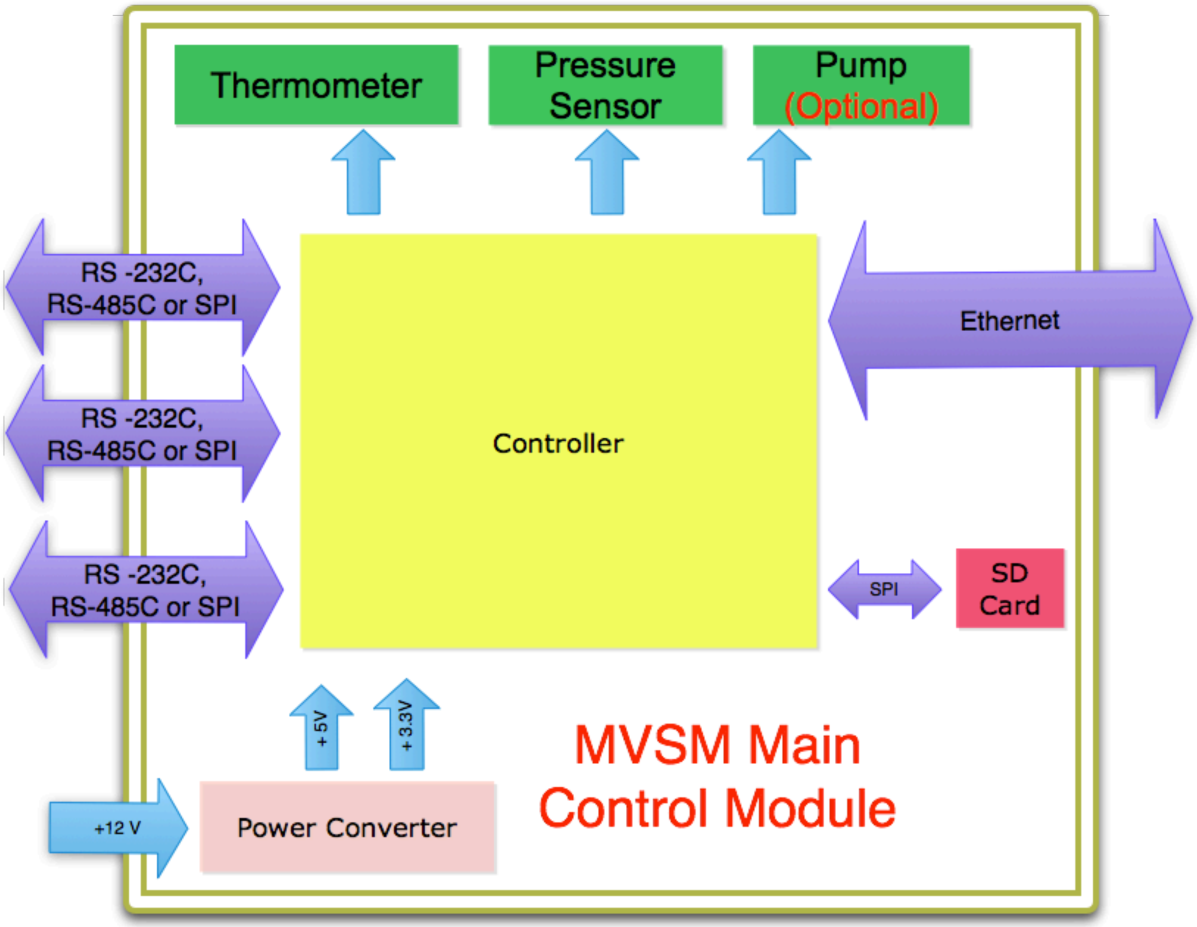


*Figure 3.2.1: Main Control Module block schema*

For the subsystem connections peripherals connection, serial communication ports can be used. The benefits of using serial communication is simplicity – there is no need for complex software drivers and the Seven-bit American Standard Code for Information Interchange (ASCII), that the usually RS232/485 uses, are known for virtually all software and hardware [14].

For communication between the external user interface and the device, Ethernet can be used. A good choice for internal storage device is Secure Digital Memory Card (SD Card) which uses Serial Peripheral Interface Bus (SPI) to exchange data. The good thing about this is that a lot of microcontrollers have SPI communication standard already integrated and therefore there is no need for additional hardware drivers [15].

