Final Report
of the STSM
COST-STSM-TD1207-27649

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Host Institution: RWTH Aachen University
Prof. Martin Frank (Department of Mathematics)
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Purpose of the STSM

This Short Term Scientific Meeting was a visit whose main aim was to continue the collaboration with Professor Martin Frank at MATHCCES department of RWTH Aachen University (Germany), on the optimization of the heliostats field design. The scientific plan was to continue working on a previously studied topic in collaboration with the solar thermal energy research group (STERG) at Stellenbosch University, and to start exploring new methods (automatic differentiation techniques) to improve the field designs obtained so far.

Description of the work carried out during the STSM

A Solar Power system comprises basically a tower with a receiver on the top and a field of mirrors called heliostats. Each heliostat has two axis movement which allow to follow the sun at each time instant and reflect the sunlight into the receiver. The heliostats location problem deals with a black-box objective function and nonconvex constraints, as collisions between heliostats must be avoided. The study of optimization techniques to optimize the heliostats field is an active field nowadays. A greedy-based heuristic algorithm and a genetic-based algorithm had been proposed by the Seville group and the MATHCCES group respectively.

Firstly, the problem proposed by the STERG group has been completed: the optimization of the field design using triangular structures (triangular pods with six heliostats) instead of individual heliostats. Different experiments have been carried out to study among other things the optimal triangle size for a given configuration (tower-receiver characteristics and number of heliostats). In Figure 1, the heliostat field layout obtained when applying the greedy-based algorithm with triangular pods is shown.

Secondly, an optimization strategy to locally improve the heliostat positions has been studied using derivatives. The aim of this procedure is to optimize the whole field by iterative optimizing the positions of small number of heliostats. This way improved field designs, taking as initial solution those obtained so far with our algorithms, could be achieved.

As we deal with a black-box objective function automatic differentiation software offer the possibility to compute directly the derivatives of the objective function. We have been working with Automatic Differentiation for Matlab (ADiMat) which is a software for the computation of precise and efficient derivatives of Matlab programs. ADiMat transforms a given MATLAB code for the evaluation of some mathematical function into a new MATLAB code for the evaluation of user-specified derivatives of that function. The ADiMat software was started and developed by André Vehreschild and Johannes Willkomm among others, at the Institute for Scientific Computing, TU Darmstadt, Germany and formerly the Institute for Scientific Computing, RWTH Aachen University.

We applied also the derivatives obtained with Adimat to study the problem of the

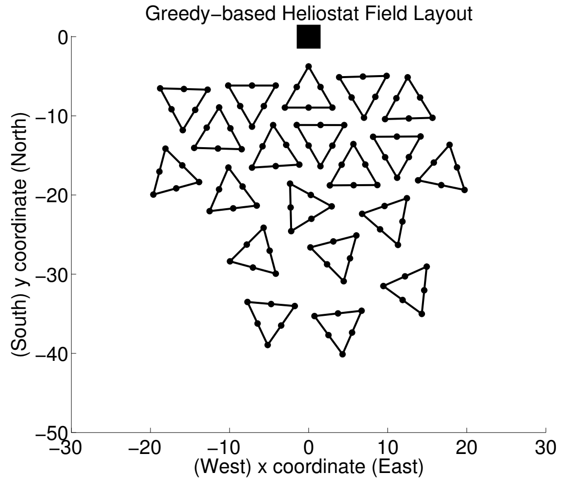

Figure 1: Greedy-based layout with triangular pods

optimal heliostat trajectory. In this problem a mobile heliostat is considered that is, the heliostat is provided with a small motor and it can move along fixed rails to follow the sun's positions during the day. This mobile heliostat concept has been already used in the Variable Geometry Central Receiver test facility by the CTAER in Almería (Spain). In this facility the receiver is also mobile and heliostats move along fixed circular rails around the tower. In our first approach we simplify the problem considering a single heliostat and a static receiver.

Description of the main results obtained

Regarding the triangular pods problem, we have studied the optimal triangle side for a fixed SPT configuration and carried out comparisons between individual heliostat fields and triangular pods fields. The results have been included in the working paper submitted to Proceedings of SolarPaces 2015.

The derivatives provided by the Adimat tool have been used to perform some optimization experiments. In Figure 2, the first 100 heliostat from the reference plant PS10 have been considered as initial field (black points) and the red points are the five heliostats selected to be repositioned. In this test case shadowing and blocking effects are not included and the only constraints included are the safety constraints (clear-out circle around each heliostat center). The solutions obtained after the optimization are given by the blue points. As shadowing and blocking effects are not included the heliostats move closer to the tower (maximum energy point) as expected.

