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1012723

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APPLICATION NUMBER: 62/756,028

FILING DATE: November 05, 2018

RELATED PCT APPLICATION NUMBER: PCT/US19/42763

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
		Application Number	
Title of Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

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☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
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Inventor Information:

Inventor 1				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Daniel		Flanigan	
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service				
City	Petaluma	State/Province	CA	Country of Residence ⁱ US
Mailing Address of Inventor:				
Address 1		201 8th Street		
Address 2				
City	Petaluma	State/Province	CA	
Postal Code	94952	Country ⁱ	US	
Inventor 2				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Tyrus		Hudson	
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service				
City	Petaluma	State/Province	CA	Country of Residence ⁱ US
Mailing Address of Inventor:				
Address 1		523 Purrington Road		
Address 2				
City	Petaluma	State/Province	CA	
Postal Code	94952	Country ⁱ	US	
Inventor 3				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Charles		Almy	

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
		Application Number	
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City	Berkeley	State/Province	CA	Country of Residence ⁱ
US				

Mailing Address of Inventor:

Address 1	1668 Lincoln Street			
Address 2				
City	Berkeley	State/Province	CA	
Postal Code	94703	Country ⁱ	US	

Inventor 4

Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Jack		West	

Residence Information (Select One)		☒ US Residency	☐ Non US Residency	☐ Active US Military Service
City	San Rafael	State/Province	CA	Country of Residence ⁱ
US				

Mailing Address of Inventor:

Address 1	612 Point Gallinas Road			
Address 2				
City	San Rafael	State/Province	CA	
Postal Code	94903	Country ⁱ	US	

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Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).			
☐ An Address is being provided for the correspondence information of this application.			
Customer Number	157339		
Email Address	pmancini@ojjo.com	Add Email	Remove Email

Application Information:

Title of the Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits		
Attorney Docket Number	PPA18	Small Entity Status Claimed	☒
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	8	Suggested Figure for Publication (if any)	

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Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
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Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

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Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)

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This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ⁱ (if applicable)

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Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. ☐ NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.
--

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	PPA18
	Application Number	
Title of Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

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A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

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The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
		Application Number	
Title of Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

- ☐ Assignee
 ☐ Legal Representative under 35 U.S.C. 117
 ☐ Joint Inventor
- ☒ Person to whom the inventor is obligated to assign.
 ☐ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name Ojjo, Inc.

Mailing Address Information For Applicant:

Address 1	47 Mark Drive		
Address 2			
City	San Rafael	State/Province	CA
Country ¹	US	Postal Code	94903
Phone Number	415-786-4685	Fax Number	
Email Address	pmancini@ojjo.com		

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
		Application Number	
Title of Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits		

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If the Assignee or Non-Applicant Assignee is an Organization check here. ☐				
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Address 2				
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA18
		Application Number	
Title of Invention	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits		

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Phillip D. Mancini/			Date (YYYY-MM-DD)	
First Name	Phillip	Last Name	Mancini	Registration Number	46743
Additional Signature may be generated within this form by selecting the Add button.					