Long-term autonomous measurements require large storage space and may require the use of a file system. The realization of a file system without the use of Real Time Operating System (RTOS) is rather complicated. In addition, the RTOS enables the opportunity to use Ethernet as a data transfer protocol with the external control device. The use of Ethernet is very useful when transferring large amounts of data, obtained over a long period of field works, in a reasonable time.  Also using RTOS generally requires a use of 32-bit processor.

The controller has to satisfy the requirements set above. Although we could buy a microcontroller and all the other components and build ourselves a board that fulfills the needs for the module, it is more efficient and timesaving to buy a development board with all the peripherals and microcontroller already soldered to it. Using development board gives us a base of the module from where we can build our system.

#### 3.2.1.2 PMT Control and Measurement Module (PMT juht- ja mõõtmismoodul)

PMT control module has to control the PMT sensitivity and to measure PMT output current. One option is to control the PMT and it's supporting components with the main controller, but if the PMT managing and control logic proves to be more complicated and time critical than originally anticipated, it is better to use a separate controller for the PMT.  In addition the main controller is also busy calculating the scattering coefficients and coordinating the measurement process and communication between subsystems.

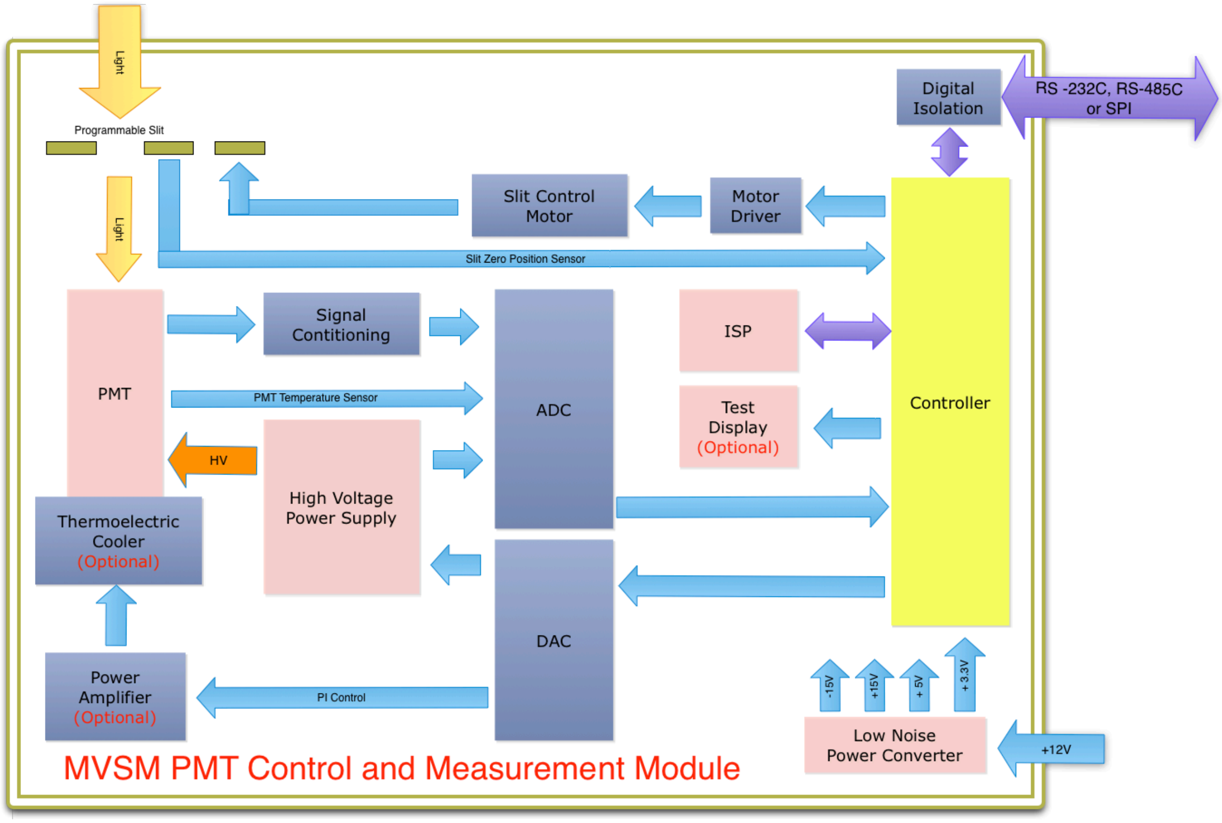


*Figure 3.2.2: PMT Control and Measurement Module block schema*

### 3.2.1.3 Prism Control Module (Prisma juhtmoodul)

There are two options for controlling the rotating prism. The first one is to control the prism motors with the microcontroller from the Light housing. But if we consider the partitioning logic of the system, that every subsystem is an independently controllable package, then a separate controller should be used. In that case the programming and building is much more easier. Figures 3.2.3 and 3.2.4 illustrate the two versions of the Prism Control model.

