North Dakota Renewable Energy Council
Interim Report

Solar Soaring Power Manager

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Introduction

This document describes the accomplishments and current status of projects during phase II of the Solar Soaring Power Manager project. These activities took place at Packet Digital's facilities in Fargo, ND as well as at the Naval Research Lab (NRL) facilities. Progress has been made on all phase II deliverables and the project is on track as per the original proposal. A status update of each deliverable is listed below.

Objective:

This research and development project will create a solar soaring power management system for Unmanned Aircraft Systems (UAS) to initially double fly times and ultimately provide unlimited endurance powered by solar energy. This will be achieved by harnessing solar energy with high-efficiency, flexible photovoltaics and auto-soaring technology to enable the UAS to autonomously gain lift from rising hot air along with advanced power management algorithms. Packet Digital will create an advanced solar power management and distribution system (PMAD) combining flexible, high-efficiency power conversion circuitry to dramatically extend flight times in unmanned aircraft.

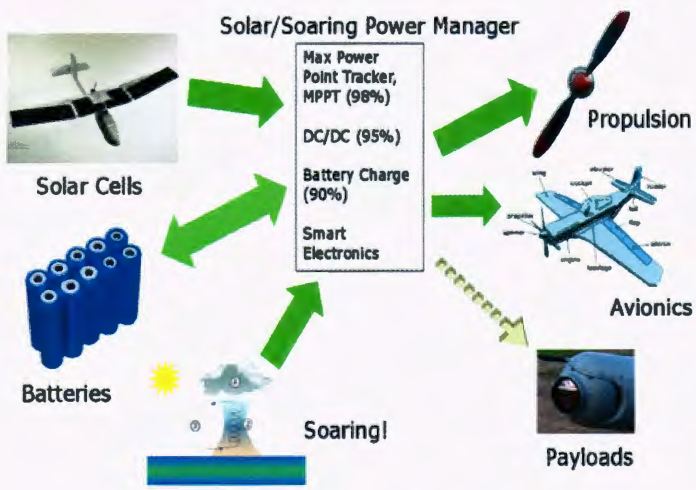

Figure 1: System Overview

This product will optimize the power conversion from the solar array to the batteries, from the batteries to the electronics, and from the batteries to the propulsion motor. The power conversion circuitry will provide state-of-the-art high efficiency power while the microprocessor will run advanced algorithms for maximum power point tracking and auto-soaring.

Schedule

This project is divided into three phases, of which phases I and II are of 9 month duration and phase III of 6 months. This interim report covers the progress made during months 3-6 of phase II.

Deliverables

Phase II Deliverables:

- Produce a solar cell covering the desired spectrum with 30-35% efficiency, with a target of 40%
- Implement solar soaring algorithms into a prototype of a commercially feasible product
- Design a Maximum Power Point Tracker (MPPT) and Power Management and Distribution (PMaD) system that is compatible to the commercial industry standards for unmanned aircraft that improves the performance of Unmanned Aircraft Systems (UASs) similar to the Altavian UAS manufactured by ComDel. The industry compatible system will be integrated into a solar unmanned aircraft and tested at the Northern Plains Test Site.
- Develop a hybrid smart battery combining multiple storage technologies to be charged by solar in flight
- Produce an optimized torque motor control prototype, with a target of improving propulsion system efficiency 5% and reducing airframe vibration
- Test all prototyped solutions integrated in a lab environment

Status Updates

Objective 1: Solar Cell Development

During this reporting period, NRL continued development of the high efficiency solar cells and the integration of the solar arrays on to the wings of the UAV.

The highest performing solar cells are based on multijunction (MJ) technology in which various semiconductor materials are combined to achieve maximum solar absorption and, most importantly, highest solar to electric energy conversion. During the last reporting period, the NRL Multibands software was used to model and simulate the multijunction solar cells for use on the UAV wings. The results of the modeling established a six junction solar cell design capable of achieving 40% efficiency.

In this reporting period, several material growth runs were completed. These were initial material growth runs consisting of 3 junction cells based on Gallium Arsenide (GaAs) stacked upon 2 junction cells based on Indium Phosphide (InP). Figure 1 below shows the full, 5 junction device, where a visible image shows the top, GaAs, 3 junction cell and a IR image shows the bottom, InP, 2 junction cell. These cells demonstrated efficiencies of nearly 37%. The next stage is to establish the full 6 junction cell using Gallium Antimonide (GaSb) bottom cells where efficiency of ~40% is expected.