FIG. 1A

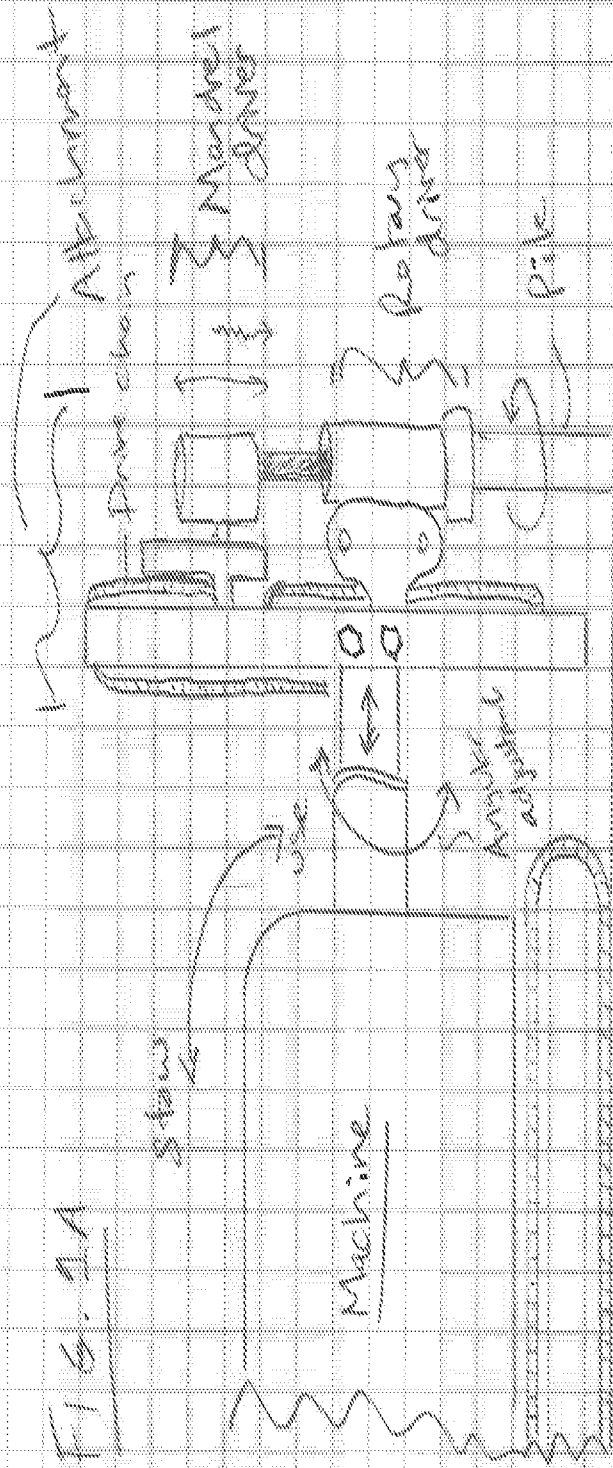


FIG. 1B

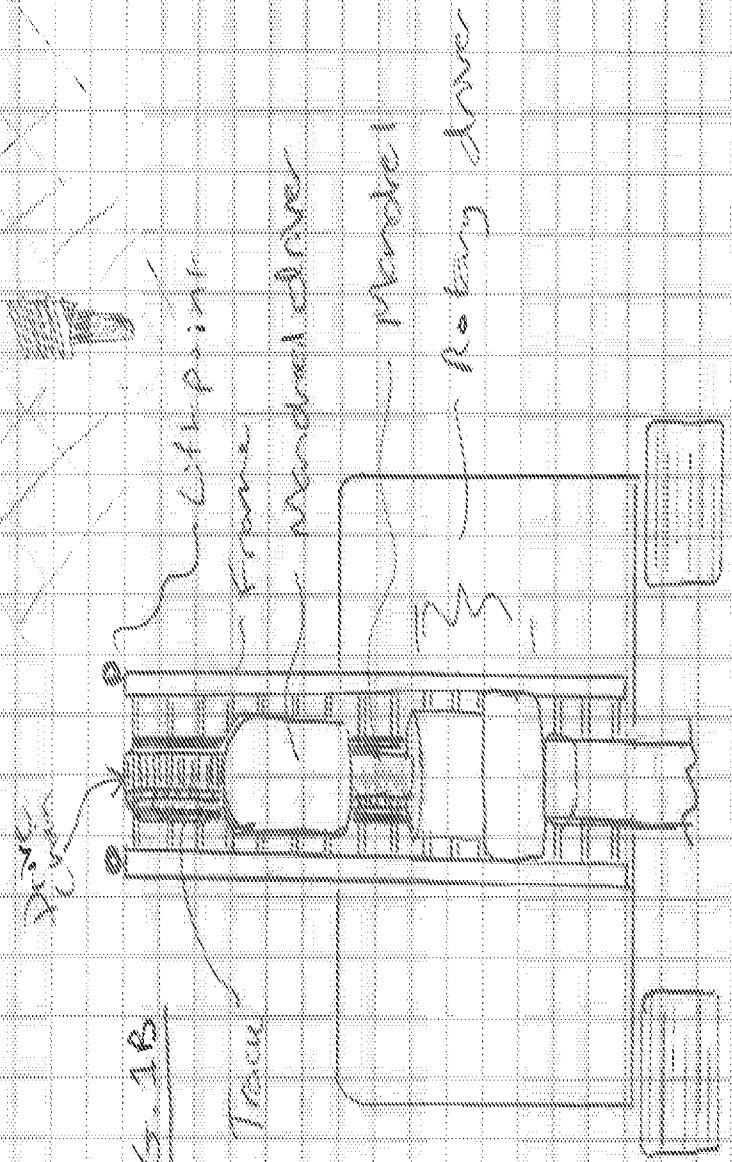


Fig. 2

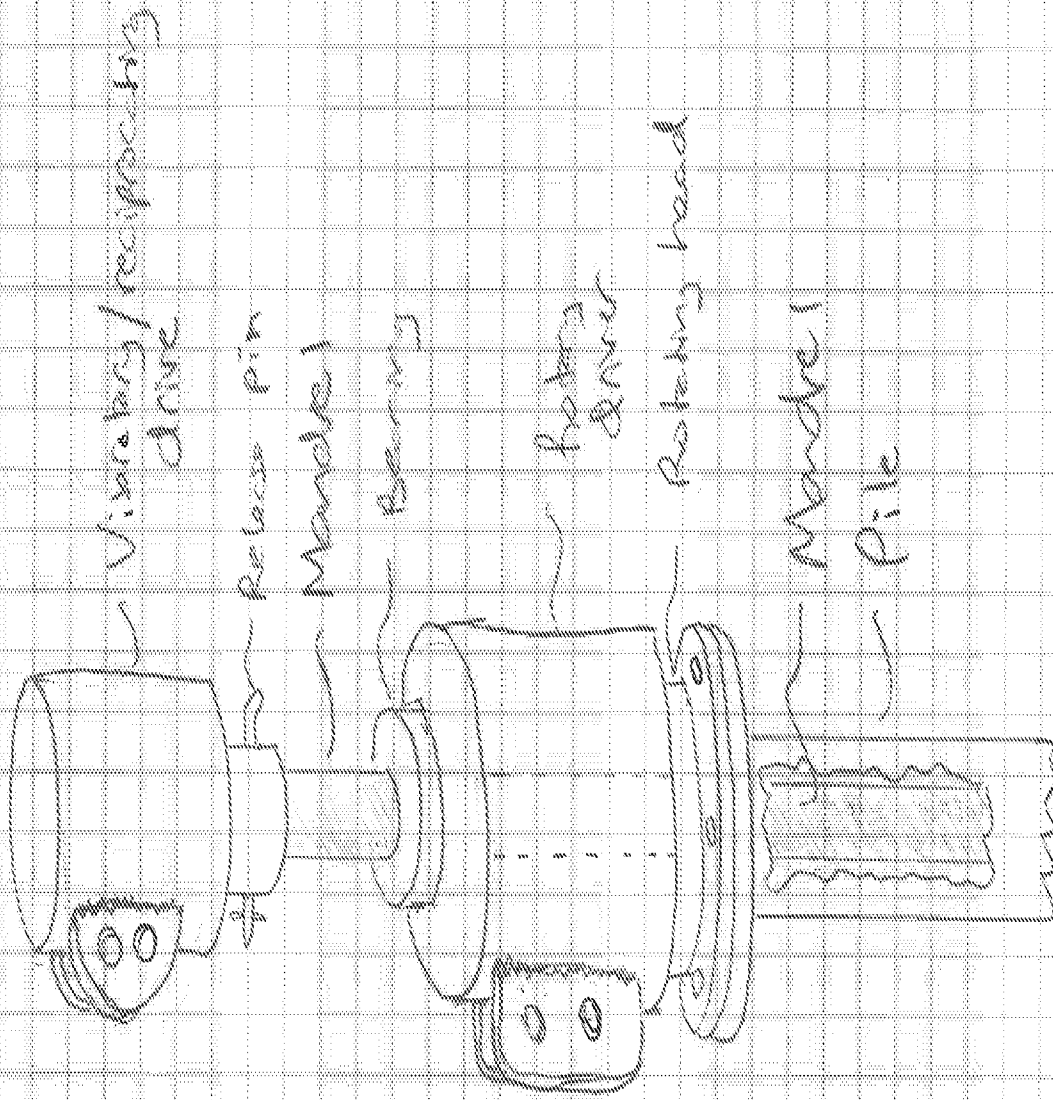


FIG. 3