In the optimal heliostat trajectory problem we have considered for simplicity only one mobile heliostat and an static receiver. The problem then is reduced to obtain the optimal rail shape where the heliostat has to move. The problem can be written as de maximization of the following functional:

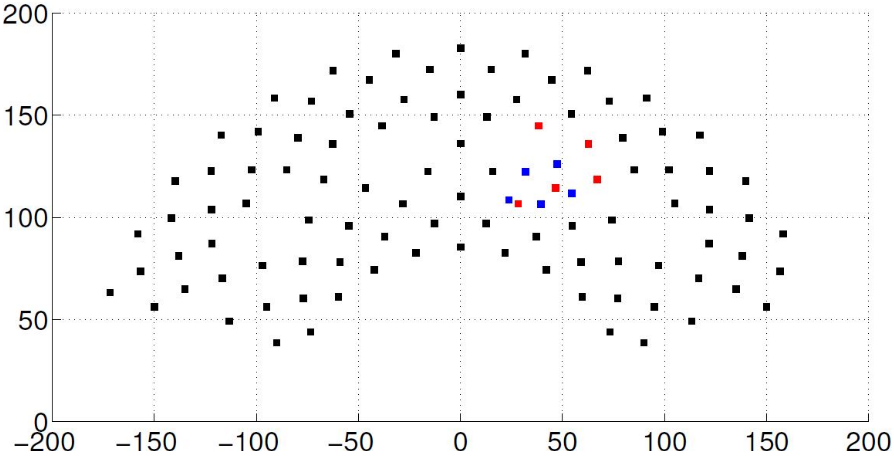

Figure 2: Heliostat Layout Local Improvement

$$\xi \to J(\xi) := E\left(\left\{(x_t, y_t) = \underset{(x,y)\in\Gamma(\xi)}{\arg\max} P(t,x,y)\right\}_{t=0}^{T}\right)$$

where Γ describes the parameterized trajectory with parameter ξ and (x_t, y_t) is the optimal heliostat position at time t in the fixed trajectory. Note that this is a nested optimization problem.

A discretization of the time has been done considering one representative day per month ($21st$) and the solar hours for each day. Firstly, a circumference centered in the origin has been used considering as optimization variable the radius and then, the circumference center has been included also as a variable. The different parameterization obtained have been studied and compared against the optimal positions if no fixed trajectory is needed. However, regarding the optimal positions obtained for each time instant of the considered discretization (see Figure 3), it is clear that a circumference shape is not the best choice. Different parameterization and/or optimization approaches need to be developed and applied to obtain a better solution.

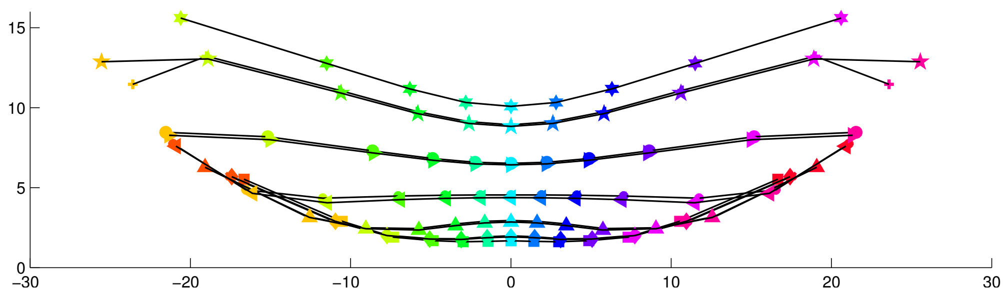

Figure 3: Heliostat optimal trajectory for each selected day

Future collaboration with the host institution

The first point will be to finish the research topics already open, the local optimization of the field design with Adimat software and the calculation of the optimal trajectory for a mobile heliostat including also a mobile receiver and several heliostats at the same time. I am optimistic about future cooperation with Martin Frank in order to study, not only this type of problems, but also others related with solar tower plants optimization.

Foreseen publications resulting from the STSM

A paper has been submitted for publication in the Proceedings of SolarPaces 2015 conference. It is my hope that the research done during my stay leads for another paper about the Adimat applications to the solar field layout.

Seville, 15th of August, 2015.
Carmen-Ana Domínguez Bravo
Visitor, University of Seville

Confirmation by the host institution of the successful execution of the STSM

I have read the final report written by Carmen-Ana Dominguez Bravo describing her STSM visit to RWTH Aachen University to collaborate with my research group. I am extremely satisfied with the results of the visit. We have successfully deepened a cooperation that we had started at the ECMI 2014 conference. We developed optimization techniques for a heliostat field of a solar tower power plant, which is planned in South Africa, and consists not of individual heliostats, but pod systems. The result was an abstract that was accepted at SolarPACES, the most important international conference in the solar industry.

I hope this fruitful cooperation will continue in the future as well.

Aachen, 15th of August, 2015.

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