Using Augmented Reality in a Planetary Surface Greenhouse for Crew Time Optimization

Conrad Zeidler

EDEN Research Group, Institute of Space Systems, Department of System Analysis Space Segment, German Aerospace Center (DLR), Bremen, Germany, conrad.zeidler@dlr.de

Gerrit Woeckner

Technical University of Braunschweig, Institute of Space Systems, Braunschweig, Germany, g.woeckner@gmail.com

In the future, humankind will build habitats on Moon or Mars to conduct research or eventually build long-term settlements. As integral part of these habitats, greenhouses will be integrated into the habitat infrastructure to produce food, recycle water or air. As crew time is a precious good in space missions, operating of such greenhouses should use as less crew time as possible. In this workshop paper, we present how augmented reality (AR) technologies can facilitate the work of the operators of such a greenhouse on Moon or Mars and the remote support team on Earth as well as to reduce overall crew time.

Additional Keywords and Phrases: EDEN ISS, Crew time, Workload, Remote support, Operations, Greenhouse, Space analogue, Life support system, Antarctica, Neumayer Station III, Augmented Reality

1 INTRODUCTION AND MOTIVATION

Sustained human presence in space will incorporate greenhouses as integral part of habitats on Moon and Mars. Higher plants cultivated in planetary greenhouses will provide the opportunity to produce food, reduce carbon dioxide, produce oxygen, recycle water and manage waste products [1]. Moreover, fresh crops have a significant beneficial effect on the astronauts psychological well-being [1]. A regular supply of resources from Earth to a habitat is associated with high effort and costs resulting in the necessity for the crew on Moon or Mars to have the capabilities to supply themselves as self-sufficiently as possible.

Within the scope of the European Union Horizon 2020 project, EDEN ISS consortium has designed and tested essential Controlled Environment Agriculture (CEA) technologies inside a greenhouse called the Future Exploration Greenhouse (FEG) [2]. The FEG was designed with respect to future planetary bio-regenerative life support system deployments. The technologies were tested in a laboratory environment as well as at the highly-isolated Antarctic Neumayer Station III, operated by the Alfred Wegener Institute [3]. Another line of research investigated within the EDEN ISS project comprises the development of food safety, system and plant handling procedures, which are essential for the interaction between the operators and plants within greenhouse. The first experimental phase was conducted in the winter season 2018 [4]. A dedicated Mission Control Center (MCC) at the DLR Institute of Space Systems in Bremen allows the EDEN team to remotely operate the EDEN ISS greenhouse (see Figure 1) in Antarctica [5].

Earth-based bioregenerative life support system test-beds like EDEN ISS serve as means to test larger-scale and fully integrated systems, in particular with a focus on increasing the reliability of such systems. The ground-based tests also provide a means to evaluate the crew time [6] necessary to operate these facilities while at the same time exploring possible opportunities to reduce overall crew time requirements.

Figure 1: View into the EDEN ISS Future Exploration Greenhouse (FEG) in Antarctica full of plants during the analogue mission in 2019 (Photo credit: Hanno Müller).

Astronauts in future greenhouses as integral part of habitats on Moon and Mars cannot be expected to have the capabilities to handle all occurring situation during a space mission, nevertheless they are well-trained and equipped with detailed procedures. Due to this, they will be supported by experts in the MCC on Earth. [7]

In addition to that, the remote operations during the first three missions in Antarctica have already shown, respectively confirmed that crew time is a valuable and limited resource, which needs to be optimized to increase the time required for scientific work [6].

In this workshop paper, we propose to use augmented reality (AR) [8, 9] to facilitate the work of the operators of such a greenhouse and of the experts in the backrooms on Earth. By means of this, the field of vision of an operator on-site could be extended by virtual displays of interactive elements and, thus, contribute to shortening the working hours and reducing the workload for the involved crew members [10]. Direct interaction with the virtually displayed elements takes place via various input and output options resulting in a possible renunciation of paper lists and keyboard entries [11]. In addition, procedural errors occurring during maintenance activities resulting in failures and delays can be mitigated [10].

2 ARCHI: CONCEPT OF AN AR APPLICATION FOR A PLANETARY SURFACE GREENHOUSE

Figure 2 and Figure 3 show a concept of an AR interface called ARCHIE[2] ("**A**ugmented **R**eality **C**omputer **H**uman **I**nterface for gr**EE**nhouses") in the EDEN ISS greenhouse. The main focus of the interface is to e.g. save crew time, reduce errors or increase safety for crew and plants, but also to facilitate the processes to enable the integration of untrained personnel in the operating process of a greenhouse [10]. We envision that the AR interface supports the five main fields of activities as shown in Table 1. We derived these activities from the experiences and implications gathered from the operations of the FEG, which has already been tested for three years under extreme Antarctic conditions and supplies the polar research station Neumayer III. In addition, we used the operating procedures developed during the past years examined with the objective to find possible applications for AR technologies to facilitate the working processes in the space analogue greenhouse. During the first two seasons in 2018 and 2019, the crew time [6] needed to operate the greenhouse and to support the operator on-site from the MCC was measured and analyzed. We plan to use these measurements as a baseline to compare with the performance of the remote support team and the on-site operator team using the AR interface shown in Figure 2 and Figure 3 during a future EDEN ISS mission in Antarctica.