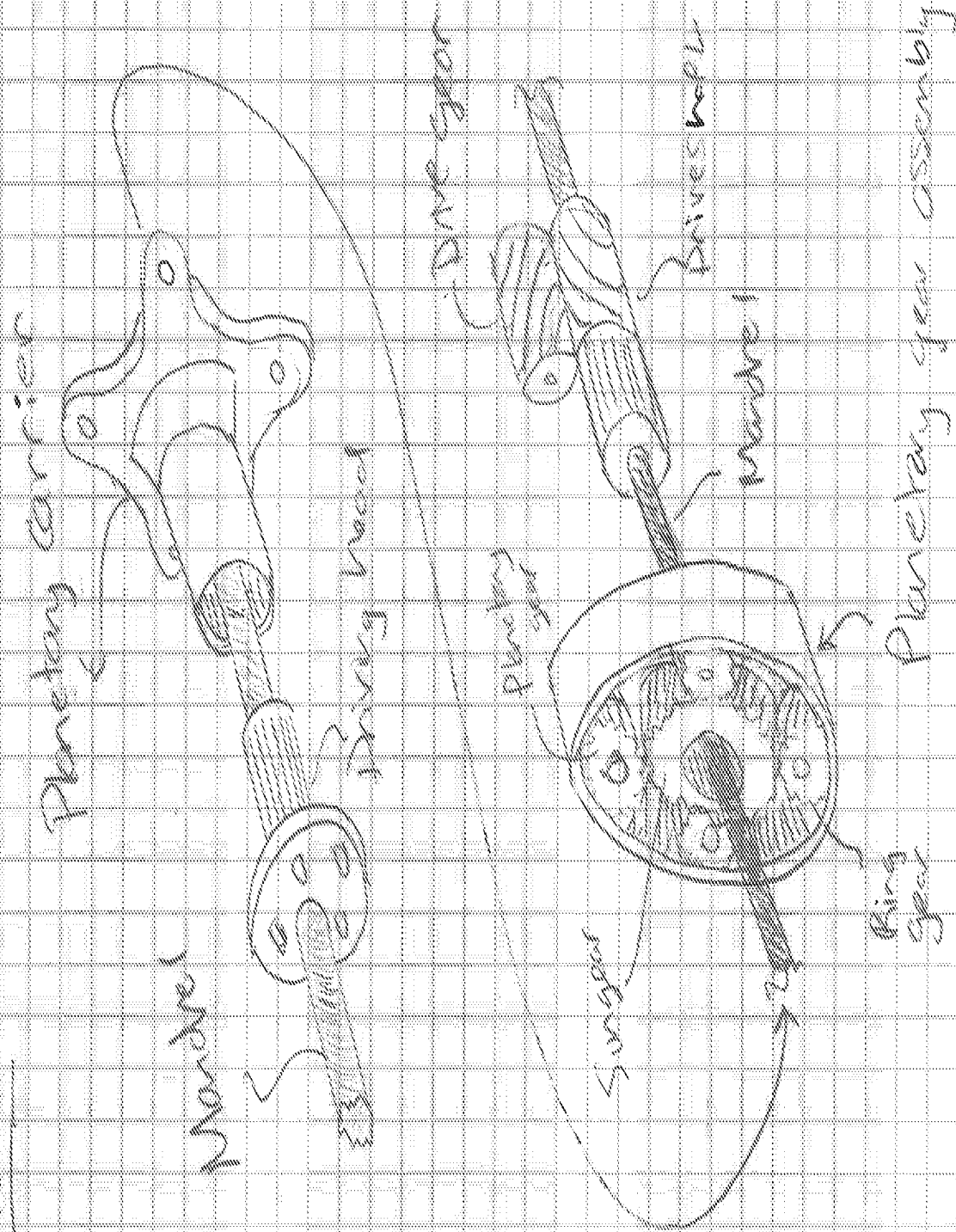


FIG. 24

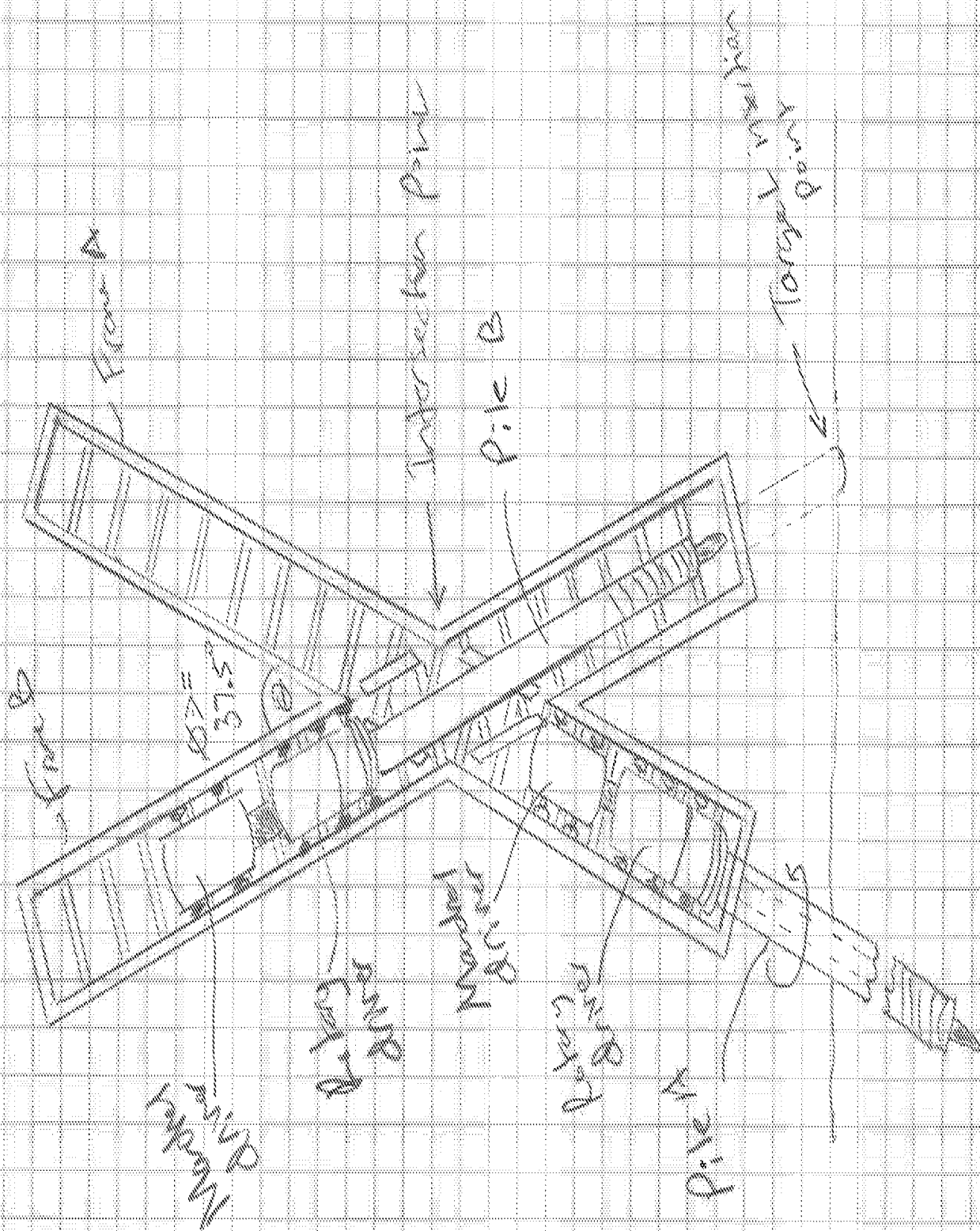


Fig. 5

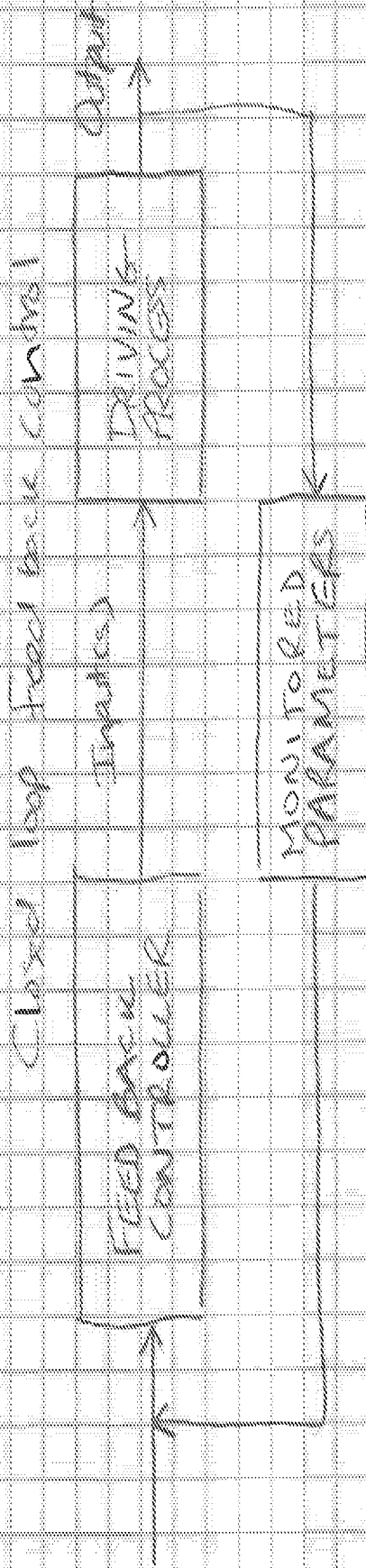


Fig. 6

System Architecture