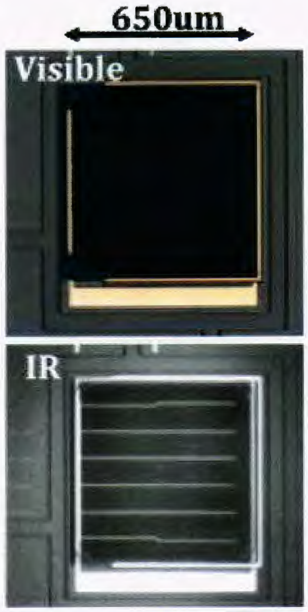

Figure 1: Photograph of a stacked cell. Top picture (visible) shows the GaAs-based cells, the bottom figure (IR) shows the bottom, InP cells.

In parallel with the stacked, 6 junction cell development, the solar arrays have been designed and prototyped. This has required significant design work since typical solar arrays are based on glass encapsulated, rigid modules which are not suitable for use on UAVs. During this reporting period, NRL has established a design for flexible solar arrays that will serve as the top most layer of the UAV wing skin. Several prototype array structures have been built (Figure 2), and they are now in the process of being tested in the NRL lab, and in particular, the wind tunnel. Thus far, the prototype arrays have been assembled using dummy solar cells. In the next phase, the commercially available 3 junction cells discussed in the last reporting period, will be used to build functional arrays that will be incorporated into the UAVs.

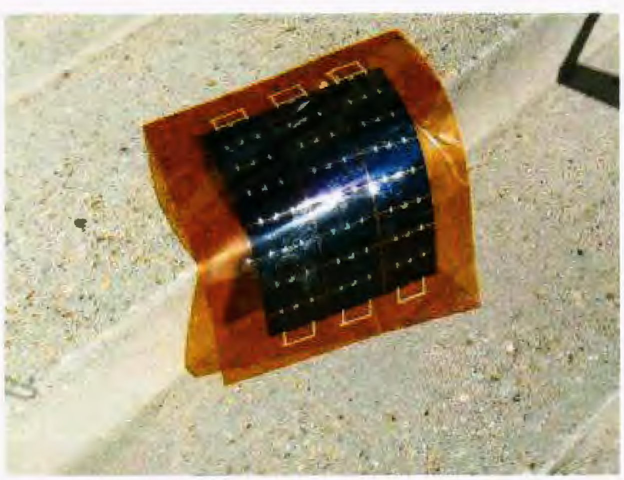

Figure 2: Flexible solar array material being used to develop the UAV wing skin. This example uses multijunction, large area solar cells with flexible encapsulation.

The solar array development utilizing Si solar cells continues. NRL has received the arrays and verified 22% efficiency (Figure 3). The next stage is to incorporate the Si arrays into the UAV wing skin, as is being done for the multijunction solar cells. The Si arrays will be incorporated into the UAV wing skin at NRL, and the results will be reported in the next reporting cycle.

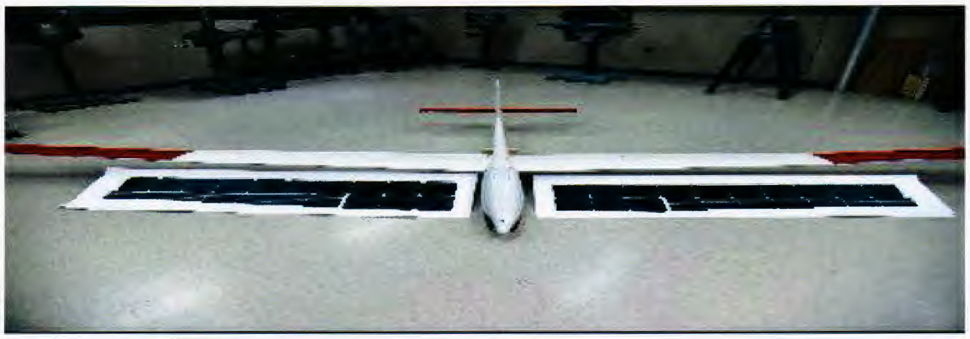

Figure 3: A photo of the flexible Si arrays next to one of the UAVs. These arrays will be used as the wing skin for a new wing assembly.

Objective 2: Update Power System to Support Commercial UAS

In phase II, the power electronics for the phase I fixed wing UAS were optimized for use in other airframes. The primary means of optimization was using a smaller form factor and adding the CAN communication scheme.