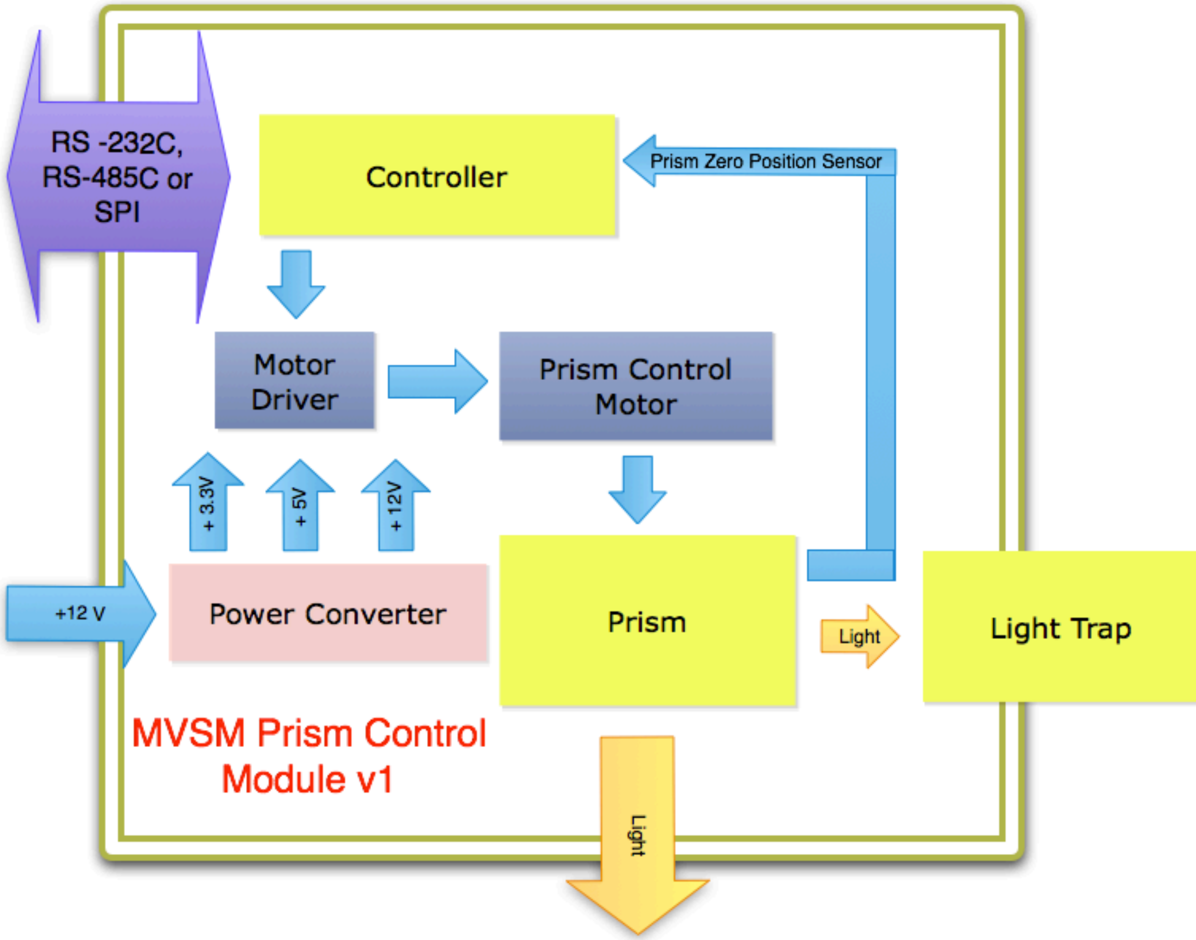


*Figure 3.2.3: Prism Control Module v.1 block schema*

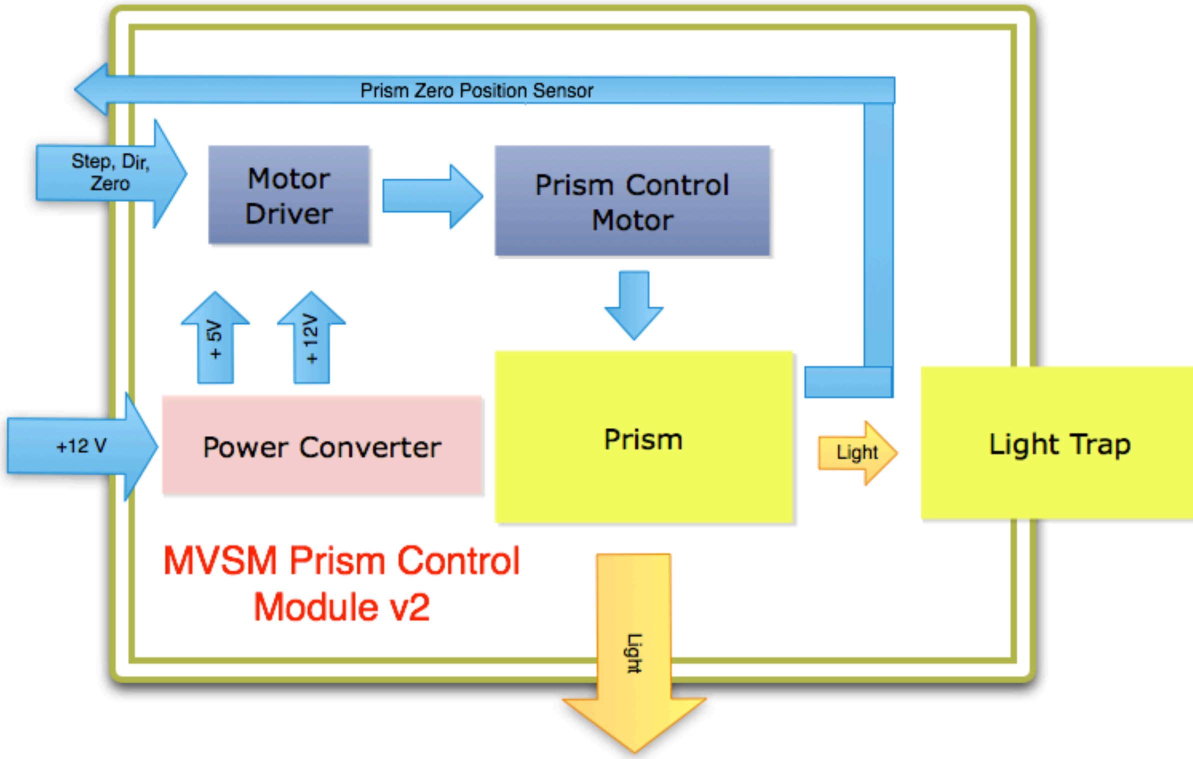


*Figure 3.2.4: Prism Control Module v.2 block schema*

Measurement Chamber, where the sample volume and rotating prism is situated, is the only part of the device that contains water. Therefore all the optical parts, which are in contact with water, have to be resistant to the effects of salty water.

#### 3.2.1.4 Light Control Module (Valguse juhtmoodul)

As mentioned in section 2.3.1, the device has to take measurements up to twelve different spectral ranges. To achieve this, twelve light sources with different wavelengths can be used. One option is to use powerful light emitting diodes (LEDs) mounted on a rotating carrier. The problem with using LEDs, with fixed wavelengths is that the availability of LEDs with different suitable wavelengths is limited. So if there is a need for specific wavelength measurements, another option should be taken under consideration.

The other option is to use a tungsten halogen lamp and changeable color filter in front of the photomultiplier tube or on the light source. Interference color filters can be ordered for all necessary wavelengths. The benefits of using LEDs over halogen lamp are energy efficiency, longer lifetime, lower power consumption and lower heat production.

The figures 3.2.5 and 3.2.6 illustrate two options of Light Control Module. The first one shows the usage of LEDs and the other of halogen lamp as device's light source.