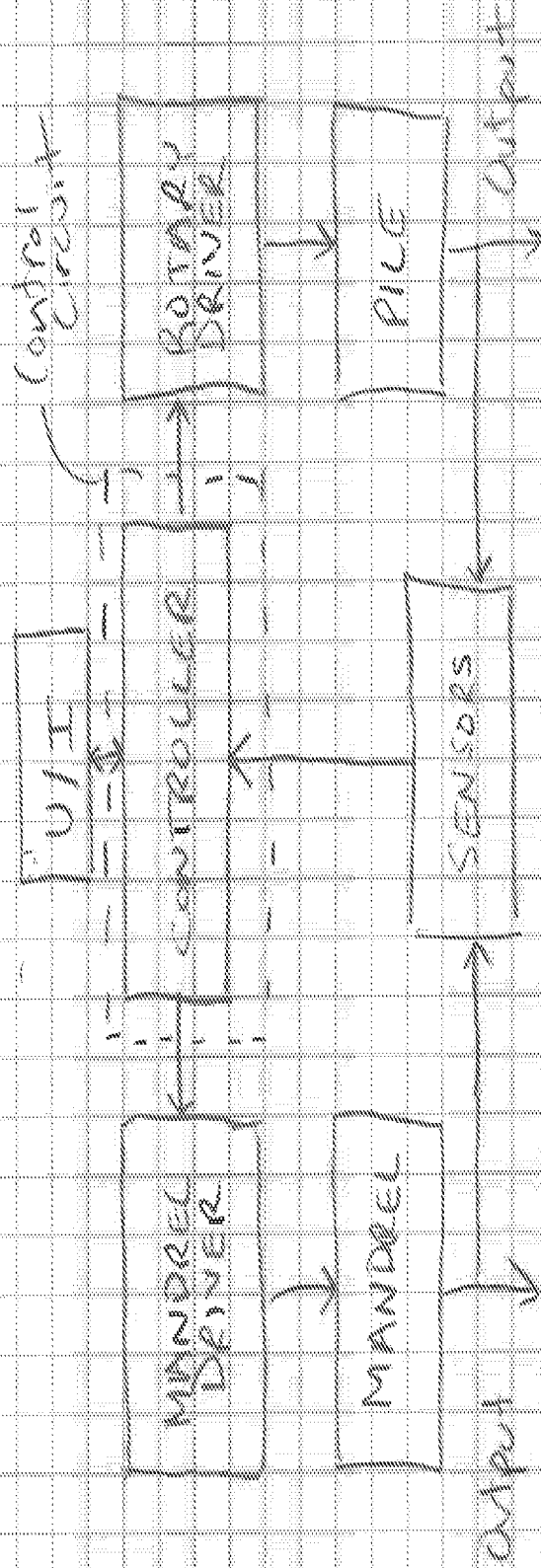


Fig 7

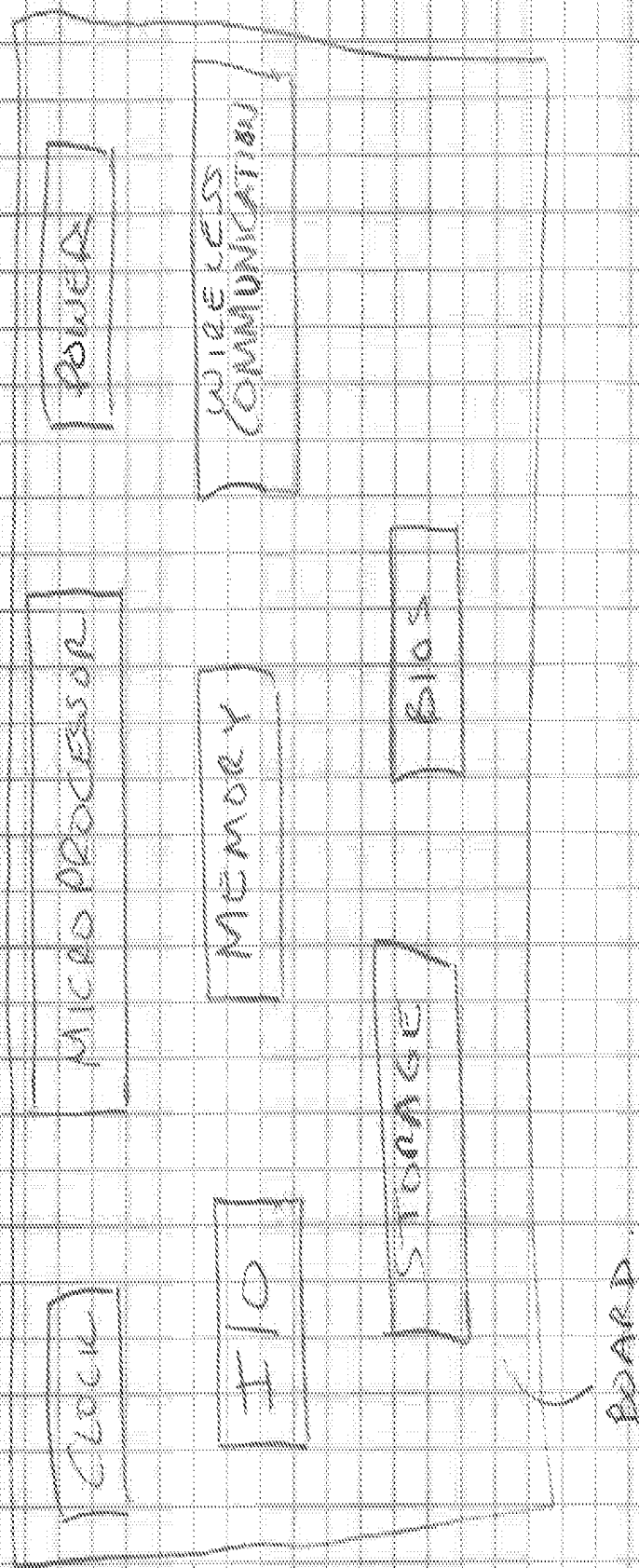


Fig. 8

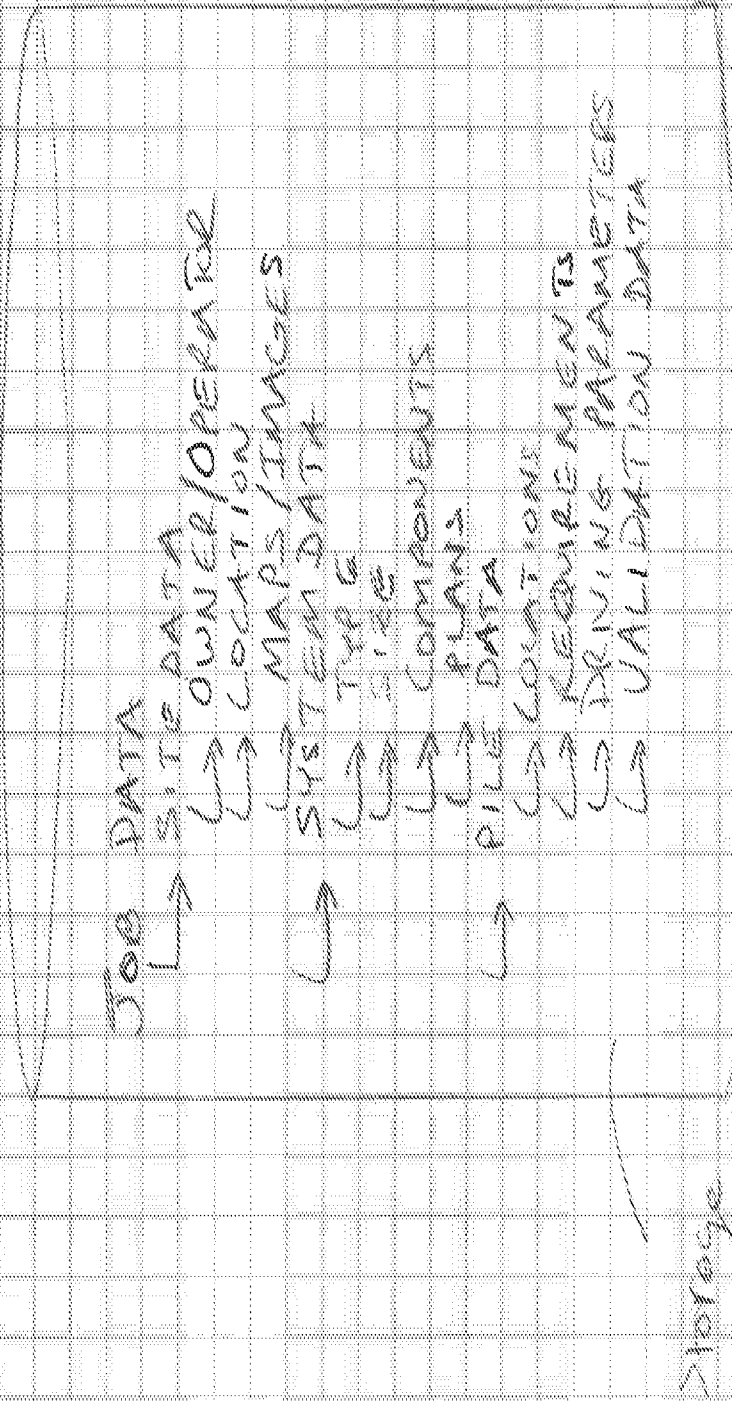
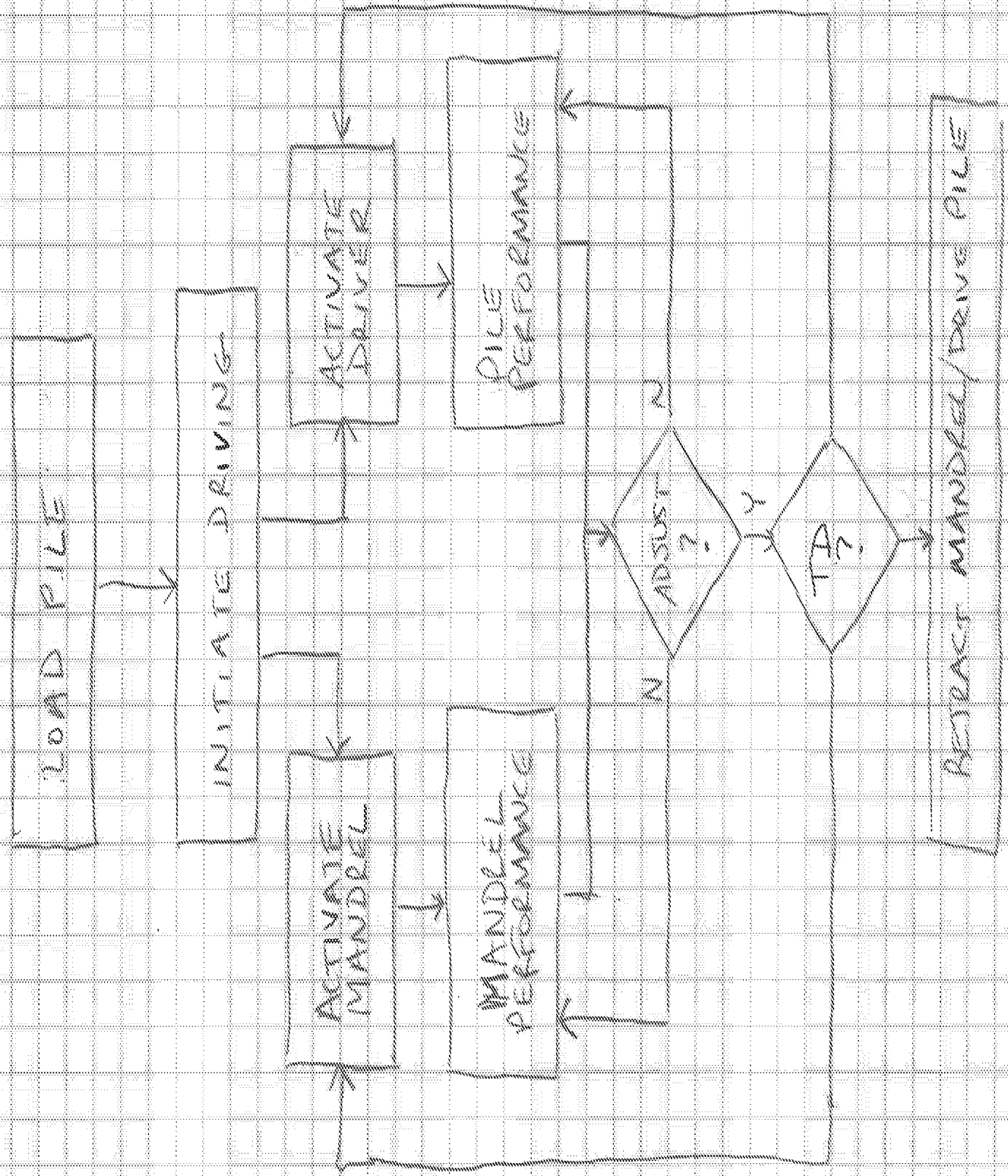