The maximum power point tracker (MPPT) testing has completed with good results. The only issue that arose is thermal dissipation. Due to the small size of the Gallium Nitride FETs and the small board size, there was less thermal relief than required. Various thermal compounds and heatsinks were evaluated and a workable solution was found. It will require a PCB modification in order to add space and proper heatsink mounting.

Figure 4: GaN MPPT

The PMAD Lite was flight tested in February and it performed very well. It will be the standard PMAD used until a UAV requires more than one battery or one MPPT.

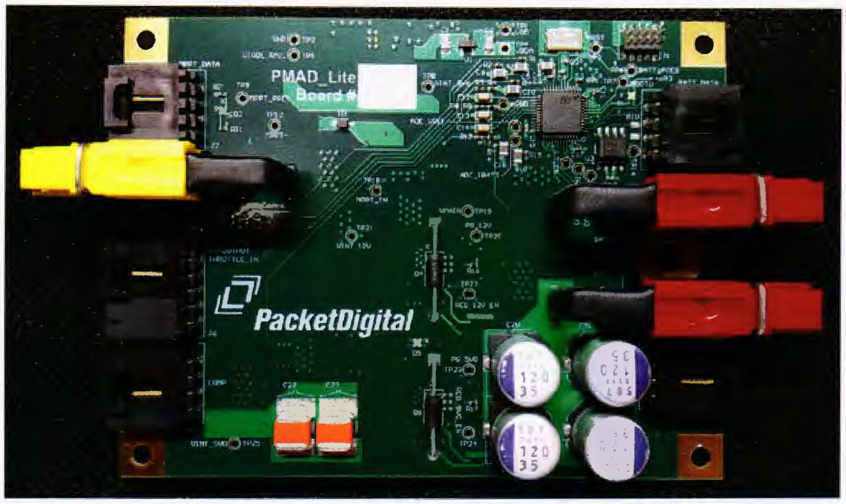

Figure 5: PMAD Lite

Objective 3: Hybrid Smart Battery

In the last couple months, a new battery technology was made commercially available to UAV enthusiasts. These batteries use graphene to enhance battery performance when compared to a standard LiPo battery. The advantages are listed below.

Advantages of Graphene LiPo Batteries over a standard LiPo Battery:

- Lower internal impedance
- Higher charge/discharge rate
- Cooler operating temperature
- Longer cycle life

The smart battery from phase I is currently being modified to create a hybrid smart battery by replacing one of the six lithium subpacks with a graphene LiPo subpack. This results in a 50% reduction in total impedance, at the expense of a 10% reduction in total capacity. This reduction in total impedance is critical for low-temperature environments, when lithium ion impedance increases significantly. This can be an issue for glider-type UAVs that have propulsion systems optimized for cruise at the expense of takeoff performance.

Figure 6: Graphene Battery Pack

Work on hydrogen fuel cells also continued with additional conversations with UAV fuel cell manufacturers. Simulations have been run to help assess the performance of a hydrogen fuel cell. One of the key challenges in equipping a UAV with a hydrogen fuel cell is fitting the tank inside the fuselage and maintaining the appropriate center of gravity.

Objective 4: Optimized Torque Motor Control

Significant work has been done on the optimized torque control (OTC) design. A supplier of a power application controller was identified and an evaluation board for their product was acquired. This controller includes an ARM microcontroller core as well as the integrated gate drivers and other circuitry required for advanced motor control. The controller also includes firmware for the optimized torque control algorithms. Figure 7 shows a block diagram of the controller.