Table 1: Exemplary list of application areas for Augmented Reality in a planetary greenhouse.

Possible Fields of Application	Exemplary Execution
1. Display of technical green-house information	• Sensor data e.g. temperature, relative humidity, CO2-level, light settings • Actuator data e.g. pressure/temperatures in tubes or pumps, system active or inactive • Handling of alarms in greenhouses
2. Display of plant specific information	• Plant data e.g. seeding time and location, transplanting time or cultivar • Real-time Plant Health Monitoring System e.g. display of plant health status
3. Display of planning tools	• Operation procedures for tasks performed in the greenhouse e.g. tending plants, maintenance work or repair tasks • Daily planning tool • Automatic crop planning tool to calculate the optimal seeding time and location transplant or harvest data to generate continuous output • Support for recording crew time
4. Communication tool	• Support of tele-operation tasks e.g. document sharing, video conferencing • Remote assistance: Two-way voice and video communication to Mission Operation Center for faster troubleshooting in case of emergency or repairs
5. Document processing functions	• Share, edit or view documents • Taking notes

The AR concept envisages that the on-site operator has to put on AR glasses after entering the greenhouse. Image A in Figure 2 displays the **Home Screen and Tasks** menu, which is visualized on the display of the AR glasses after initial start-up of the AR interface. Through the **Home Screen** menu (see left side of Figure 2A), the operator gets access to the submenus **Greenhouse Environment, Plant Environment, Communication, Documents** and **Settings**. The **Tasks** menu (see right side of Figure 2A) displays information regarding scheduled tasks such as daily, weekly, monthly checklists (see left image in Figure 3) or procedures and alerts, which need immediate action (see point 1 and 3 in Table 1). The information icons next to the alert help to identify the issue and the effected plant/system that needs a task to be performed. At the end of a completed checklist or procedure, it is possible for the on-site operator to send a summary report of the activity to the remote support team in the MCC. [11]

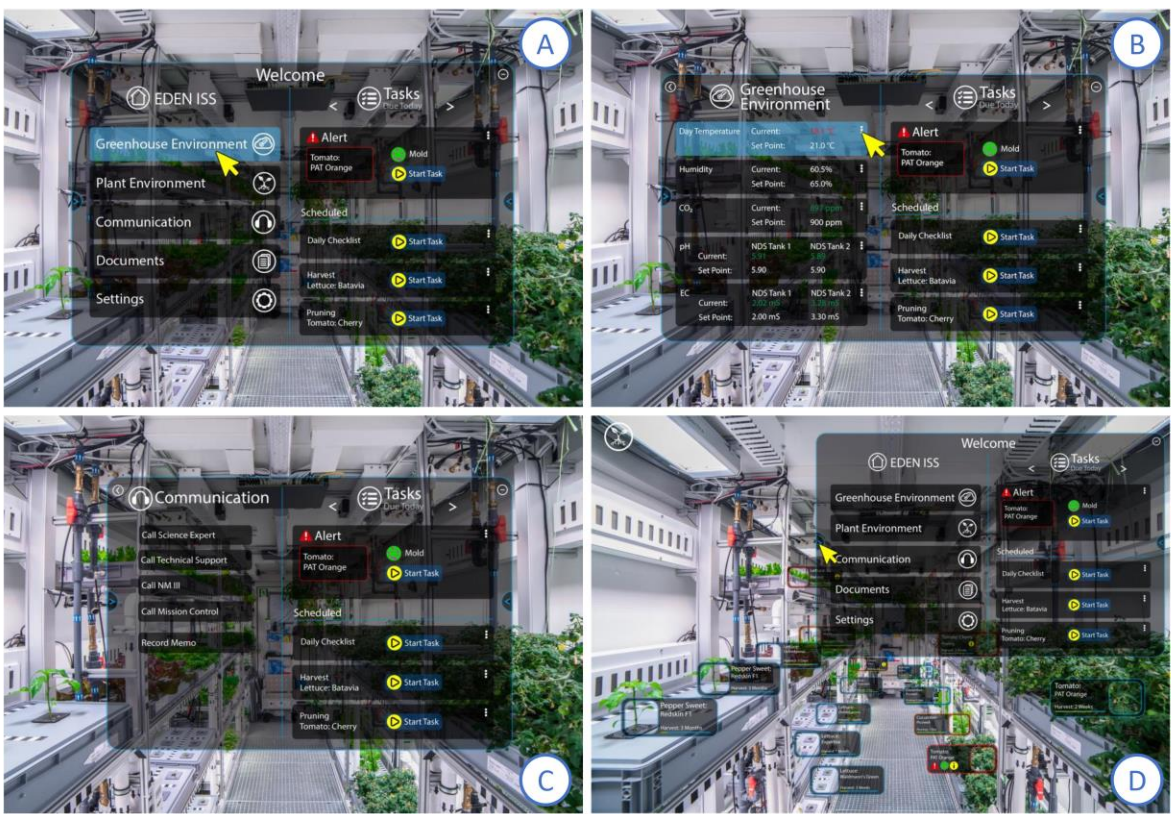

Figure 2: Concept of an AR interface in the EDEN ISS greenhouse in Antarctica: [A] Home Screen and Tasks menu; [B] Greenhouse Environment and Tasks menu; [C] Communication and Tasks menu; [D] Plant Environment turned on [11].