FIG. 9



Electronic Acknowledgement Receipt	
EFS ID:	34218032
Application Number:	62756028
International Application Number:	
Confirmation Number:	2822
Title of Invention:	Closed loop feedback control for improved solar pile driving and related systems, methods, machines, and circuits
First Named Inventor/Applicant Name:	Daniel Flanigan
Customer Number:	157339
Filer:	Phillip Dominick Mancini
Filer Authorized By:	
Attorney Docket Number:	PPA18
Receipt Date:	05-NOV-2018
Filing Date:	
Time Stamp:	20:19:25
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$ 140
RAM confirmation Number	110618INTEFSW20210100
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Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	WebADS.pdf	146163	no	8
			d23c9f105f7aac2ebca85ec94651127908c64c91		
Warnings:					
Information:					
2	Specification	PPA18.pdf	150523	no	21
			e385e68d74d0ed08f297c459f2ea7ab6943f0fad		
Warnings:					
Information:					
3	Drawings-only black and white line drawings	PPA_18DWG.pdf	2902056	no	8
			41be653c35244120de458a77843d8e6c5f6cda81		
Warnings:					
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4	Fee Worksheet (SB06)	fee-info.pdf	29847	no	2
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CLOSED LOOP FEEDBACK CONTROL FOR IMPROVED SOLAR PILE DRIVING AND RELATED SYSTEMS, METHODS, MACHINES AND CIRCUITS

BACKGROUND

[0001] Since the advent of the computer, automated process control techniques have improved process times, reduced reliance on human labor, and increased the accuracy and consistency of many industrial processes.

[0002] Closed loop feedback control improves on industrial automation by examining the output(s) of a system and using the output(s) to adjust the system's inputs to achieve a current set point for the process. In the simplest case of a machine, for a given input there is an expected or desired output. A negative feedback loop can examine the actual output and compare it to the expected output for the given level of input. If, for example, the input is torque on a driver, the output could be the expected movement resulting from that torque. If that movement is greater or less than expected for the level of input, an adjustment to the torque may be made to achieve the desired output (e.g., movement) or to protect the torque motor. As a slightly more sophisticated example, in the context of automobiles, monitoring the rotational speed of a vehicles wheel with a closed loop feedback system can alert an automated traction control system of a dangerous condition and allow it to adjust power distribution in real time. For example, if vehicle's wheel suddenly spins faster than expected for a given level of engine output in a known gear, the vehicle's stability control system may determine that the wheel has lost traction and may curtail power to that wheel, may redistribute power to other wheels or take other measures to correct this undesirable situation. The possibilities for incorporating negative feedback into automated or semi-automated industrial process are limited only by the imagination.

[0003] One common feedback mechanism used in industrial control systems requiring continuously modulated control is so called proportional-integral-derivative (PID) control. PID is a control loop feedback mechanism (controller) that continuously calculates an error value as the difference between a desired setpoint and a measured process variable. The PID algorithm consists of three coefficients – proportional, integral and derivative – that are

varied to get an optimal output response. In a typical control system, the process variable is the parameter that needs to be controlled, such as, for example, temperature, pressure or flow rate. A sensor is used to measure that process variable and the difference between the measured value and the set point is used by the control system algorithm to determine the appropriate actuator output to achieve the setpoint.

[0004] There are many PID controllers available in the market that can perform this type of automated continuous feedback control. However, in more dynamic situations, a higher level and more sophisticated control system may be necessary to achieve a desired outcome. This is especially true when the setpoint is not known or is not constant, or when there are unpredictable or dynamic situations that can occur requiring different responses.

[0005] This disclosure focuses on the use of negative feedback control to improve and optimize outcomes when installing foundation components and more specifically, foundation piles for axial solar arrays. Axial solar array arrays include single axis trackers and fixed tilt solar arrays. These types of arrays are laid out along North-South or East West axes respectively to optimize energy harvest.

DESCRIPTION

[0006] The invention will now be described in the context of the drawing figures where like elements are referred to with like designations. Various embodiments of the invention are directed to systems and methods for closed-loop feedback control of a pile driving machine that includes a rotary driver for driving in a screw pile and a mandrel driver for plunging a mandrel through the center of the screw pile to assist driving the pile. The invention may be especially useful for controlling and improving a driving process for foundation piles for axial solar arrays but will also be useful for controlling and improving the driving process for foundations for numerous other structures.

[0007] Turning now to FIGS. 1A and 1B, these figures show side and front views respectively of an exemplary machine for driving foundation piles with a control system according to various embodiments of the invention. As shown, the machine includes a main body riding on a set of parallel tracks. It should be appreciated that the machine could instead ride on tires, on a combination of tires and tracks, on a floating barge, on rails or on

other known means. As shown, the machine has an attachment mounted to the end of an articulating arm. In various embodiments, the articulating arm is part of the base machine and can move through an arc of approximately 90 degrees from a stowed position where the arm is substantially perpendicular to the ground to an in-use position where the arm is substantially parallel to the ground. In various embodiments, the end of the articulating arm is also able to rotate through a range of angles about its axis (e.g., plus or minus 30 degrees from perpendicular) so that piles may be driven into the ground at angles with respect to normal. This also decouples the pile driving direction from the orientation of the machine allowing it to compensate for uneven terrain. In various embodiments, the end of the articulating arm will support a pile driving attachment with a main axis that is substantially perpendicular to the articulating arm. Therefore, when the arm is in the stowed position, the attachment will be substantially parallel to the ground, minimizing its height, whereas when the arm is in the in-use position, the pile driving attachment will be substantially perpendicular to the ground.

[0008] As shown in the example of FIGS. 1A/1B, the pile driving attachment includes a ladder-like frame that functions as a scaffold to support a rotary driver and a mandrel driver, and that provides an axis for them to move along. In various embodiments, the frame includes a pair of parallel side members that are interconnected by perpendicular cross members. The frame may also include one or more tracks that the mandrel driver and rotary driver travel along. Alternatively, the mandrel driver and rotary driver may travel on wheels within the inside of the parallel side members. In various embodiments, one or more drive chain and motor assemblies may be used to move the mandrel driver and rotary driver along the tracks attached to the frame. In various embodiments, they can move along the track independent of one another. In other embodiments, they may move along the track together.

[0009] In various embodiments, the rotary driver may be powered by electric current or by hydraulic actuation in a manner known in the art. Similarly, the mandrel driver may be powered by compressed air, electric current or by hydraulic actuation. In various embodiments, and as shown in the figures, the mandrel driver and rotary driver may be

oriented concentrically on the frame in the direction of the track so that the shaft of the mandrel can pass through the rotary driver and move up and down within the driver while the driver is spinning a screw pile into the ground. In this manner, the mandrel may operate ahead of the screw pile, projecting out of its open tip, to clear a path for the pile. This may also allow for the mandrel to be dropped down through the rotary driver once it is decoupled from its driver for repair and/or replacement without completely disassembling the attachment.

[0010] In various embodiments, concentric operation is accomplished with a planetary gear assembly in the rotary driver, having a sun gear with an open center so that the mandrel shaft can pass through while the planetary gear assembly is rotating. In various embodiments, at least one annular bearing or collar may reside at the center of the sun gear, above, and/or below the rotary driver to allow the gear and mandrel to reciprocate or vibrate without effecting the rotary driver's motion.

[0011] With continued reference to FIGS. 1A and 1B, the machine has a main body portion housing the machine's motor or engine, a fuel tank, a chassis, counter weights, an operator's seat, steering, a control interface, and tracks. The machine may also have an air compressor and air lines for supplying pressurized air to other equipment, a power take-off for mechanically transferring power, an electrical connection for providing electric power to the attachment, and one or more hydraulic interfaces for communicating hydraulic fluid to the attachment. In the example of FIGS. 1A/1B, the articulating arm projects away from one end of the machine (e.g., front or rear), functioning as an attachment support. In other embodiments, it may project from either side. In still further embodiments, the arm may be mounted on a rotatable turret that can rotate completely around a vertical axis over the tracks to any radial orientation.

