1. Publishable summary

Abstract

The **PV-Servitor** project focuses on concepts for a **fully autonomous** cleaning **robot** for **ground mounted large scale photovoltaic power plants**. The **PV-Servitor** shall be able to automatically clean glass surfaces of solar modules in large areas in an unrestricted way. Its application will increase the electricity output of the PV plant by 8% at a service cost of only 3%, thus resulting in a 5% user-benefit by cost reduction of the electricity yield.

Europe's largest PV companies active in the **main European PV markets** such as **Germany and Spain**, strongly support this SME project as end-users and **grant access** to their large scale PV power plants. This end-user involvement will also help to secure the SMEs a **rapid market success** after the completion of the PV-servitor project.

Tasks for research are lightweight construction, automated cleaning of glass surfaces, the synchronisation of technical and economical lifecycles, sustainable outdoor mobility including the challenge to replace rechargeable batteries with a long life energy supply system, unrestricted navigation and cognitive vision systems for pollution detection and cell inspection.

PV-Servitor is a research project **supported by the European Commission** (FP7 SME). The proposal was submitted on April 11th 2008 and the project started the **1st of September 2009** with a duration of **24 months**. Further information can be found in several languages at the project website: www.pv-servitor.eu

Summary description of the project objectives

According to an EU publication photovoltaics (PV) is the **most capital-intensive** renewable source of electricity. Currently, the **generation costs** of grid-connected PV electricity in Europe range from € 0.25 /kWh to € 0.65 /kWh, depending on both local solar irradiation and market conditions. The average market price of electricity at the European Energy Exchange in the first quarter 2008 was € 56.20 /MWh, which is € 0.056 /kWh and a still valid price as per today (30th June 2010).

The PV-Servitor project will focus on the **reduction of the generation cost** of grid-connected PV electricity in Europe by 5% through **automated add-on services**. The automated service of a PV power plant will result in an **increase of energy output of 8 %** and will **cost 3 %** of the installation value of the PV power plant, resulting in a **benefit of 5 %** for the PV power plant operating company.

The **potential users** are all free terrain **PV-project operating companies** in **Germany** and other countries such as **Spain** and **Italy** with an EEG type income from photovoltaic energy production for the public-grid. The **EEG** is a very successful **German law** which states the **obligation of the grid-operator** to pay for renewable energy being fed into the public-grid.

Description of the work performed in the first nine months

PV-Servitor is organized in seven work packages plus a WP for management (WP0). As depicted below **one basic research** (WP1) and **three applied research WPs** (WP2-4) conclude into the final research WP prototype evaluation (WP5). IPR protection (WP6) and dissemination & exploitation (WP7) are the final project WPs.

The plan was: Initially WP0 – WP5 shall **start the project in parallel** due to the limited project duration of two years and the importance for **prototype evaluation to start as soon as possible**. WP1 to WP 4 shall be completed by **midterm**. WP5 will run somewhat longer in the second half of the project. IPR protection (WP6) will commence **after midterm** once the research WPs have resulted in protectable know-how. WP7 must strictly start after WP6, otherwise too early publication will prevent intellectual property protection.

However, due to an **early success** and a **ground-breaking new approach** regarding movement on PV modules and a **running prototype** (WP2 and WP5) at the first quarterly meeting (!), IPR protection activities WP6 started already in the second and third quarter of the project. Also WP7 activities were started early and the project website went online in the first quarter. With respect to WP1 and WP4, the researchers needed to adjust and adapt their work to the solutions found earlier and will continue in P2. Different to the plan, WP2, WP3 and WP5 will be **completed during the remainder of the project**.

Additionally to the **kick-off meeting** in Burgdorf, Switzerland, the **first quarterly meeting** in Regensburg, Germany and the **second quarterly meeting** in Valencia, Spain (all part of WP0) two further meetings, one between MRU and DTI and one between MRU, Profactor and MS were organised to **adjust the course of RTDs** to the solution found in the first quarter. Several **end-users participated** at the planned management meetings. ILIOTEC was involved in additional extraordinary meetings, from which a visit of a **6.3 MW PV power plant in Ponholz** near Regensburg is especially noteworthy. ILIOTEC and SOLON **sponsored solar-modules**.

A work breakdown structure is depicted in the figure below.