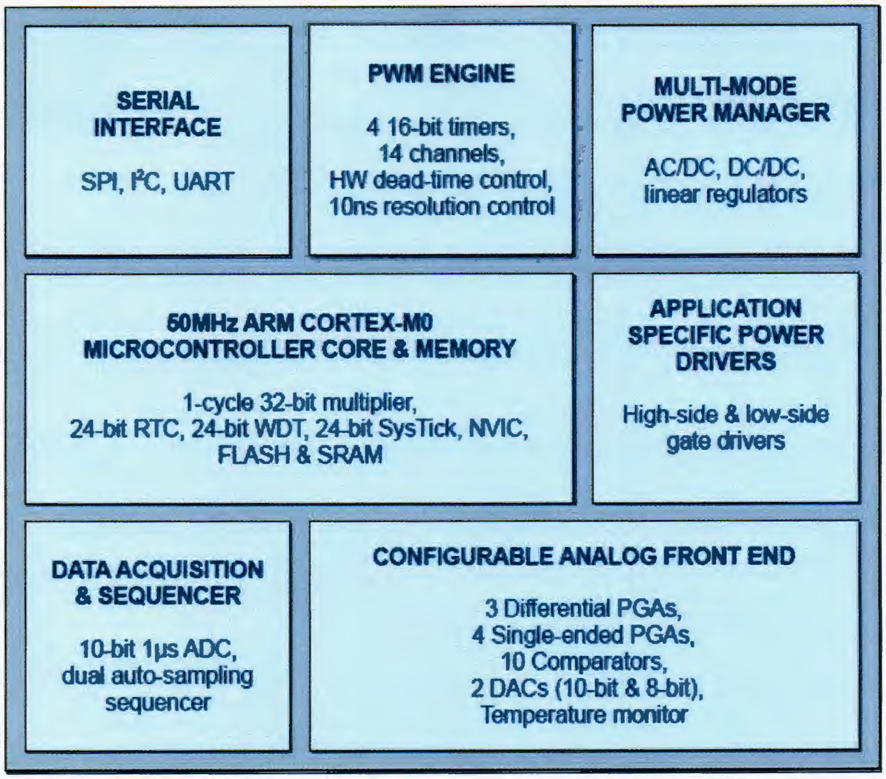

Figure 7: Power Application Controller

Figure 8 shows the test setup used to characterize the efficiency of various motor controls and motors. Initial efficiency data looks promising when using the OTC controller. The controller has been tuned for the targeted motor and efficiency data is being taken and compared against data from the original motor control. It is anticipated that with the OTC controller and appropriate transistor selection, efficiency will exceed that of the existing motor control.

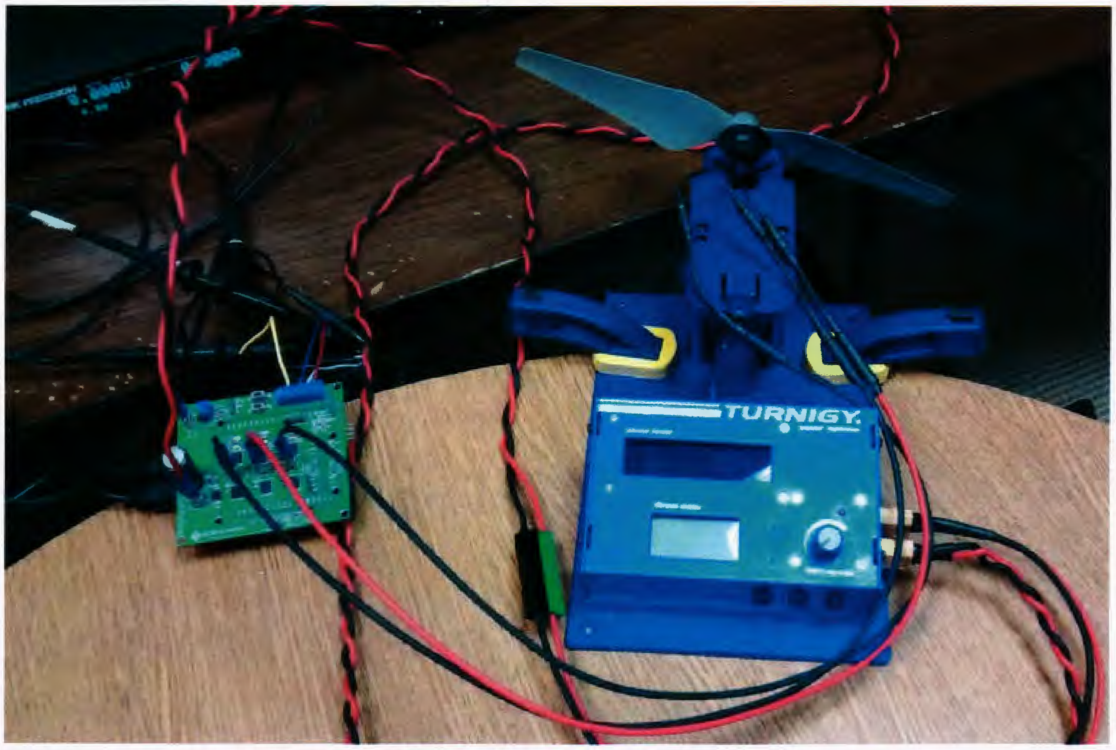

Figure 8: ESC Prototype Board and Thrust Monitor

Objective 5: Implement Solar Soaring Algorithms

Work continues with the conversion of the solar soaring algorithms into UAV compatible microprocessor code. An additional platform with significantly more processing power has been obtained. This is a Xilinx Zynq platform which combines ARM processors with FPGA fabric. Since the Zynq is capable of running a linux OS as well as RTL, algorithms will initially be written in Python. Once the algorithms are written and verified in Python, they will be converted to C code. Then the Xilinx high level synthesis tools can convert the C code to RTL for execution on the FPGA fabric. It is expected that this will result in faster computation and lower power consumption. A picture of the Xilinx Zynq evaluation boards is shown in Figure 9.