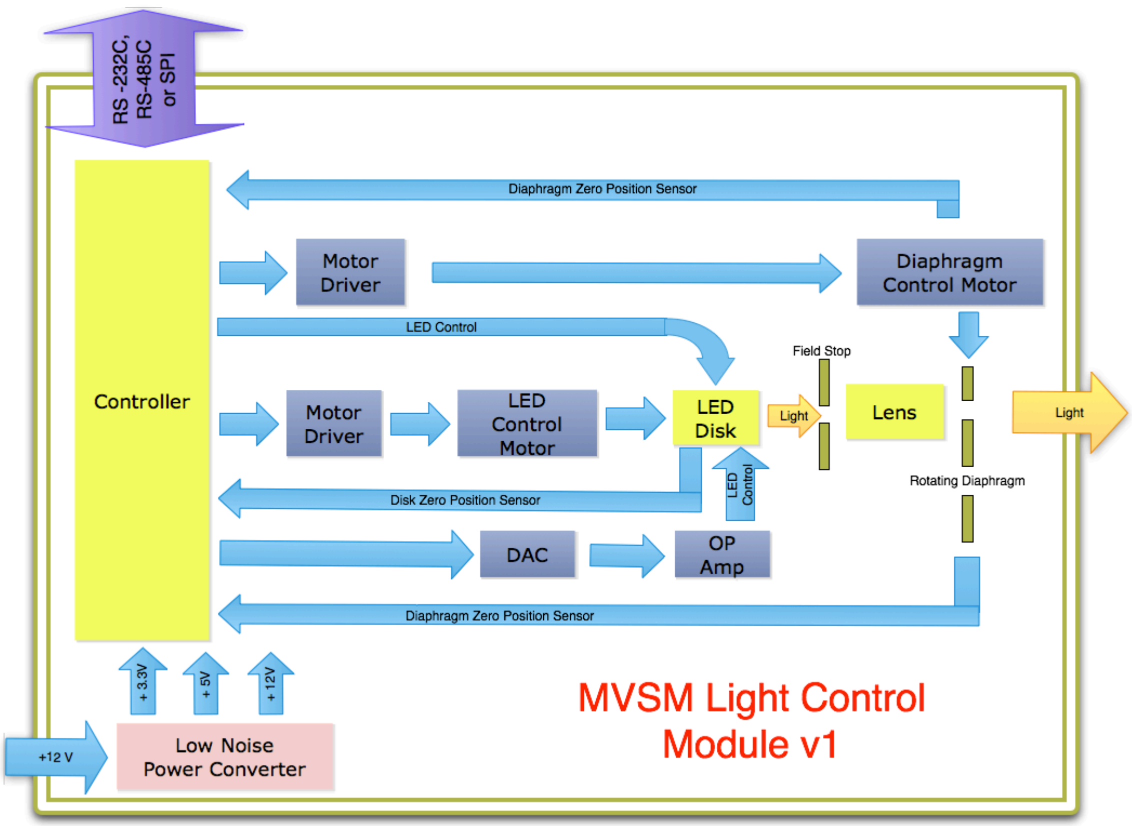


*Figure 3.2.5: Light Control Module v.1 block schema*

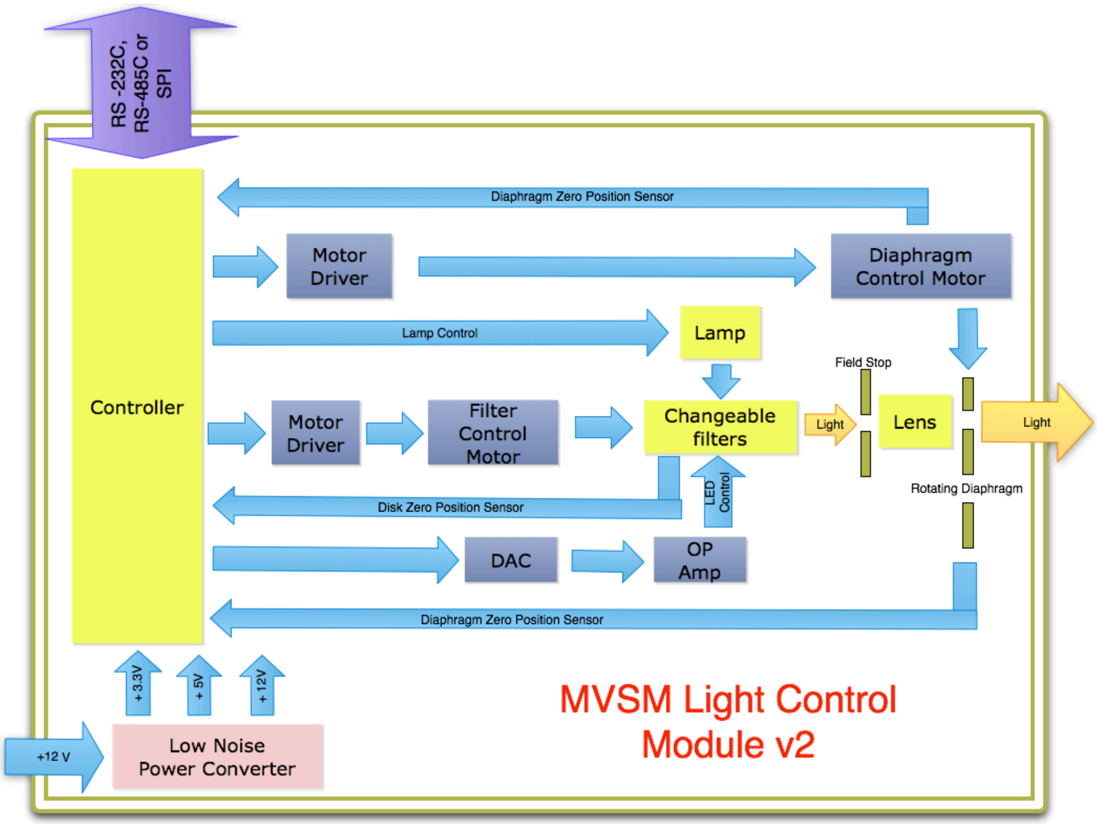


*Figure 3.2.6: Light Control Module v.2 block schema*

### 3.2.2 Durability (Vastupidavus)

When the instructions for care and maintenance (described in section 3.7.1) are followed precisely then the instrument should be operational for about a decade. After that period a general-overhaul should be carried out. The lifespan of the instrument depends greatly of the sample waters used in the measurements.

Although all the parts of the device are securely fixed inside the stainless steel chassis, there are some principles to go by when transporting and storing the device.

The MVSM should be stored and transported in a shock-protected environment. A sturdy wooden crate would be a good choice. Using the crate will assure that the instrument can be safely transported, providing it is handled in a reasonably careful fashion.

### 3.2.3 Adaptability (Kohandatavus)

If the first prototype is built and intensively tested in the laboratory and also field conditions, then the second prototype prepared will go into small volume production. The device helps scientists to take accurate measurements to study the volume scattering function and develop models for scientific research. After a successful completion of the first prototype, there is definitely room for improvements to make the instrument more user-friendly and universal.

One of the options would be that clients that order the device can choose which spectral ranges they want to be covered. As a result the Light Housing would be fixed with certain LED's, if possible, or with halogen lamp and color filters if LEDs with wished wavelength are not produced. Also, users should be granted with more flexibility and options when constructing measurement cycles for the device. If the device is connected to the computer, then the user should have a simple user interface (UI) for controlling and monitoring the device, and also making backup of the data. The UI should work on different computer platforms and be as versatile as possible.

### 3.2.4 Environmental Conditions (Keskonnatingimused)

As mentioned above, the instrument has to work in laboratory and in field conditions, where the environmental conditions are mainly defined by the water temperature. The supposed water temperature, where the device operates, should be in the range of 0 to 25 °C.  Because of the hermetically packed components, it is critical to analyze the heat dissipation produced by the device's electronics to avoid overheating and ensuring the minimal measuring noise and granting longer lifetime for the instrument.

## 3.3 System Life Cycle Sustainment Requirements (Nõuded süsteemi eluea tagamiseks)

### 3.3.1 Care and Maintenance (Hooldus)

The MVSM is durable and built for field deployment. The instrument doesn't require a lot of maintenance, but following some simple recommendations will assure optimum data integrity as well as longer lifetime of the instrument.