[0012] Turning to FIGS. 2 and 3, these figures show a partial cut-away close-up of the mandrel and rotary driver and an exploded view of the rotary driver internals respectively. As shown, at its top end, the mandrel is pinned to the reciprocating/vibratory mandrel driver with a release pin. This will allow the mandrel to be quickly and easily removed. Next, as shown, the mandrel passes through a bearing positioned at top of the rotary driver.

In various embodiments, this bearing will allow the mandrel to move axially with respect to the driver, such as, for example, when reciprocating, and will allow the gear assembly surrounding the mandrel to rotate without effecting it. In FIG. 2, a pile is attached to the rotary driver via interconnection between a rotating head on the driver and a driving plate at the above-ground end of the pile. The cut-away of the pile shows the mandrel concealed within the shaft of the pile. It should be appreciated that a different geometry may be used at the driving head. For example, the head of the pile may be squared or divided into five or six segments like the head of a bolt and the rotating head on the driver may be shaped like a socket to receive the head of the pile.

[0013] FIG. 3 shows an exemplary drive train and gear assembly stack that allows the rotary driver to work concentrically with the rotary driver. The top of the stack includes a drive gear engaging a drive shaft. In various embodiments, the driver gear is mechanically coupled to an electric motor or hydraulic actuator and engages with the drive shaft via reciprocal gears. The drive shaft in this example has a driven portion for engaging with the drive gear and a driving portion for driving a sun gear of the planetary gear assembly. In various embodiments the driving portion may be splined to interface with reciprocal grooves formed in the center of the sun gear, making the sun gear the input to the planetary gear assembly. The sun gear in turn drives a set of planetary gears, in this example, four of them, to rotate within a fixed ring gear. A planetary carrier is attached to the center of each planetary gear to generate output power for the rotary driver. The planetary carrier in this example includes a splined female hub that mates with a splined driving head. The splined driving head includes a driving plate with a series of projections spaced around its surface. In various embodiments the projections will mate with an opening formed on a driving plate at the head of the pile to enable the rotary driver to impart torque and downward pressure to the pile. Though not shown, a second bearing collar may be positioned between the planetary carrier and the driving head to keep the mandrel on center and prevent it from interfering with the planetary carrier output.

[0014] Although A-frame style foundations offer substantial material reductions over H-piles because of the different force profile, one advantage that can't be overcome purely

with material savings is the time required to drive two piles as opposed to one. To compensate for this, various embodiments of the invention provide a machine, an attachment, and a system and related methods for driving a pair of adjacent piles at the same time or in overlapping time. To that end, FIG. 4 shows an attachment like that of FIGS. 1A and 1B, but with a pair of intersecting frames that intersect in the same plane at an angle to one another. In various embodiments, each is offset from vertical by more than 18 degrees for a total angle between them of 37.5 degrees or greater. In various embodiments the frame fits together with gaps in the track at the points of intersection so that each driving assembly can travel down its axis, crossing the other intersecting axis.

[0015] For example, looking at FIG. 4, frame A is angled from right to left and includes a first driving assembly consisting of a rotary driver and mandrel driver. In this example a pile has been attached to the rotary driver with a mandrel plunged through its center and projecting out of the leading end. Once the mandrel driver and rotary driver assembly has traveled past the point of intersection, that is, has been driven far enough that both components have crossed the intersection point, the second pile may be loaded onto the second driving assembly. The second driving assembly here consists of essentially the same components – a rotary driver and a mandrel driver traveling on a second track built into frame B. In various embodiments, frame A and frame B will be welded or otherwise attached to form a unitary X-shaped structure. In various embodiments this X-shaped structure is attached to the articulating arm of a machine, such as that shown in FIGS. 1A and 1B. In other embodiments, the machine may be attached to the arm of an excavator, skid-steer loader, tractor or other suitable machine and will interact with and function in a similar manner to single frame attachment of FIGS. 1A and 1B.

[0016] For the respective driving assemblies to travel through the intersection point, it may be necessary to form breaks in the frame members making up the rail so that each assembly can pass through the other assembly's rails. This is seen, for example at the point labeled "intersection point" in FIG. 4. Though not shown, a bracket or adapter may be used to securely attach the X-shaped attachment assembly to the articulating arm of the machine supporting it. It should be appreciated that in various embodiments it may be desirable to

use a larger angle Θ between the two intersecting frame sections than that shown here, such as, for example 40 degrees or larger, to reduce the compressive and tensile forces on the A-frame legs due to lateral loads. In various embodiments the X-shaped frame may have a level built-in so that an operator can adjust the arm clockwise or counter clock-wise to adjust for variations in ground level. Off plane variations in level may be compensated for by adjusting the height of the articulating arm on the machine.

[0017] Though not shown, in various embodiments, the two independent driving assemblies may move about their respective tracks via a chain drive system or other known movement system in a manner analogous to the attachment shown in FIGS. 1A and 1B. In various embodiments, the attachment may require a second set of electrical, hydraulic and/or compressed air connections to the base machine to power the second drive assembly. In other embodiments, one or more manifolds or like devices may be used to divide pressurized hydraulic fluid or air.

[0018] Turning now to FIG. 5, this figure shows a generic closed loop feedback control system used to adjust inputs based on detected outputs to achieve a desired output. Feedback control is often employed in automated process to keep performance at the desired set point. Closed loop feedback control monitors output in real-time, compares that to the current set point, and if necessary, adjusts inputs to achieve the current setpoint. Here, the inputs are inputs to a pile driving process. The inputs could be instructions from a user interface (e.g., initiate a pile driving process) or lower level inputs like control signals from a controller to an actuator to cause the actuator to perform a process step in the pile driving process. Sensors monitor the output parameters (e.g., rate of penetration, rotational speed, etc.) and determine if the output is consistent with the set point. If not, the feedback controller adjusts the system inputs to try to achieve the desired setpoint.

[0019] FIG. 6 is a functional block diagram showing elements of a system to perform closed-loop feedback control such as that shown generically in FIG. 5 in a pile driving machine and attachment such as that shown herein. In this exemplary architecture a single controller controls all system components and performs feedback control. The box labeled

controller here may be a microcontroller, computer, PC board, or other known process-based computing device. The controller receives inputs and sends output to a user interface device, labeled U/I in the drawings. The U/I may be digital touch screen, a set of knobs, dials and buttons (e.g., physical user interface), lights, speaker, and/or other indicators. Alternatively, the U/I may reside on a separate device (e.g., smartphone app) and communicate the other system elements via a wired or wireless communication protocol (e.g., Wi-Fi, Bluetooth, ZigBee, 3G, 4G, LTE, etc.). The user interface is used to send commands that are translated by the controller into machine language and sent to the various system components (e.g., machine, mandrel driver, rotary driver, peripheral systems, etc.). The user interface is also used to receive information from the controller such as status information, real-time operating parameters, and alerts.

[0020] The mandrel driver includes circuitry that controls power to the mandrel and controls the functioning of the motor or hydraulic actuator controlling it (e.g., how much power it receives, mode of operation, direction of operation, magnitude of downward force, etc.). The mandrel itself is simply a piece of hardened metal without any circuitry or control interface other than its physical interface to the mandrel driver. However, one or more sensors may be positioned proximate to the mandrel head or in the mandrel driver to detect vibration levels, sound waves, or other detectable phenomena that may be indicative of the real-time soil conditions at the mandrel tip. Also, the mandrel driver itself has multiple operating parameters that are monitored by the controller including vibration frequency if a vibratory mandrel, reciprocating frequency, downward force, penetration rate, position relative to the pile, current delivered to the driver, hydraulic pressure delivered to the driver, and/or air pressure delivered to the driver. This information is sent to the controller in real time so that the controller can optimize the driving process and detect refusals before the mandrel or pile are damaged.

[0021] Similarly, the rotary driver includes control circuitry that controls the operating parameters of the rotary driver including the speed of rotation, hydraulic pressure supplied to the driver, electrical current supplied to the driver, and downward force applied to the pile. Like the mandrel, the pile itself is simply a piece of metal, however, one or more

sensors may monitor the rotational speed and rate of ground penetration, so called speed and feed rates. The ratio of speed to feed can indicate whether the pile is being driven or only augering (i.e., spinning in place). This information along with the real-time operating parameters of the rotary driver are supplied to the controller so that it can keep the driving process within a desired range of operation, prevent augering and quickly detect refusals or other malfunctions.