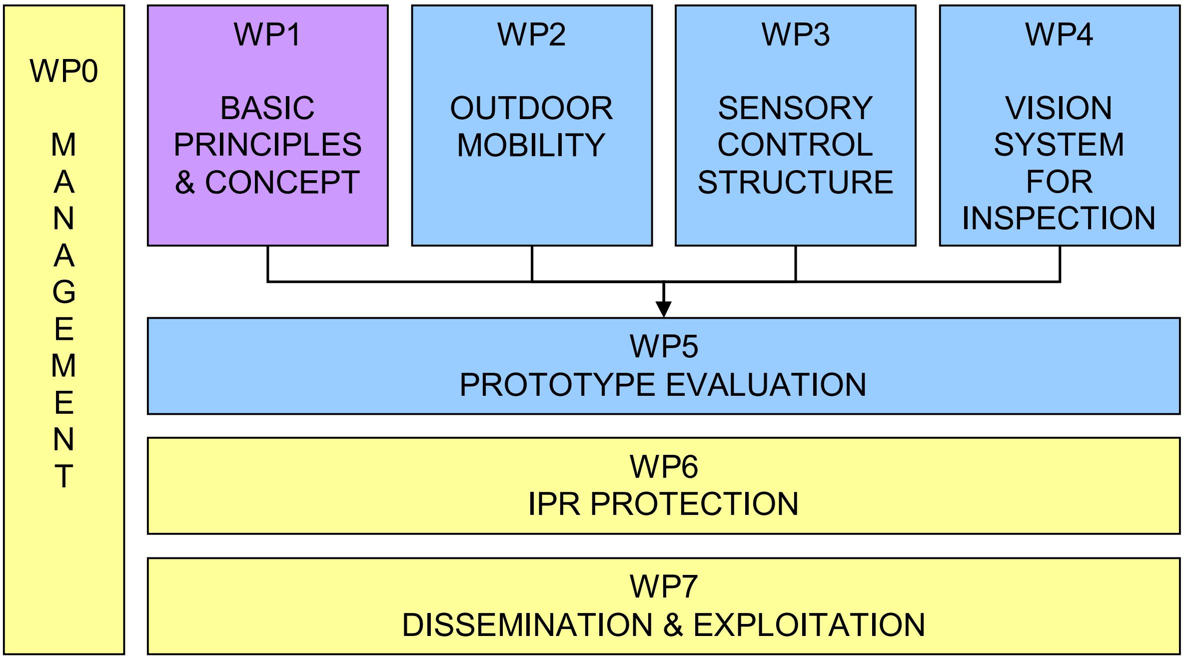

Figure 1: Work breakdown structure

Description of the main results achieved in the first nine months

Within the first few months a very valuable result was achieved by MRU regarding a **mechatronic motion system** optimised for long rows of crystalline modules that can move in a **self-restricted** way in an otherwise unrestricted area. This result has a **real benefit** for end-users. Further description will be publishable, once a **patent application** has been filed successfully by a patent lawyer.

Based on the previous result of a robot traversing long rows of PV-modules in one single linear motion back and forth, the scanning of the modules should as well take place in one **single linear motion**. Profactor recommended an alternative type of sensors developed and used for industrial applications for further research to result in a **PV row scanner.** Further description will be publishable, once a **patent application** has been filed successfully by a patent lawyer.

Expected final results and their use

Project Result (No)	Planned Project Result (Description)	Expected Final Results (Description)
1	Methods and associated robot for autonomous cleaning, polishing and inspection of photovoltaic modules	Based on the evaluation of prototype A, this result is clearly expected in P2 as final result for long rows of PV modules. However, a similar excellent result for PV power plants build in a large area is not expected within the time frame of the project. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.
2	Long life energy supply systems and methods for mobile robots	Not expected as research could not find a better solution for energy supply than rechargeable traction batteries. An idea of grid-connected robots was thought of, in order not to solve, but to avoid the problem of storing electrical energy. However no cost effective concept could be found in P1.
3	Movement systems and methods for mobile robots on glass surfaces	This result was achieved in P1. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.
4	Mobile vision systems and methods for navigation in unrestricted outdoor environments	As discovered in P1 solar modules in newer PV power plants have matrix codes of their serial number on the top side of the modules. A map building prototype with the feature navigation by map is expected in P2. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.
5	Mobility systems and methods for robust operation of a robot in outdoor environments	This is an expected result in P2. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.
6	Sensory control structures for mobile robots in outdoor environments	This is an expected result in P2. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.
7	Mobile vision systems and methods for inspection of photovoltaic modules	A PV row scanner based on the research performed in P1 is expected in P2. The expected type of exploitation is ownership by MS and licensing by Robotnik and Shadow.

Table 1: Expected final results

Potential impact and use of the project results

The SMEs plan **direct utilisation** of the knowledge after the research project through a **product PV-Servitor**.

The end-users are planned to be the first customers. Especially **ILIOTEC** services with **Ponholz** a **6.3 MW PV power plant** nearby to Regensburg, where MS and MRU are located. The long rows of Q-CELLS mono-crystalline modules in Ponholz and the used Krinner mounting structure fit technically to the strategy of PV Servitor Wiper prototypes. According to the newspapers the installation cost was EUR 18 million. The simplified calculation of **user benefit** and **add-on industry benefit** for one ILIOTEC PV power plant in Ponholz would be:

$$UB_S = I_C \cdot 5\% = 18{,}000{,}000€ \cdot 5\% = 900{,}000€$$

$$S_C = I_C \cdot 3\% = 18{,}000{,}000€ \cdot 3\% = 540{,}000€$$

UB_S: **Simplified user benefit** for the PV power plant operator and investor per 100 kW
I_C: PV Installation cost
S_C: Cost of automated service through a PV-Servitor robot, **add-on industry benefit**

ILIOTEC services Ponholz and smaller plants such as several 1.3 MW plants (Falkenstein, Amberg) and new plants of about double size in the near future of the same construction type.

IBC has in its test installation the **PV power plant Hafenpreppach** only a small section used for crystalline modules, therefore monitoring of this plant is **important to create knowledge** for example regarding the **cleaning effect of the robot**, and less important for the use of the knowledge.

A **PV power plant database** used for research purposes will be re-used to identify more plants, which could be potentially impacted by the PV-Servitor solution. However initial analysis shows that many plants from juwi and IBC use thin-film modules. For technical reasons PV-Servitor will focus in the first step on crystalline framed modules and only in a second step on thin-film modules.

The potential impact identified in an early version of the PV power plant database is **larger than expected** in the project plan (880 MW). It is unknown how much cumulative power was installed in large scale PV power plants currently and how much of this has not yet been included in the database. However the database values specifically for **large scale PV power plants** are:

Installed power

Installed power total	3820 MW
Installed power end-user	345 MW
Installed power in GERMANY	1059 MW
Installed power in SPAIN	2122 MW
Installed power in UNITED KINGDOM	
Installed power in UNITED STATES	132 MW

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Figure 2: PV power plant database report