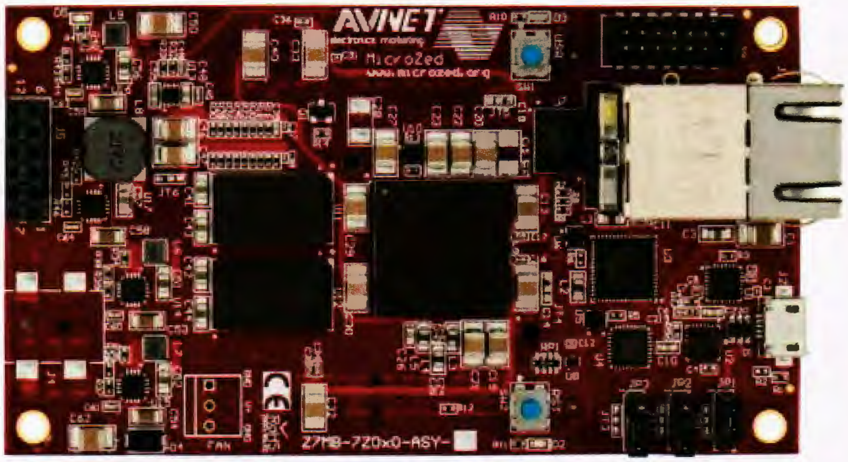

Figure 9: Xilinx Zynq Eval Board

Other activities:

Packet Digital met with representatives from the Northern Plains Unmanned Systems Test Site to discuss the details of conducting a test flight in North Dakota. Significant progress was made and discussions will continue as the UAS nears flight-readiness.

Budget

Total project cost for phase II was expected to be $1,000,000, of which $350,000 is provided by NDIC, and $650,000 is provided by matching funds. Of the matching funds, $600,000 is provided by the Naval Research Lab and $50,000 is from a private investor. Table 1 lists the budget estimate for Phase II and Table 2 lists the budget status as of March 31, 2016.

Table 1: Phase II Budget Estimate

Project Associated Expense	NDIC's Share	Private Sponsor Share	Naval Research Lab Share	Total
Direct Personnel Costs	$181,200	$0	-	-
Indirect OH and G&A (65%)	$117,800	$0	-	-
Total Personnel Costs	$299,000	$0	$486,000	$785,000
Software Costs/Materials	$51,000	$50,000	$114,000	$215,000
Total	$350,000	$50,000	$600,000	$1,000,000

Table 2: March Interim Budget Status

Project Associated Expense	NDIC's Share	Private Sponsor Share	Naval Research Lab Share	Total
Direct Personnel Costs	$154,251	$0	-	-
Indirect OH and G&A (65%)	$100,011	$0	-	-
Total Personnel Costs	$254,262	$0	$224,398	$478,660
Software Costs/Materials	$15,965	$15,339	$74,799	$106,103
Total	$270,227	$15,339	$299,197	$584,763

Summary

Phase II Deliverables:

- Solar cell development
  - NRL has fabricated 5 junction solar cells capable of nearly 37% efficiency, 6 junction cells are in process.
  - The manufacturing process for flexible solar arrays which will incorporate solar cells into the into wing skins has been defined and prototyped.
- Update power system to support commercial UAS
  - Initial prototypes of the smaller, more flexible MPPT and PMAD have been developed and are undergoing testing.
- Hybrid smart battery
  - Incorporating graphene LiPo batteries into the current smart battery to reduce impedance while minimizing impact to capacity.
  - Continuing to evaluation electrical and mechanical impact of adding a hydrogen fuel cell into our UAV.
- Optimized torque motor control
  - Optimized torque control motor controller is being characterized against industry standard motor controls. Firmware and tuning optimizations are ongoing.
- Implement solar soaring algorithms
  - Converting algorithms to Python code.
  - Targeting Xilinx Zynq devices as one possible implementation target.

Significant progress has been made in phase II of this project and Packet Digital is on track to have a complete the objectives as per the original project timeline. NRL is also on track in terms of the solar cell development.