[0022] FIG. 7 is a generic circuit diagram showing exemplary elements of the control circuit shown in the dotted outline box of FIG. 6. The elements shown here include a microprocessor, memory, storage, basic input/output system (BIOS), system clock, input/output (I/O), wireless communication module and power, all interconnected on a bus board. In various embodiments, the circuit may be an integrated or modular programmable logic controller (PLC). Alternatively, it may be a personal computer (PC) running a system control program. The storage may be a hard disk drive, solid state drive or so-called hybrid drive. The storage may be part of the physical circuit, communicatively and electrically coupled to the physical circuit, remote to the physical circuit, or a combination of these. For example, the storage may contain the operating system of the PLC or PC, which needs to be present on the board for real-time operation. The control program may be written in one of several known programming languages for PLC programming including function block diagram, ladder logic, sequential flow chart, structured text and instruction list. Alternatively, if a generic PC is used, the control program may be written in C, C++, .NET Framework, or other suitable PC-compatible programming language.

[0023] The storage may also contain information generated during driving operations. It may be desirable to store this type of acquired information remotely (e.g., in a cloud-based database) because it may be useful to have this information stored with other information about the job site that is not necessary for operation of the driver control system. Therefore, the circuit may store this information temporarily and transfer it to available cloud-storage via the wireless communication module or other communication device connected to the circuit via the physical I/O interface.

[0024] FIG. 8 is a diagram showing elements of a database storing information corresponding to a pile driving job, such as, for example an axial solar array (e.g., single-axis tracker) including high level information about a job including job owner, system operator, location, maps/images. The database also includes system data including the type of system, size of the system, components of the system and job plans (e.g., what size/type piles to install where). The database also includes information that is generated during driving operations. This information includes, the specific location where piles were driven (e.g., GPS coordinates, the position on a site map, etc.), the operating parameters generated during each driving operation (depth, time, soil conditions, refusals) and any validation data for that pile (e.g., pull test pass/fail). In various embodiments, the components of this data that are specific to driving will be generated and accumulated by the control circuit during driving and will be batched to cloud database after each driving operation, at the end of the day, or when the entire job is complete. A smartphone application or other external device may be used to initiate transfer of this data.

[0025] Turning now to FIG. 9, this figure is a flow chart showing the steps of a method for controlling a driving operation according to various embodiments of the invention. The method begins with loading a pile onto the driver and orienting the pile and mandrel driving assembly to the desired driving location and orienting the articulating arm to the desired driving angle. If the driving attachment is one capable of driving two piles at the same time, such as that shown in FIG. 4, the second pile may not be able to be loaded until the first pile is partially driven into the supporting soil so that the first driver assembly has cleared the path of the second driving assembly.

[0026] Machine control begins with an operator hitting a button or selecting a control on the user interface to initiate the driving process. In various embodiments, this will cause the controller to activate the mandrel driver and the rotary driver. The mandrel driver may simply push the mandrel down through the opening in the pile or may begin reciprocating itself while pushing down. Likewise, the rotary driver may begin rotating the pile to screw it into the supporting soil with a combination of rotation and downward pressure. In various embodiments, the controller will begin receiving information from the mandrel driver and

the rotary driver regarding their respective performance. Some of this information will be operating parameters of these respective devices, including their input power, operating speed, etc. Other information may include sensed information such as rate of penetration, resistance to the mandrel (as indicated by vibration or other measurable metric), position of the pile relative to the mandrel, and depth of the pile. This information is fed to the controller in real-time so that the controller can determine whether any operating parameters (e.g., system inputs) need to be adjusted to keep the driving process within specification and/or to mitigate a refusal or other unstable condition. This may entail altering the rotational speed and/or the feed rate of the rotary driver, or even pausing it completely to provide time for the mandrel to clear a rock or other obstruction.

[0027] In various embodiments, and as shown in the flow chart, before making any process adjustments, the machine may confirm whether the target depth has been reached and therefore the driving process can terminate. If not, the process adjustment is made, and monitoring continues. Otherwise, the first stage of the driving process stops. Because the mandrel is working ahead of the pile, the mandrel may create a void below the pile tip. Therefore, in various embodiments, if the target depth has been achieved, the controller will issue a command to the mandrel driver to retract it into the pile so that the rotary driver may continue rotating the pile down until the pile has traversed the additional length of any void created by the mandrel.

[0028] The embodiments of the present invention are not to be limited in scope by the specific embodiments described herein. For example, although many of the embodiments disclosed herein have been described with reference to systems and methods for installing foundation for axial solar arrays, the principles herein are equally applicable to systems and methods for installing foundations for other structures. Indeed, various modifications of the embodiments of the present invention, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such modifications are intended to fall within the scope of the following appended claims. Accordingly, the claims set forth below should be construed

in view of the full breath and spirit of the embodiments of the present inventions as disclosed herein.

CLAIMS**Claim Set One**

1. A control system for a solar pile driver having a rotating driver for driving a pile and a mandrel driver for controlling a plunging mandrel within the driven pile, the system comprising:
 - a user interface;
 - a controller;
 - a rotating driver;
 - a mandrel driver;
 - first monitoring circuitry configured to monitor input and output performance parameters of the rotating driver; and
 - second monitoring circuitry configured to monitor input and output performance parameters of the plunging mandrel, wherein the first and second driver monitoring circuitry is communicatively coupled to the controller and the controller is operable to send controls signals to the rotating driver and the mandrel driver based on the monitored performance parameters to adjust a performance parameter of at least one of the rotating driver and the mandrel driver.
2. The control system according to claim 1, wherein the input and output performance parameters of the rotating driver include one or more parameters selected from the group consisting of a hydraulic pressure delivered to the rotary driver, an electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an axial force exerted by the rotary driver, a rate of ground penetration by the driven pile, and a depth of the driven pile.
3. The control system according to claim 1, wherein the input and output performance parameters of the plunging mandrel include one or more parameters selected from the group consisting of a hydraulic pressure delivered to the mandrel, an electric current delivered to the mandrel, an air pressure supplied to the mandrel, a frequency of vibration of the mandrel, a frequency of reciprocation by the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

Claim Set Two

4. A machine comprising:

a chassis;

a drive motor;

an actuatable extension arm, the extension arms operable to sweep through a range of angles from substantially parallel to grade to substantially perpendicular to grade and further operable to rotate about its axis;

a frame attached to the actuatable extension arm, the frame defining an axis;

a rotary driver mounted on the frame and operable to travel along the axis of the frame while rotating a foundation pile into supporting ground; and

a plunging mandrel driver mounted on the frame, axially aligned with the rotary driver and operable to actuate a plunging mandrel within a shaft of the foundation pile to form a path ahead of the pile during driving.

5. The machine according to claim 4, wherein the plunging mandrel passes through the rotary driver.

6. The machine according to claim 4, further comprising a feedback controller communicatively coupled to the rotary driver and the mandrel driver, the feedback controller adjusting an operation of at least one of the rotary driver and the mandrel driver based on one more monitored parameters during driving.

7. The machine according to claim 6, wherein the monitored parameters are one or more parameters selected from the group consisting of a hydraulic pressure delivered to the rotary driver, an electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an axial force exerted by the rotary driver, a rate of ground penetration by the driven pile, a depth of the driven pile, a hydraulic pressure delivered to the mandrel, an air pressure delivered to the mandrel, an electric current delivered to the mandrel, a frequency of vibration of the mandrel, a frequency of reciprocation by the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

8. The machine according to claim 6, wherein adjusting an operation of one of the rotary driver and the mandrel driver comprises sending a control signal from the feedback controller to adjust one of the monitored parameters.
9. The machine according to claim 6, further comprising a user interface coupled to at least one of the feedback controller, the rotary driver and the mandrel driver, the user interface containing a control for initiating a driving process.
10. The machine according to claim 9, wherein the driving process comprises rotating a pile into the supporting ground with the rotary driver while simultaneously actuating the plunging mandrel ahead of the pile.
11. The machine according to claim 10, wherein actuating the plunging mandrel comprises vibrating the mandrel ahead of the pile.
12. The machine according to claim 10, wherein actuating the plunging mandrel comprises reciprocating the mandrel ahead of the pile.
13. The machine according to claim 9, wherein the feedback controller is operable to detect an obstruction likely to cause a refusal, to pause the driving process, and to provide an indication on the user interface device of the obstruction.