In the **Greenhouse Environment** submenu (see Figure 2B), technical information regarding the greenhouse (see point 1 in Table 1) such as sensor or actuator data can be derived. Green-colored values indicate that the current system status is in the targeted setpoint range. A white- colored value shows that the status is not in the targeted setpoint range, but has not yet reached a critical deviation from the setpoint below, which is indicated by a red-colored value. By clicking on the three-point icon, it is possible to go to a subsequent submenu to e.g. report the issue to the MCC or visualize a graphical history of values. [11]

Relevant plant information can be displayed using the toggle on/off function of the **Plants Environment** menu (see point 2 in Table 1). The activated **Plants Environment** is visualized by the white plant icon in the upper left corner of Figure 2D. In this menu information such as cultivar or next task to be performed are bound to the location of the specific plant in the greenhouse. A progress bar indicates the duration until the next plant related task has to be performed. A blue-framed icon indicates "no tasks required", an orange-framed icon "task required at next day" and a red-framed icon "task required at present day". [11]

Entering the **Communication** submenu (see Figure 2C), the operator can call various points of contact for remote support via an integrated communication interface (see right image in Figure 3) such as science experts or technical support (see point 4 in Table 1). In addition, the operator can record memos, which are directly translated into written documents without access to a computer or the use of a pencil, saved on-site and/or transferred to the MCC (see point 5 in Table 1). [11]

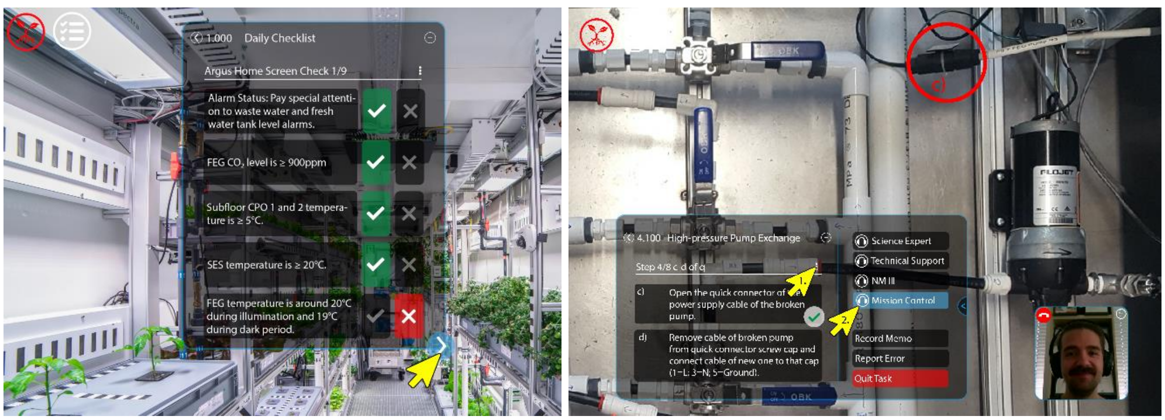

Figure 3: Left: Example for a daily checklist inside the EDEN ISS greenhouse in Antarctica; Right: Exemplary remote support of on-site operator while exchanging a high-pressure pump in the FEG [11].

In the **Documents** submenu, the on-site operator has access to crop cycle related information and all procedures needed to operate the greenhouse clustered by the task categories (see point 5 in Table 1). The last submenu is **Settings**, where the general properties of the AR interface can be set. [11]

3 CONCLUSION AND FUTURE WORK

In this workshop paper we described the potential impact of AR technology integrated into the operation process of a future planetary surface greenhouse on the workload and crew time of the operators. We present a first concept of an AR application, which can be used in a planetary surface greenhouse. For that purpose, the crew time and workload of the on-site operators of such a greenhouse on Moon/Mars as well as of the remote support operators on Earth has to be studied in detail to examine the application potential of AR to facilitate the operations of both groups. In the future, we plan to develop and test the AR application during a mission in Antarctica and investigate if the interfaces facilitate the work of the operator on-site in Antarctica. The study will conclude with an outlook of the usage of AR technology in future space missions and a comparison against the crew time measurement we have already collected. We hope gather valuable inspirations and evaluations during the workshop discussions, that help will us to drive the development of the AR concept forward.

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