After fieldwork the MVSM should be cleaned before storing; at least minimum cleaning is always required if instrument is used in salt-water environment to avoid contamination of optical parts with dried salt. The following steps will help prolong the life of the instrument:

- Cables disconnected and connections securely sealed with dummy plugs, the measuring chamber should be thoroughly rinsed down with fresh water. For cleaning off oily residue, a dilution of mild soapy water can be used. After rinsing the pressure housing, the primary drying should be done.
- The windows of the instrument should be cleaned with dilute soapy water and then extensively rinsed down with clean water. The final cleaning should be done by ethyl alcohol and then rinsed clean with distilled water. When drying the windows, a lint free cleaning paper should be used.

When using a halogen lamp as a light source, the need to change a lamp arises periodically, because the lifetime of the lamp is about 200 hours. The changing of the light bulb has to be simple enough that the instrument operator or technician can manage it. If LED’s are used as a light source, changing them is done by replacing the whole module with a factory adjusted one.

# Summary

The volume scattering is a fundamental optical property of water, used in the calculation of radiative transfer for many applications. At the same time, measurements of the volume scattering function are very difficult to perform and devices previously constructed for this purpose were complicated and they were not able to take measurements of the function in full angular range. Do solve these problems a new instrument for measuring the volume scattering function of seawater and other natural waters across a hemispheric angle range was introduced.

Work resulted in a document, which gives a better overview of the Multispectral Volume Scattering Meter requirements, identifying problems, analyzing them and coming up with acceptable solutions. The document offers different options how to allocate and partition the instrument, to improve computing speed and efficiency. Suggestions for the physical environment where the system is going to be installed are also included in the document. Work explains the usage and operations of the device in two configurations: laboratory water samples and hydrographic deploying. Conditions and modes of operation were described thoroughly to set the functional requirements of the instrument. Also, recommendations for storing, transporting and maintenance were given to ensure the smooth running and the life cycle sustainment of the system.

The following system design process will take the requirements and analysis pointed out in this document into consideration and comes out with a functional and architectural design solution, which will form the blueprint to the actual solution of the Multispectral Volume Scattering Meter.

## Kokkuvõte

# Multispektraalse ruumhajuvusmõõtja nõuded ja analüüs

Aare Puussaar

Ruumhajuvusfunktsiooni varieerumisest veekeskkonnas on põhiliselt teada teoreetiline pool – praktilisi mõõtmistulemusi on vähe ja samuti on vähe ruumhajumisfunktsiooni mõõtmiseks sobivaid universaalseid mõõteseadmeid. See on tingitud asjaolust, et ruumhajuvusfunktsiooni mõõtmisi on keeruline teostada. Paljud praegu kasutusel olevad kiirguslevi mudelid on loodud kasutades umbes 20 aastat tagasi tehtud väga piiratud hulka mõõtetulemusi. Korrektseks veealuse kiirguslevi modelleerimiseks on hädavajalik faasifunktsiooni varieeruvuse teadmine. Seadmed, mida on varem kasutatud ruumhajuvusfunktsiooni mõõtmiseks, on keerulised, kohmakad ja mis kõige olulisem: need ei ole võimelised mõõtma funktsiooni kogu poolsfääri nurga ulatuses, mis on vajalik kiirguslevi võrrandi lahendamiseks.

Bakalaureusetöö tulemusena valmis uue multispektraalse ruumhajuvusmõõtja (*Multispectral Volume Scattering Meter* – MVSM) nõuete kirjeldus ja analüüs. Dokument kirjeldab uut meetodit ruumhajuvusfunktsiooni mõõtmiseks, kus kasutatakse spetsiaalset periskoop-prismat, mille abil on võimalik teostada mõõtmisi kogu poolsfääri nurga ulatuses.

Töös on esitatud võimalikult täpselt teadaolevad mõõteseadme ehitamiseks vajalikud nõuded ning analüüsitud disaini mõjutavaid tegureid. Samuti kirjeldatakse seadme kasutusmalle ja erinevaid operatsioonistsenaariumeid, et anda parem ülevaade seadme funktsionaalsusest. Käesolevas töös välja toodud nõudeid ja nende analüüsi on plaanis kasutada selleks, et luua mõõteseadme arhitektuuriline ja funktsionaalse disain ning valmistada töötav prototüüp. Töö teostatakse Euroopa Kosmoseagentuuri PECS-i (*Plan for European Cooperating States*) projekti raames ja kirjeldatavat seadet hakatakse tulevikus kasutama ühe osana optilise radiomeetria rakendusteenuses veekeskkonna jälgimiseks (ORAQUA).

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