Claim Set Three

14. An automated method of controlling a solar pile driving machine comprising:
 - receiving a command at a controller initiating a driving operation via a user interface;
 - activating a rotary driver to begin rotating a pile into supporting ground;
 - activating a mandrel driver to operate a mandrel within the pile to clear a path ahead of it;
 - monitoring at least one operating parameter of the machine during the driving operation with a feedback controller; and
 - adjusting a performance characteristic of at least one of the rotary driver and the mandrel driver with the feedback controller based on the step of monitoring.
15. The method according to claim 14, wherein adjusting a performance characteristic comprises adjusting at least one operation selected from the group consisting of adjusting a hydraulic pressure delivered to the rotary driver, adjusting an electric current delivered to

the rotary driver, adjusting a speed of rotation of the rotary driver, adjusting a direction of rotation of the rotary driver, adjusting an axial force exerted by the rotary driver, adjusting a rate of ground penetration by the driven pile, adjusting a hydraulic pressure delivered to the mandrel, adjusting an electric current delivered to the mandrel, adjusting a frequency of vibration of the mandrel, adjusting an air pressure supplied to the mandrel, adjusting a frequency of reciprocation of the mandrel, adjusting an axial force exerted by the mandrel, and adjusting a position of the mandrel relative to the pile.

16. The method according to claim 15, further comprising detecting a refusal by the feedback controller based on a value of at least one of the monitored parameters.

17. The method according to claim 16, further comprising, upon detecting a refusal, sending a signal to cause the machine to pause the driving operation and activating a notification to alert an operator of the refusal via the interface device.

Claim Set Four

18. A circuit for implementing feedback control on a pile driving machine comprising:

a feedback controller, a system clock, a memory, a data store, an input/output module, a BIOS, and a communication module, all communicatively coupled to a bus;

a power supply powering the bus;

a feedback loop coupled to the input/output module, the feedback loop providing real-time feedback corresponding to at least one performance characteristic of the pile driving operation to the controller, the controller:

quantifying the real-time feedback to a value;

comparing the quantified value to an expected value based on at least one current input; and

issuing a command to at least one of a rotary driver and a mandrel driver to adjust an operating parameter thereof based on the step of comparing.

19. The circuit according to claim 18, wherein adjusting an operating parameter comprises adjusting a parameter selected from the group consisting of a hydraulic pressure delivered to the rotary driver, electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an axial force exerted by the rotary

driver, a rate of ground penetration by the driven pile, a depth of the driven pile, a hydraulic pressure delivered to the mandrel, an electric current delivered to the mandrel, a frequency of vibration of the mandrel, a frequency of reciprocation by the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

20. A feedback-controlled method of driving a foundation pile with a pile driving machine comprising:

- receiving a command to initiate a pile driving process at a controller from a user interface;

- actuating a rotary driver to begin rotating the pile into supporting ground;

- actuating a mandrel driver to plunge a mandrel through the pile ahead of the pile;

- monitoring at least one parameter of the pile driving process in real time with a feedback controller;

- issuing a command with the feedback controller to adjust a performance metric of at least one of the rotary driver and the mandrel driver based on the step of monitoring if the parameter is outside of an acceptable range; and

- if the mandrel reaches a target depth, automatically withdrawing the mandrel into the pile and continuing to drive the pile with the rotary driver until the pile has penetrated an additional depth approximately equal to length of the mandrel projecting out of the pile during driving.

21. The method according to claim 20, further comprising, after achieving the additional depth with the pile, validating the pile by applying a pulling force to the pile with the machine and determining with the feedback controller that the pile resisted the pulling force without moving more than a predetermined amount.

22. The method according to claim 21, further comprising sending an indication to the interface device of whether the pile resisted the pulling force.

23. The method according to claim 22, wherein monitoring at least one parameter of the pile driving process comprises monitoring a parameter from the group consisting of a hydraulic pressure delivered to the rotary driver, an electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an

axial force exerted by the rotary driver, a rate of ground penetration by the driven pile, a depth of the driven pile, a hydraulic pressure delivered to the mandrel, an air pressure delivered to the mandrel, an electric current delivered to the mandrel, a frequency of vibration of the mandrel, a frequency of reciprocation of the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

24. The method according to claim 23, wherein the feedback controller is programmed to determine a real time condition of the soil based on monitoring the at least one parameter.

25. The method according to claim 24, wherein the feedback controller is programmed to adjust a performance metric of at least one of the rotary driver and the mandrel based on the real time condition.

26. The method according to claim 24, further comprising creating a data record in a data store communicatively coupled to the machine, the data record storing information corresponding to a current driving operation in association with information corresponding to a job site.

27. The method according to claim 26, wherein information corresponding to a current driving operation comprises information selected from the group consisting of a location of the current pile, a soil condition encountered driving the current pile, and information corresponding to the at least one monitored parameter.

28. The method of claim 20, wherein issuing a command with the feedback controller to adjust a performance metric of at least one of the rotary driver and the mandrel driver comprises issuing a command to change a hydraulic pressure delivered to the rotary driver, to change a level of electric current delivered to the rotary driver, to change a speed of the rotary driver, to change a direction of the rotary driver, to stop the rotary driver, to change an axial force exerted by the rotary driver, to change a hydraulic pressure delivered to the mandrel, to change a level of electric current delivered to the mandrel, to change an air pressure delivered to the mandrel, to change a frequency of vibration of the mandrel, to change a frequency of reciprocation of the mandrel, to change an axial force exerted by the mandrel, and to change a position of the mandrel relative to the pile.

29. A solar pile driver attachment for a piece of heavy equipment comprising:

- a frame defining an elongated axis;
- a set of rails attached to the frame;
- a rotary driver attached to the set of rails operable to move along the axis;
- a mandrel driver attached to the set of rails operable to move along the axis;
- a mandrel coupled to the mandrel driver, a portion of the mandrel passing through the rotary driver;
- a user interface; and
- a controller, the controller communicatively coupled to the user interface, the rotary driver and the mandrel driver for controlling operation of the attachment.

30. The attachment according to claim 29, wherein the controller is programmed to monitor at least one operating parameter of the attachment during a pile driving operation, and to adjust a performance characteristic of at least one of the rotary driver and the mandrel driver based on the step of monitoring.

31. The attachment according to claim 30, wherein monitoring at least one parameter comprises monitoring a parameter from the group consisting of a hydraulic pressure delivered to the rotary driver, an electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an axial force exerted by the rotary driver, a rate of ground penetration by the driven pile, a depth of the driven pile, a hydraulic pressure delivered to the mandrel, an air pressure delivered to the mandrel, an electric current delivered to the mandrel, a frequency of vibration of the mandrel, a frequency of reciprocation of the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

32. The attachment according to claim 31, further comprising creating a data store communicatively coupled to the processor, the data store storing information corresponding to a current driving operation in association with information corresponding to a current job site.

33. The method according to claim 32, wherein the information corresponding to a current driving operation comprises information selected from the group consisting of a location of the current pile, a soil condition encountered driving the current pile, information

corresponding to the at least one monitored parameter, and an identification number of a current pile.

34. A solar pile driver attachment for a piece of heavy equipment comprising:

- a first elongated frame having a first set of rails formed therein;

- a second elongated frame having a second set of rails formed therein, wherein the first frame and the second frame are interlocked to form a pair of intersecting axes that intersect each other in the same plane at angle greater than or equal to 37.5 degrees;

- a first pile driving assembly movably attached to the first set of rails, the first pile driving assembly comprising a first rotary driver and a first mandrel driver concentrically oriented to one another;

- a second pile driving assembly movably attached to the second set of rails, the second pile driving assembly comprising a second rotary driver and second mandrel driver concentrically oriented to one another;

- at least one user interface, the user interface operable to receive instructions to actuate the first and second driving assemblies; and

- at least one controller communicatively coupled to the at least one user interface and the first and second pile driving assemblies to begin driving a second pile into supporting ground with the second pile driving assembly while simultaneously driving a first pile into the ground with the first pile driving assembly.

35. The attachment according to claim 34, wherein the controller is programmed to monitor at least one operating parameter during a pile driving operation, and to adjust a performance characteristic of at least one of the first or second pile driving assembly.

36. The attachment according to claim 35, wherein monitoring at least one parameter comprises monitoring a parameter from the group consisting of a hydraulic pressure delivered to the rotary driver, an electric current delivered to the rotary driver, a speed of rotation of the rotary driver, a direction of rotation of the rotary driver, an axial force exerted by the rotary driver, a rate of ground penetration by the driven pile, a depth of the driven pile, a hydraulic pressure delivered to the mandrel, an air pressure delivered to the mandrel, an electric current delivered to the mandrel, a frequency of vibration of the

mandrel, a frequency of reciprocation of the mandrel, an axial force exerted by the mandrel, and a position of the mandrel relative to the pile.

37. The attachment according to claim 34, further comprising a data store communicatively coupled to the processor, the data store storing information corresponding to a current driving operation in association with information corresponding to a current job site.

38. The attachment according to claim 37, wherein the information corresponding to a current driving operation comprises information selected from the group consisting of a pile location, a pile identification number, a soil condition encountered driving, and information corresponding to the at least one monitored parameter.